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Age effects in temporal auditory processing: modulation masking release and forward masking effect

Efeito da idade no processamento auditivo temporal: benefício da modulação do mascaramento e efeito do pós-mascaramento

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ABSTRACT

Purpose: The purpose of this study was to investigate the age-related effects of modulation masking release and forward masking. **Methods**: Ten younger (mean age of 18.4) and ten older (mean age of 64.3) adults participated in the study. All participants were native speakers of Brazilian Portuguese with normal hearing. Sentences of the Brazilian version of the Hearing in Noise Test were used to obtain speech recognition thresholds in the presence of steady-state noise and amplitude-modulated noise (10 Hz). To investigate forward masking, auditory thresholds were determined at time intervals of 4, 16, 64, and 128 ms after noise interruption. The Shapiro-Wilk test was applied to evaluate the normality of the results. In the variables in which normality was indicated, the Student's *t*-test was applied for the independent samples, and the Mann-Whitney test was applied in cases where normality was not found. A significance level of 5% was adopted for all statistical analyses. **Results**: Modulation masking release was present in both groups; however, it was significantly smaller in the elderly group. As for forward masking investigation, higher thresholds were obtained after noise interruption, and improved as the time interval between noise and stimulus presentation increased. Forward masking was higher in the elderly group, whit higher thresholds for the time interval of 128 ms. **Conclusion**: An age-related effect was identified on modulation masking release and forward masking.

Keywords: Hearing; Older listeners; Temporal masking; Speech perception; Noise

RESUMO

Objetivo: Investigar o efeito da idade no benefício da modulação do ruído mascarante (*masking release*) e no pós-mascaramento (*forward masking*). **Métodos:** Participaram da pesquisa jovens (média de idade de 18 anos e quatro meses) e idosos (média de idade de 64 anos e três meses) falantes nativos do Português Brasileiro e com audição normal. Mediante uso de sentenças da versão brasileira do *Hearing in Noise Test*, determinou-se, para ambos os grupos, limiares de reconhecimento em presença de ruído estável e em presença de ruído modulado em amplitude (10 Hz). Para a pesquisa do pós-macaramento, foram determinados limiares auditivos em intervalos de tempo de 4, 16, 64 e 128 milissegundos, após a interrupção do ruído. Para avaliar a normalidade dos resultados obtidos, foi aplicado o teste de Shapiro-Wilk. Nas variáveis em que a normalidade foi indicada, aplicou-se o teste t de Student para amostras independentes e nos casos em que a normalidade não foi encontrada, aplicou-se o teste de Mann-Whitney. Foi considerado o nível de significância de 5%. **Resultados:** Observou-se o benefício da modulação do mascaramento nos dois grupos. Porém, esse benefício foi menor para o grupo dos idosos (p-valor < 0,001). Na investigação do pós-mascaramento, houve diferença significativa entre os grupos, na média de limiares em 128 milissegundos, após a cessação do ruído (p-valor = 0,006). **Conclusão:** O estudo mostra efeito da idade no benefício de modulação do ruído mascarante e no pós-mascaramento.

Palavras-chave: Audição; Idoso; Mascaramento temporal; Percepção de fala; Ruído

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INTRODUCTION

Processes involving speech recognition in the presence of competitive noise have been a subject of study for several years, and are still a challenge for several researchers of Speech, Language and Hearing Sciences. The ability to recognize speech amid background noise is one of the most important aspects of hearing to be assessed, especially with respect to human communication disorders, because some listening conditions require listeners to perceive degraded or distorted speech information. This occurs in several social situations, when the speaker's speech is masked by background noise (competitive noise)[1]. The masking caused by background noise hinders the ideal perception of speech by listeners, and is thus characterized as low-redundancy speech[2]. This situation demands listeners to separate the speech one wishes to listen to, that is, set the target message apart from the competitive noise.

An important aspect regarding the masking effect in speech recognition is the improvement in perception of acoustic cues by a normal-hearing listener when background noise fluctuates in intensity (amplitude modulation) or frequency (frequency spectrum modulation) compared with steady-state background noise[3]. This phenomenon is called modulation masking release (MMR). It is believed that listeners can perceive the acoustic speech cues that do not match the acoustic characteristics (intensity or frequency) of the masking noise.

Smaller magnitude of MMR is observed in the elderly population even in individuals with normal peripheral hearing. A senescent auditory system seems to be less capable of perceiving acoustic speech cues that are not masked over time when noise intensity decreases due to modulation[4]. A question can thus be raised: Why are older adults with normal hearing less capable of recognizing speech in environments with modulated background noise compared with younger listeners? One hypothesis is that a greater forward masking effect occurs in older than in younger adults. Forward masking (FM)[5] means that, even after background noise interruption, the masking effect lasts for a few milliseconds, hindering perception of the sounds that occur immediately after interruption. This effect is understood as one of the characteristics of temporal masking. Temporal masking is defined as any change in threshold caused by the presence of another sound (masking sound), whether presented before, after, or concurrently with the target sound[5,6]. In the case of FM, the masking noise precedes the target sound. For this reason, the Brazilian scientific literature has been referring to this effect as "*mascaramento antecessor*" (backward masking)[7]. The term refers to the fact that the masking noise precedes the target stimulus, but the original term in English (forward masking or post-masking) was chosen to highlight what occurs after interruption of the masking noise: a prolonged masking effect[5,6], rather than the position of the masking noise in relation to the target stimulus. Thus, the expression chosen to represent this phenomenon in the present study (forward masking) will follow the original logic, because this study intends to highlight the effect of masking and not the position of noise in relation to the target stimulus.

Within this reasoning, the terms backward masking and pre-masking are used in English to name the masking effect that precedes the background noise and will be referred to herein in Portuguese as "*pré-mascaramento*". The term that is being used for this phenomenon in Portuguese is "*mascaramento sucessor*"[7], because it refers to the position of the masking noise in relation to the target stimulus (the noise is presented after the stimulus; however, it is able to mask sounds that are presented milliseconds before)[5,7].

Concerning the elderly population, one possible explanation for the reduced MMR is that backward masking and forward masking present greater magnitude in this population and, consequently, the temporal spaces with reduced background noise intensity (amplitude modulation), which serve to make the listener perceive more acoustic cues, are reduced[4]. This would justify the worse performance of older listeners in speech recognition in the presence of modulated noise compared with that of younger listeners. Some aspects should be considered when assessing the ability to hear in the presence of noise. One of them is the speech material used[8]. Although syllables and words have been used to measure speech recognition tasks in some studies[9], the use of sentences seems to be more appropriate because they are more closely related to real communication situations[10].

Other aspects to be considered are the nature and form of presentation of the masking noise, which usually has a speech spectrum, or even uses the speech of a single person or several individuals together. In the case of modulated noise, the modulation patterns usually follow the wave envelope (sine or square).

A third aspect that has been observed in the study of MMR is speech-to-noise ratio (SNR). Several studies have shown that, for listeners with normal hearing, MMR decreases as SNR increases[11].

The relationship between the magnitude of MMR and FM is still not well explored. Although some studies have reported prolonged masking effect in normal-hearing elderly populations[4], this finding is not a consensus in the literature[12], and the nature of this deficit is still poorly understood. This study aimed to investigate temporal masking in older listeners with normal hearing.

METHODS

Two experiments were conducted: the first experiment investigated the magnitude of modulation masking release (MMR) as a function of age to verify the hypothesis that older listeners with normal hearing benefit less from modulation masking compared with younger listeners with normal hearing; the second experiment assessed forward masking (FM) in younger and older adults aiming to confirm the hypothesis that the latter present an increase in this effect compared with the first[13].

Statistical analysis of data was performed as follows: the Shapiro-Wilk test was applied to evaluate the normality of the scores obtained in the thresholds of both experiments; the Student's t-test was used in the independent samples for the variables in which normality was indicated; the Mann-Whitney test was applied in the comparison of the results between younger and older listeners and in cases in which normality was not found. All conclusions were obtained considering a 5% significance level.

Experiment 1: modulation masking release as a function of age

Participants

Ten younger (mean age of 18 years and four months) and ten older (mean age of 64 years and three months) adults participated in the study. All individuals were native speakers of Brazilian Portuguese with normal hearing: pure-tone thresholds ≤25 dB NA for the octave and inter-octave frequencies of 250-8000 Hz and 3000 and 6000 Hz, respectively, in the test ear for younger listeners and pure-tone thresholds ≤25 dB NA for the octave frequencies of 250-4000 Hz in the test ear for older listeners. None of the participants reported a history of otological or neurological disorders. All individuals agreed to participate and signed an Informed Consent Form (ICF) prior to study commencement. This survey was approved by an American ethics committee (Institutional Review Board - IRB) under protocol no. 11-1113 and by the Human Research Ethics Committee of the Center for Health Sciences of the Federal University of Pernanbuco - UFPE under protocol no. 233/2012. The younger adults were recruited among university students, whereas the older adults were selected in social groups of senior citizens.

Stimuli

The speech material was composed of sentences from the Brazilian version of the Hearing in Noise Test (HINT). The masking noise had the same frequency spectrum of the original sentences (speech-shaped noise) and was presented, continuously, under two conditions: steady-state and amplitude modulated. Steady-state noise was presented at the fixed intensity of 65 dBNPS, whereas amplitude-modulated noise (square wave) was presented at frequencies between 65 and 30 dBNPS with modulation rate of 10 Hz[14,15]. Both stimuli were produced on a digital signal processing platform (RZ6, Tucker-Davis Technologies) together with a MATLAB™ script, customized and presented to the right or the best (when variation of the thresholds obtained between the ears was >5 dB) ear, using Sennheiser HD580 headphones.

Procedure

Participants were taken to a sound room and instructed to repeat each sentence exactly as they listened to them. As each sentence was presented, the text appeared on the screen in the examiner's computer, with all the words highlighted in a shaded, marking-sensitive rectangle. The examiner used the computer mouse to mark the words that had been omitted or repeated incorrectly. Sentences were considered in a global score as "correct" or "incorrect", that is, to be considered correct, the sentences had to be correctly repeated in their entirety. Any difference between the test sentence and the participant's emission, such as changes in the use of articles, verbal conjugation, and inclusion or omission of words, even without changing the original meaning, produced an "incorrect" score.

For determination of the speech recognition threshold, the adaptive procedure in which the thresholds converge to 71% correctness was used[16]. In this procedure, the level of presentation of the next sentence is reduced by 2 dB after two correct responses and the level of presentation of the next sentence is increased by 2 dB after one incorrect response (two-down/one-up procedure). Each sentence recognition auditory threshold was obtained after six reversals (increasing or decreasing the intensity of the sentences presented) by calculating the mean of the four final levels (reversal intensities). The initial masking noise type was chosen randomly.

Three speech recognition thresholds were obtained in each masking noise condition (steady-state and amplitude-modulated at 10 Hz) for each participant. A new threshold was obtained if a difference between thresholds ≥3 dB was observed. After determination of the three (or four) thresholds, the arithmetic mean of all of them was calculated. Calculation of modulation masking release (MMR) was performed from the difference between the sentence recognition threshold in the presence of steady-state noise and the sentence recognition threshold in the presence of noise modulated at 10 Hz.

Sentences were presented without repetition in order to eliminate variables associated with the learning phenomenon. The adaptive procedure, including the presentation of stimulus, was controlled by a customized MATLAB™ script.

Experiment 2: forward masking effect assessment

Participants

Twenty individuals with the same characteristics described in Experiment 1 participated in this experiment.

Stimuli

For this experiment, a speech-shaped masking noise with 400 ms duration and 65 dBNPS peak intensity was used, which was then abruptly reduced to 30 dBNPS intensity. The target tone was a speech-shaped noise with spectral parameters identical to those of the masking noise, but with a duration of 30 ms[17]. The target tone was presented at four fixed intervals after the masking noise: 4, 16, 64, and 128 ms. The stimuli were generated using the same platform and software script of Experiment 1. They were also presented to the right or the best (when variation of the thresholds obtained between the ears was >5 dB) ear using Sennheiser HD580 headphones.

Procedure

Participants were taken to a sound room, told to put on the headphones and hold a box with light signals to identify the presence of the stimuli and indicate their responses. Prior to test commencement, the auditory thresholds were obtained for the target tone with steady-state noise at high (65 dBNPS) and low (30 dBNPS) intensities for both groups. These values were determined in the presence of simultaneous masking noise, so that they serve as reference to observe the thresholds obtained at established time intervals.

For assessment of the forward masking effect, the masking noise was presented at 65 dBNPS intensity during 400 ms and then abruptly reduced to 30 dBNPS intensity, remaining at this level for 400 ms and once again increased to 65 dBNPS. This sequential presentation of the noise provided an auditory sensation of three independent noises. During the time the masking noise was at low intensity (400 ms), the target tone was presented at different time intervals after the abrupt decrease in the masking noise (4, 16, 64, and 128 ms). The masking noises were presented in random order (Figure 1).

Participants were informed that they would hear three sounds as they observed three light signals related to the three switches in the box they were holding. They were then informed that one of the three sounds would sound differently, and that they should identify it by pressing the switch that corresponded to its light signal (Figure 2). In this way, the auditory threshold was determined so that the forward masking effect could be assessed for each target tone at the different time intervals (4, 16, 64, and 128 ms).

As in the first experiment, the target tone auditory thresholds were obtained using the adaptive procedure in which the thresholds converge to 71% correctness[16]. In order to investigate auditory thresholds at different time intervals, the initial intensity of the target tone was established at 5 dB above the reference threshold of each participant, which was obtained in the presence of steady-state noise at 65 dBNPS. After two correct responses, the target tone intensity was decreased by 4 dB, whereas for each incorrect response, it was increased by 4 dB. After two reversals (correct/incorrect responses), the decrease/increase intensity pattern was changed to 2 dB.

The threshold was obtained after eight reversals were completed. Each target tone auditory threshold was calculated by the arithmetic mean of the last six intensities where the reversal occurred. Three measures of target tone auditory thresholds were taken, as long as their variation was <3 dB; when this occurred, a fourth measure was taken, and the mean of all measures was calculated to reach the final auditory threshold for each assessment condition.

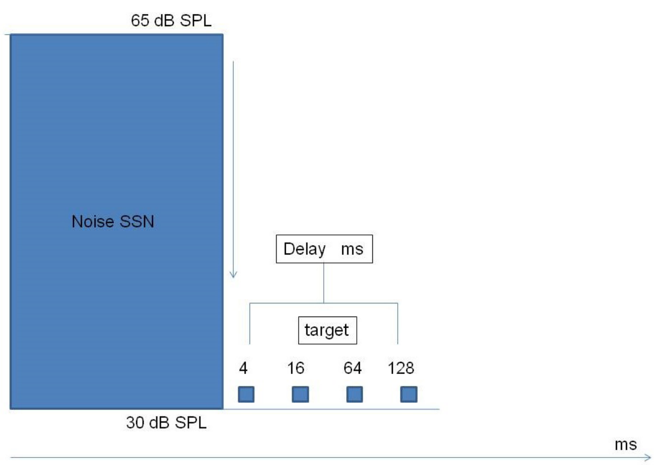

Figure 1. Presentation of the target tone according to its temporal position relative to the noise
Captions: SSN = Speech-shaped noise

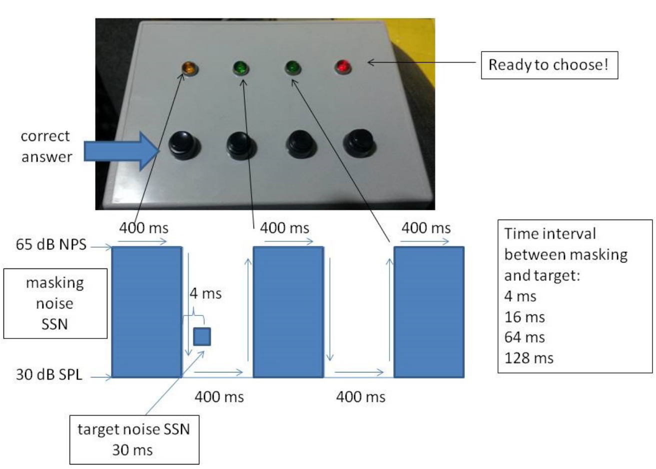

Figure 2. Illustrative model of the box used in the forward masking effect assessment
Captions: SSN = Speech-shaped noise

RESULTS

Table 1 shows the results of Experiment 1: comparison of the means of the sentence recognition thresholds in the presence of steady-state noise and amplitude-modulated noise between younger and older listeners. No statistically significant difference was observed between the means of sentence recognition thresholds in the presence of steady-state noise in younger and older adults (*p*=0.491). However, the means of sentence recognition thresholds in the presence of amplitude-modulated noise were higher for the group of elderly listeners (*p*<0.001). Comparison between the modulation masking release (MMR) means (difference between speech recognition thresholds in the presence of steady-state noise and amplitude-modulated noise) showed statistically significant difference (*p*<0.001) between the two groups, indicating higher MMR in the group of younger adults (mean of 8.68 dB). Comparison of the means of the sentence recognition thresholds in the presence of steady-state noise and amplitude-modulated noise between younger and older listeners is presented in Table 1.

Table 2 shows the results of Experiment 2, where the same response pattern was observed for younger and older adults, that is, the target tone auditory thresholds decreased as the time intervals increased. These findings suggest that forward masking (FM) was smaller for the longer time intervals in both groups. Comparison of the means of the thresholds obtained in the different time intervals (4, 16, 64, and 128 ms) after noise interruption between the younger and older adults evaluated showed that the latter presented higher means in all assessments performed; however, statistically significant difference compared

Table 1. Comparison of the means of the sentence recognition thresholds between younger and older adults

Sentence recognition thresholds	Age group assessed		p-value¹
	Younger adults (18-25 years)	Older adults (≥60 years)	
Steady-state noise	61.42 ± 1.44	61.90 ± 1.61	0.491
Amplitude-modulated noise	52.74 ± 2.08	58.18 ± 3.14	<0.001
MMR	8.68 ± 1.51	3.73 ± 2.18	<0.001

[1]*p*-value of the Student's *t*-test for comparison between the means in the independent groups
Captions: MMR = Modulation masking release

Table 2. Comparison of the means of the auditory thresholds at different time intervals after noise interruption between younger and older adults

Hearing thresholds	Age group assessed		p-value
	Younger adults (18-25 years)	Older adults (≥60 years)	
Steady-state noise (65 dB)	63.83 ± 0.93	65.60 ± 1.31	0.003[1]
Steady-state noise (30 dB)	35.29 ± 1.67	37.34 ± 3.40	0.059[2]
FM 04	56.86 ± 2.60	59.82 ± 4.11	0.070[1]
FM 16	51.94 ± 2.54	54.71 ± 6.13	0.212[1]
FM 64	44.18 ± 1.67	46.30 ± 5.97	0.304[1]
FM 128	39.49 ± 1.53	44.68 ± 4.61	0.006[1]

[1]*p*-value of the Student's *t*-test for comparison between the means in the independent groups; [2]*p*-value of the Mann-Whitney test
Captions: FM = Forward masking

with the younger listeners was observed only in the assessments performed in presence of steady-state noise at 65 dBNPS ($p = 0.003$) and at 128 ms after noise interruption (FM 128) ($p = 0.006$). In the other assessments, results of the younger and older listeners were similar, indicating that the target tone auditory thresholds under the FM effect were significantly higher for the older adults only at the time interval of 128 ms (Table 2).

DISCUSSION

Results of Experiment 1 confirmed the hypothesis of this study that normal-hearing younger adults present greater modulation masking release (MMR) compared with that of older adults with normal hearing, corroborating the findings of other studies that addressed MMR in these two populations(4,12,18). Gifford and collaborators(4), for instance, compared the performance of younger and older listeners in speech recognition in the presence of steady-state noise and amplitude-modulated noise and found significant difference in a modulated noise background (with 10 Hz modulation rate) between these two groups, with greater difficulty for elderly individuals.

These authors revealed that elderly individuals cannot perceive the acoustic cues of speech in the same way as the younger individuals do at moments of low intensity of the masking noise. One explanation for this difficulty is that, in this population, the effect of forward masking (FM) lasts longer, causing the acoustic cues to be masked even after interruption of the competitive noise.

This hypothesis led to the completion of Experiment 2. The results confirmed the hypothesis, considering that the target tone auditory thresholds were higher in the group of older listeners compared with those in the group of younger listeners, especially for the time interval for presentation of the target tone in 128 ms after noise interruption.

Several other studies(4,12,13,18) have demonstrated increased FM in the elderly population. Gifford and Bacon explained that this increase may be associated with changes in neural functioning, and not in non-linear processes of the cochlea(13). Perhaps, recovery time (after neural explosion caused by the noise) of the afferent neural fibers is longer in senescent auditory systems, justifying the increase in FM. With advancing age, the nerve auditory fibers lose their ability to recover spontaneously, or recover more slowly. The increased target tone auditory thresholds found in this study may be associated with the physiological aspects of senescence.

However, it was observed that statistically significant difference between the two groups occurred only for thresholds at the time interval of 128 ms. At the other intervals, although the threshold means for younger adults were lower than those for older adults, the results were not statistically different, showing that the effect of FM is similar in these age groups when the target tone is presented within 64 ms after interruption of the masking noise. It seems that, even if the recovery time of the afferent neural fibers is shorter in younger listeners, this difference favors them when the stimulus is located at short time intervals (≤64 ms), but it becomes evident as the time intervals increase. A similar study conducted with longer intervals (>128 ms) could contribute to prove this hypothesis.

Not only can aspects associated with FM be related to the explanation of the smaller MMR magnitude in speech recognition in normal-hearing older adults, but also cognitive, attention, memory and learning aspects(4).

The relationship between cognitive aspects and the deficit in temporal auditory processing in the elderly population was investigated(19) through the ability to detect intervals between two sounds (gap detection). This study discussed that the decreased performance of older listeners in identifying time intervals may be associated with cognitive and attention aspects, which contribute to slower processing of sounds with advancing age. Therefore, the aspects responsible for the difficulty of older adults in understanding speech in a competitive background may be diverse, and not exclusive.

Participants of this study were not investigated regarding cognitive matters. Therefore, it cannot be inferred that the results presented were due exclusively to temporal auditory processing. Future studies conducted with larger samples and addressing auditory and cognitive aspects may contribute to a better understanding of the relationship between FM and MMR.

CONCLUSION

Older adults with normal hearing presented smaller modulation masking release (MMR) compared with that of younger adults with normal hearing. In addition, greater forward masking (FM) effect was observed in the elderly population. It is believed that there is a relationship between increased FM and decreased MMR; however, the greater difficulty in perceiving speech acoustic cues under low amplitude-modulated noise intensity may also be associated with cognitive factors not investigated in the present study.

Results reinforced the idea that difficulties in temporal auditory processing should be associated with the difficulty of older listeners in understanding speech in noisy environments, but participation of other (cognitive) factors can not be excluded.

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