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Original Article

Artigo Original

A new paradigm for temporal masking assessment: pilot study

Um novo paradigma para a avaliação do mascaramento temporal auditivo: estudo piloto

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Keywords

Auditory Perception
Perceptual Masking
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ABSTRACT

Purpose: To determine the feasibility and applicability of a clinical backward masking test, focusing on the analysis of inter-stimuli interval, and not on the intensity thresholds as it has been traditionally done, thus proposing a new paradigm for temporal masking assessment. **Method:** The test consisted of the presentation of a target tone of 1.000 Hz followed by a broadband masking noise (950–1.050 Hz), with inter-stimuli interval of 0, 10, 20, 50 and 100 ms. The stimuli were presented monaurally to both ears, with intensity ratio between masker and target tone varying between -10, -20, -30 and -40 dB. Twenty undergraduate students, without hearing or auditory processing complaints, participated in this study. **Results:** Regardless of the signal-to-noise ratio, we observed decrease of average performance according to the decrease of the interval between stimuli. We also observed the indication that little or no masking occurs at the 100 ms interval, suggesting this interval is unsuitable for temporal masking assessment. The average interval threshold was below 27 ms for all investigated intensities, and increased 9 ms with every increase of 10 dB at signal-to-noise ratio. The signal-to-noise ratios of -20 and -30 were the best ratios for the test application. **Conclusion:** The paradigm proposed in this pilot study proved to be feasible, easy to apply, and trustworthy, being compatible with other researches which are the foundation for the study of temporal masking. This theme deserves further studies, continuing the analysis initiated here.

Descritores

Percepção Auditiva
Mascaramento Perceptivo
Projetos Piloto
Testes Auditivos
Adulto

RESUMO

Objetivo: Determinar a viabilidade e aplicabilidade de um teste clínico do mascaramento temporal sucessor, com foco de análise nos intervalos interestímulos e não nos limiares de intensidade, como tradicionalmente realizado, propondo, assim, um novo paradigma para a avaliação do mascaramento temporal. **Método:** O teste contou com a apresentação de um tom alvo de 1.000 Hz seguido de um ruído mascarador de banda estreita (950–1.050 Hz), com intervalos entre os estímulos de 0, 10, 20, 50 e 100 ms. Os itens foram apresentados de forma monoaural em ambas as orelhas, com relação de intensidade entre o mascarador e o tom alvo variando entre -10, -20, -30 e -40 dB. Vinte universitários, sem queixas de audição ou de processamento auditivo, participaram deste estudo. **Resultados:** Foi observada diminuição no desempenho médio de acordo com a diminuição do intervalo, independentemente da relação sinal-ruído. Observou-se também o indício de que pouco ou nenhum mascaramento ocorre para o intervalo de 100 ms, tornando-o inadequado para a avaliação do mascaramento temporal. O limiar de intervalo médio manteve-se abaixo de 27 ms para todas as intensidades avaliadas, e aumentou 9 ms a cada 10 dB de aumento na relação sinal-ruído. As melhores relações sinal-ruído para avaliação são -20 e -30 dB. **Conclusão:** O paradigma proposto neste estudo piloto provou-se factível, de fácil aplicação e confiável, mostrando-se compatível com resultados de pesquisas que fundamentam o estudo do mascaramento temporal. O tema merece outros estudos para aprofundar as análises aqui iniciadas.

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INTRODUCTION

Auditory temporal processing can be didactically divided in four categories: temporal ordering, temporal resolution, temporal integration, and temporal masking[1]. Nowadays, there are available and well-documented clinical measures to assess temporal ordering and resolution[2,3], but not temporal integration and masking[4].

Masking is the phenomenon in which detection threshold of a sound stimulus is modified by another sound stimulus presented simultaneously (simultaneous or clinical masking), before (forward temporal masking – FTM), or after (backward temporal masking – BTM)[1,5].

To recognize a target stimulus during a task of simultaneous masking, an individual depends on good spectral resolution, that is, on his/her capability to perceive and isolate the target frequency in the midst of the frequency of the masking stimulus. In tasks of temporal masking (BTM and FTM), an individual depends on temporal resolution, that is, on the ability to perceive the interval between the presentation of the target stimulus and masking stimulus, identifying them as two separate stimuli[6].

The mechanisms involved in temporal masking are not well defined. However, it seems that researchers agree that FTM has different mechanisms in comparison to BTM. It is proposed that, in BTM, cortical and nonsensory regions of the nervous system participate more markedly[4,7,8]. Moreover, when compared to the other conditions (simultaneous and FTM), BTM has more varied inter- and intrapersonal responses, and is prone to greater influence of memory, attention, and practice[9,10].

In classical studies on temporal masking, Elliot[11-13] showed some temporal masking principles, among them: (1) that masking is more effective when stimuli are presented monaurally; (2) that the duration of the masking stimulus does not influence BTM; and (3) that a greater similarity between tones and masking noises makes masking more efficient.

Furthermore, contrary to what happens in simultaneous masking and FTM, the intensity of the masking stimulus does not influence the occurrence of BTM to a large degree. In other words, higher intensities do not necessarily cause greater masking[8]. A factor of extreme influence in temporal masking, however, is the silent interval between both stimuli, inversely proportional to the efficiency of masking[4]. It has been suggested that FTM can occur in an inter stimulus interval (ISI) between 75 and 200 ms, whereas BTM is effective in intervals between 0 and 100 ms but with considerable decreases in effect from 25 ms onward[8,14].

BTM has been the topic of several studies[15-19] because of its relation with language alterations. However, the authors have analyzed the threshold of intensity in which the target signal is perceived and relied on tests elaborated in software applications that require the use of interfaces among pieces of equipment, previous training of the individual to be assessed, and significant time expenditure[4]. Therefore, this pilot study initiated the development of a test that can be quickly applied in clinical environments with no need for other equipment. For this purpose, we propose a new paradigm to assess BTM through analyzing each threshold interval, believing that, as mentioned earlier, the duration of the interval between stimuli is considered one of the main influencing factors of the masking effect in BTM. In addition, assessing BTM by intensity threshold would make this clinical test very complex and protracted.

The purpose of this study was, therefore, to determine the feasibility and applicability of the paradigm in question, observing the characteristics and procedures that were more adequate for a later validation of a specific test to assess BTM by analyzing ISIs in a more encompassing study.

METHOD

This study was approved by the ethics committee of Universidade de São Paulo’s School of Medicine (protocol number 392/12). It was conducted at the Laboratory for Investigation on Auditory Processing of the Speech-Language Pathology and Audiology Program of the same institution. All the participants signed the informed consent form.

The soundtrack of this pilot study was produced digitally (WAV* format) with the software Sound Forge® Pro 10.0 (Sony Creative Software Inc.) at 44,100 Hz and 16-bit resolution. The soundtrack had 30 items presented randomly. Each item was composed of one 25-ms pure tone (1,000 Hz, 10 ms of rise/fall) followed by a narrow-band (950–1,050 Hz) 200-ms masking noise, with ISIs of 100, 50, 20, 10, or 0 ms duration. Each one of the ISIs was presented five times. In addition to these, five other items that presented only a masking noise (without pure tones) were also included.

The test was applied with a CD player or a digital player (e.g., iPod) attached to a Grason–Stadler audiometer (model GSI-61). The soundtrack was presented through supra-aural headphones (model TDH-50), monaurally in both ears. The masking sound was set at a fixed intensity of 60 dB, and the tone was presented at the intensities of 50, 40, 30, and 20 dB. Therefore, in each application of the test, the signal-to-noise (S/N) ratio between the tone and the masking noise varied between -10 and -40. We requested the participants to press the response button whenever they perceived the presence of the target signal (pure tone). The assessment of each ear lasted about 5 minutes (1’10’’ per S/N ratio), totalizing about 10 minutes of evaluation.

Twenty university students, aged between 18 and 38 years, agreed to participate in the study and were assessed. All presented normal hearing (≤20 dB; 0.25–8 kHz) and absence of complaints about auditory processing alterations. They also stated that they had never received any musical training.

The responses were analyzed through the total percentage of correct answers and by ISI in each S/N ratio. We observed the proportion of individuals who achieved more than 80% of correct answers (four or five per ISI), and the response threshold (shortest ISI in which three or more correct answers were obtained consistently) for each S/N ratio.

To analyze the data, we used descriptive statistics, Student's *t*-test and analysis of variance, with a level of significance of 5%.

RESULTS

In regard to the ISIs, there was no difference in the individuals' performance from one ear to the other. For this reason, the results obtained in each ear were unified, totalizing a sample of 40 ears assessed with the purpose of increasing the power of the statistical analyses carried out. The highest averages of correct answers were achieved at the intervals of 100, 50, and 20 ms, and for the S/N -10 and -20 ratios. We also observed considerable standard deviations (SD), the most substantial related to the lowest averages of correct answers (Table 1).

Table 1. Average of correct answers (%) and standard deviation for each signal-to-noise ratio, according to the interstimulus interval

ISI	S/N-10		S/N-20		S/N-30		S/N-40	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
100 ms	96.5	8.90	99.5	3.10	97.0	8.50	93.0	15.3
50 ms	90.5	14.3	96.0	9.20	88.5	19.6	78.0	27.1
20 ms	84.5	20.5	82.5	24.0	76.0	29.7	67.5	29.2
10 ms	71.0	28.6	73.5	24.5	59.5	34.6	53.0	39.3
0 ms	58.0	32.2	61.0	31.0	59.0	30.7	52.0	34.7
Total	80.1	14.8	82.5	13.8	76.0	18.3	68.7	23.1

Caption: ISI = interstimulus interval; S/N = signal-to-noise ratio; SD = standard deviation

We verified significant differences among the averages of correct answers in the ISIs (p<0.001), regardless of the S/N ratio, in almost all comparisons. Exceptions were observed in the comparisons between 50 and 20 ms (S/N -40: p=0.099), 20 and 10 ms (S/N -20: p=0.101; and S/N -40: p=0.065), and 10 and 0 ms (S/N -10: p=0.060; S/N -30: p=0.945; and S/N -40: p=0.904). With a fixed ISI, we verified differences among the S/N ratios in all intervals, except at 0 ms (100 ms: p=0.038; 50 ms: p<0.001; 20 ms: p=0.019; 10 ms: p=0.015; and 0 ms: p=0.630). These differences occurred due to better responses obtained in the S/N -20 ratio, or to the worse responses in the S/N -30 and -40 ratios (Figure 1).

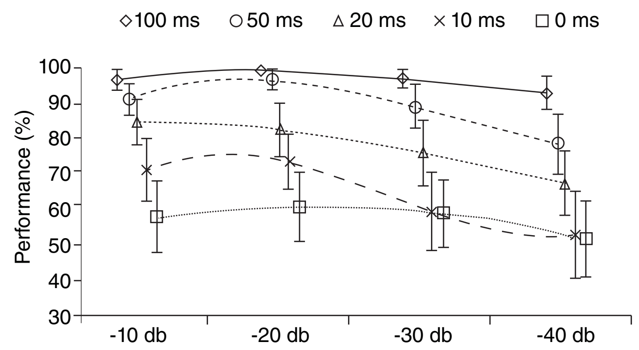

Figure 1. Average, trust interval, and polynomial trend lines of the performances (%) per interstimulus interval, according to the signal-to-noise ratio. It is possible to observe that the most marked differences in performance occur between the intervals of 100 and 0 ms, and that this difference is almost constant in all S/N ratios. Regarding the other intervals, a gradual and nonlinear decrease in the averages, and in the difference between the averages of each ISI, can be observed as the S/N ratio increases. The average of the 10-ms ISI matches that of the 0-ms ISI in the S/N -30 ratio, and this similarity is maintained in S/N -40

In regard to the thresholds obtained, we observed three or more correct answers in a consistent manner in the ISI of 0 ms in about 50% of the ears assessed in the S/N -10, -20, and -30 ratios; concerning the S/N -40 ratio, this number decreased considerably (Table 2). Statistically, we verified significant differences only between the average thresholds of the S/N -40 ratio and those of the easier ratios (S/N -10: p=0.022; S/N -20: p=0.005).

On analyzing the number of correct answers per interval, we observed that in the ISIs of 100 and 50 ms, in all S/N ratios, the majority of the ears evaluated (more than 70%) obtained four or five correct answers, therefore achieving scores ≥80%. Starting at the ISI of 20 ms, the proportion of ears with four or five correct answers decreased slightly but was not lower than 70%, except in the S/N -40 ratio, in which only about 45% of the ears assessed presented such performance. Concerning the intervals of 10 and 0 ms, the proportion of individuals with four or five correct answers per ISI decreased considerably, as it was below 60.0% for 10 ms, and 42.5% for 0 ms in all S/N ratios (Figure 2).

Table 2. Distribution and average of the threshold intervals of all ears assessed, according to the signal-to-noise ratio

S/N	100 ms		50 ms		20 ms		10 ms		0 ms		Média	SD
	n	%	n	%	n	%	n	%	n	%	(ms)	
-10 dB	1	2.5	4	10.0	8	20.0	6	15.0	21	52.5	11.5	20.07
-20 dB	0	-	5	12.5	4	10.0	9	22.5	22	55.0	9.5	15.18
-30 dB	3	7.5	5	12.5	7	17.5	5	12.5	20	50.0	18.5	28.69
-40 dB	6	15.0	5	12.5	11	27.5	3	7.5	15	37.5	27.5	34.70

Caption: S/N = signal-to-noise ratio; n = number of individuals; SD = standard deviation

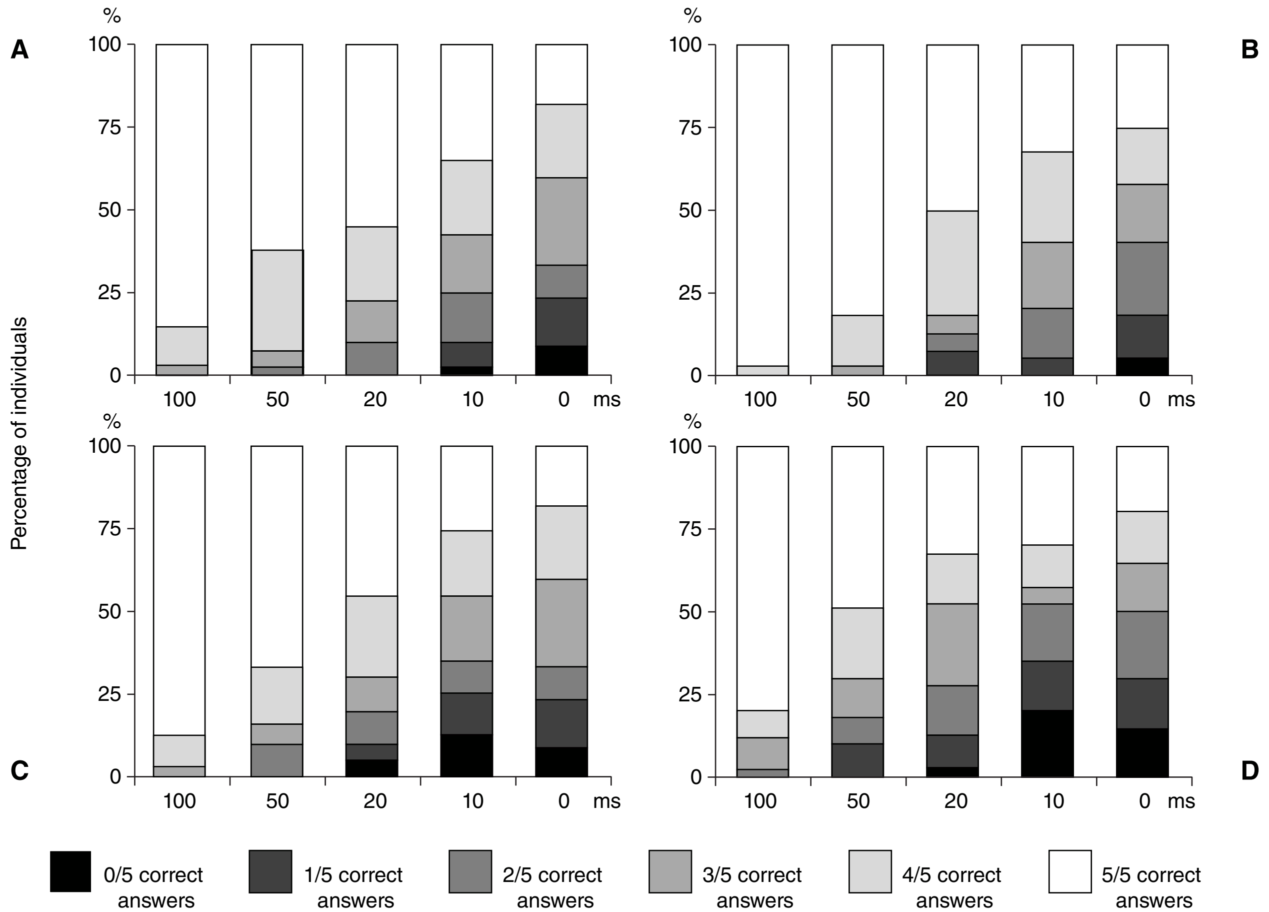

Figure 2. Distribution of the individuals (%) according to the number of correct answers per interstimulus interval in each signal-to-noise ratio assessed; (a) S/N -10 dB; (b) S/N -20 dB; (c) S/N -30 dB; (d) S/N -40 dB. The figure shows a decrease in the proportion of ears with four or more correct answers (white and lighter gray) per ISI in all S/N ratios. It is observable in (b) that the highest percentage of ears with four or more correct answers in all ISIs is in S/N -20

DISCUSSION

In this pilot study, we observed very interesting initial results pertaining to the application of this new paradigm to assess BTM. These results strengthen the possibility of developing and applying a specific clinical test to assess this aspect of temporal auditory processing.

The absence of ear effects in the application of the test developed here was expected, as monotonic tasks, such as the task assessed in this study, and contrary to dichotic tasks, activate both ipsi- and contralateral auditory pathways, resulting in a similar performance between both ears[20,21].

We observed a decrease in the average performance as the ISI decreased, regardless of the S/N ratio. This result confirms, once again, the strong influence of the interval between stimuli on the masking effect that the noise causes in the target signal[7,8,14].

However, we observed significant SDs, which were larger for the shortest intervals. These deviations may be associated with the variability of the BTM, already shown in other studies[10,15,16,18]. This allows us to infer that this is not a deficiency of the test but a characteristic inherent to the task involved in it. This inter- and intrasubject variability has been associated with nonauditory aspects (e.g., memory, attention, and learning) involved in the auditory processing of acoustic stimuli[6,19]. Although, in this study, the test under development did not present as great a dependence on memory skills as the aforementioned studies — in which the individuals had to choose, out of two or three options, the one that presented the target sound — we believe that attention greatly influenced the participants' performance.

Considering that the evaluation items were presented without any warning that alerted the individual that the stimulus was about to be presented (e.g., "number one," "pay attention") in the sound track produced for this study, therefore requiring the participant's complete attention, we believe that an attention deficit was observed during the test. The participants reported difficulties to complete the test and to sustain their attention for its entire duration. Moreover, the observation that the largest SDs are associated with the shortest intervals and the greatest S/N ratios suggests that the more intricate the presentation of the stimuli, the larger its dependence on attention. In this sense, an introduction to each item may be fundamental to decrease the SDs and the variability.

The 0-ms ISI presented the greatest variability of responses among the individuals, with almost constant worse averages from one S/N to the other, and a small proportion of individuals with performances that surpassed 80%. This indicates that, regardless of the intensity of the masking sound, the absence of an interval between stimuli caused the highest levels of masking of the target signal among the five ISIs tested.

However, regarding the 100-ms interval, almost all individuals presented performances that surpassed the 80% mark in all S/N ratios, which indicates that in this interval they were able to perceive the presence of the target sound almost every time it was presented, that is, without considering the intensity at which it occurred, the masking was weak or null.

These results are corroborated by previous studies that report significant BTM effects at an ISI between 0 and 25 ms, when the effect decreases and finally ceases around 100 ms(8,13,14). Therefore, we suggest that the 100-ms interval is not adequate to assess BTM, whereas the 0-ms ISI must be analyzed with caution because of its strong masking effect, even in normal populations.

Regarding the other intervals, we observed different performances according to the S/N ratio, with averages worsening as the masking sound intensity increased, but not in similar manner in all ISIs. For instance, concerning the 10-ms ISI in S/N -30, we observed a significant decline in the average performance, an increase in its difference in relation to longer ISIs, and equal results to the 0-ms ISI. This performance was maintained in S/N -40. This observation allows us to hypothesize that, for each ISI, there is a critical S/N ratio in which the intensity of the masking noise no longer influences performance. Therefore, although the intensity of the masking sound is not considered influential in BTM(7,9), the intensity level at which the test is conducted must be investigated further.

Concerning the S/N -10 ratio, the majority of the individuals presented very good results in all ISIs, which is a sign that the test was very easy in regard to this ratio. Conversely, in the S/N -40 ratio, in which a large proportion of the individuals had poor performances, the test seemed very difficult. Considering that any evaluation must have some level of difficulty, neither so easy that the alerted individuals have good performances nor so difficult that normal individuals present altered results(22), we conclude that the S/N -20 and -30 ratios are the most reliable ones when conducting this test.

The average threshold interval found in this pilot study was below 27.5 ms (Table 2) and varied according to the S/N ratio. We also observed a possible pattern in the increase of average threshold intervals with an increase in intensity ratios. After S/N -20 (similar to S/N -10, with a difference of only 2 ms), the average threshold interval was about 9 ms longer at every 10-dB increment to the intensity ratio between the signal and the masking sound.

In studies on BTM carried out following the traditional paradigm of intensity thresholds, a nonlinear pattern of the effect of the intensity of the masking noise can also be observed: for each 10-dB increment to the intensity of the masking sound, an increase of 3 dB in the threshold of detection of the target sound was observed(13,14).

In addition to the significant response variability discussed above, another aspect of this study that can raise doubts is the intensity at which the test was conducted. We did not consider each individual's audiometric thresholds when conducting the test; in other words, an application intensity was defined and fixed beforehand. Although all participants presented thresholds below 20 dB, in practice the individuals with lower thresholds might have experienced more difficulty to perceive the target signal in the lower S/N ratios, as this signal had an intensity that was very close to their perception threshold during silence, and not because they were unable to solve such acoustic situations.

Therefore, in future studies with the purpose of validating this test, attention must be paid to the aspects, such as conducting the test considering each individual's audiometric thresholds to determine the intensities of the masking noise and the target signal, as well as including an introductory signal for each new item with the purpose of testing the hypothesis of the influence of a participant's attention in response variability.

Shorter ISIs must be tested (between 50 and 0 ms, for instance) — they cause a more marked temporal masking effect and favor the observation of clearer response patterns — by applying this test in the S/N ratios considered more reliable in this study (S/N -20 and -30). Another possibility is using higher ratios than the ones assessed here, with the purpose of continuing to observe the response pattern of each ISI according to S/N ratios. Furthermore, the test must be applied to individuals with confirmed alterations (e.g., cortical lesions) in addition to normal individuals, so as to determine its levels of sensitivity and specificity.

CONCLUSION

In this study, we proposed to assess BTM by investigating threshold intervals instead of intensity threshold, as it has been traditionally done. The test developed was easy to produce and quick to apply, and its results proved to be compatible with those of previous studies that are considered the foundation of temporal masking theories. We conclude, therefore, that this new paradigm is feasible, easy to apply, and reliable. This topic needs future studies that will further the analysis initiated here.

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