AGE-RELATED CHANGES IN PERCEPTION OF TONES WITHIN A STREAM OF AUDITORY STIMULI: AUDITORY ATTENTIONAL BLINK

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ABSTRACT

This research explored the immediate perceptual/cognitive consequences of an attended-to tonal stimulus within a stream of tonal stimuli. Previous results have suggested that processing information about a tone within a stream of tones presented at a rate of 11 tones/s can modify perception of subsequent tones. The results of the current study suggest that perception of subsequent tones is also a function of age.

SOMMAIRE

Cette recherche explore les consequences perceptuelles cognitives, a court liees a la perception d'un son present a l'interieur d'un ensemble de stimulations tonales. Les resultats anterieurs suggeraient que le traitement d'informations comprises dans un ensemble sonore, dont le taux est de 11 sons par seconde, pouvait modifier la perception de sons qui suivent. Les resultats de la presente etude suggerent que la perception des sons subsequents est aussi fonction de l'age.

1. INTRODUCTION

Our environment forces us to detect important information embedded in a background of continuously changing distracters. In spite of the many sounds simultaneously or successively entering the auditory system, listeners can readily focus attention on priority stimuli and analyze their properties in considerable details, often at the expense of less relevant inputs [3]. Thus, when attempting to manage the vast array of information available to listeners in their everyday world, one can selectively attend to, and process particular aspects of input, usually to the exclusion of other aspects [18]. This suggests that the consequences of focusing attention on the processing of multiple stimuli whether simultaneous or sequential, is a function of selective attention [16].

This research explored the immediate perceptual and cognitive consequences of an attended-to tonal stimulus within a stream of tonal stimuli. Performance decrements in identification or detection of sound-probe (P) following identification or detection of sound-target (T) in the experimental (dual-task) condition with preserved P identification or detection in the control (single task) condition, defines the presence of an auditory Attentional Blink.

Massaro and Kahn (1973) studied the selective focusing to an attended-to sound and its consequences on the processing of a precedent sound. They found that young adults' recognition (identification) of an earlier-presented auditory stimulus (probe) improved with increases in the silent interval between the probe and the following masking stimulus (target). They also found that within the studied range of intervals (0 ms-500 ms) target identification remained poor. The results of their study indicated that the processing of an auditory stimulus is affected not only by backward masking but also by the focusing of attention on the processing of later stimuli. Poorer recognition of auditory stimuli was found not only when they were followed by the same modality stimuli, but also cross-modally, when auditory stimuli were followed by visual stimuli. Massaro and Kahn concluded, "the perceptual process of recognition requires some central processing capacity. When this processing capacity is demanded elsewhere, recognition is lowered, although not interfered with completely" ([18] p. 58). Previous studies have also examined the effects of attention when targets are followed rather than preceded by probes. In particular, the selective focusing on an attended-to stimulus (target) and the immediate consequences on subsequent stimuli (probes) within a stream of stimuli has been extensively studied in the visual domain using Rapid Serial Visual Presentation (RSVP) techniques (e.g., [25]). Typically, Rapid Serial Visual Presentation entails the computer presentation of 15 to 25 items, such as letters, digits, pictures, or words, at rates of about 6 to 20 items/s. Participants are instructed to make judgments (usually detection or identification responses) to

one target (T) or probe (P) or target and probe (P) in the stream of items. A key feature such as color or brightness distinguishes target and probe. The well documented finding is that when a target and probe (T and P) are separated by intervals of approximately 500 ms or less. The ability to identify P is reduced, a phenomenon known as the Attentional Blink [25]. Shapiro and Raymond (1994) demonstrated that the Attentional Blink reflects neither the masking of the P, nor memory limitations surrounding it, nor the time required to switch from the processing of T to the processing of P. They suggested that the Attentional Blink most likely reflects the operation of attentional mechanisms. The Attentional Blink appears relatively robust as it has been observed in cross-modal (auditory-visual) tasks as well [1]. Arnell and Jolicoer suggested that the Attentional Blink could be observed among stimuli when their processing is demanding and has to be performed within a very limited time. In agreement with Massaro and Kahn (1973), Arnell and Jolicoer also concluded that the identification of a stimulus requires a central, amodal attentional framework, perhaps because in cross-modal tasks, selective attention would operate at a post-categorical level.

Similar performance decrements in the recognition or identification of a probe (i.e., P) have also been demonstrated in the auditory domain [1, 10, and 15]. These studies have shown that an auditory stimulus embedded within a stream of stimuli can modify perception of subsequent stimuli. Goddard, Issak, and Slawinski (1998) found that the magnitude (as measured by the percentage of the performance decrement in the dual-task compared to the single-task) of the modified perception due to the auditory Attentional Blink was greater for listeners with normal vision than for congenitally blind listeners. Most recently, it has been found that auditory Attentional Blink magnitudes are greater than visual Attentional Blink magnitude [11]. Taken together, the results of these studies suggest that fundamental differences may exist between auditory and visual Attentional Blinks. Thus, despite the fact that Attentional Blinks emerge across modalities, the mechanisms which control the Attentional Blink within these modalities can be different [10; 11; 20].

Exactly when selection occurs during attentional process (early versus late) has become one of the most contentious and continuing controversies among psychologists. It has been stated that attentive behavior is the result of limitations in the capacity of any realizable perceptual system [29], which reflects a control of the amount of information that can be attended to and processed by the system. The early selection model of attention suggests that it is possible to select inputs before stimuli have been fully identified and hence, this model suggests that attention operates precategorically. A late selection model in contrast claims that attentional processes do not alter the way that stimuli are processed by the sensory-perceptual system, and attention

operates postcategorically (after identification or categorization of stimuli) [e.g., [7], [9], [26]).

It has previously been suggested that the Attentional Blink reflects an inhibitory mechanism designed to suppress attention to subsequent stimuli (e.g., P) until target (T) processing is complete [25]. Indeed, we have interpreted our auditory Attentional Blink within this attentional inhibition framework. Our interpretation is supported by physiological research on selective attention, which has indicated that the focusing on relevant at the expense of irrelevant information is processed differently in auditory and visual domain [14]. In addition, Banks, Roberts, and Cirani, (1995) have previously suggested that because auditory selective attention is not aided by any analogue of visual fixation, attentional inhibition should be more pronounced in audition than in vision. Our experimental findings [11] accord nicely with Banks et al. view.

As the ability to process auditory information presented at high rates deteriorates markedly with increasing age [24; 30], it is possible that the elderly might be more susceptible to the auditory Attentional Blink when listening to time-compressed speech relative to young listeners. Indeed, the elderly process discrete pure-tone stimuli at a slower rate than young listeners, and show reduced ability to process spectral and temporal cues in rate-altered speech [23]. Elliott, Hammer, Scholl and Wasowicz (1989) have found that older adults required larger spectral differences and/or longer duration segments than did young adults in order to discriminate frequency transitions, just as older adults required larger acoustic differences to discriminate consonant-vowel syllables that differ in the place-of-articulation. It has been postulated that the speed at which rapidly changing spectral cues must be processed may not only exceed the channel capacity of the aging adult, but may overload the cognitive system as well [22]. In consonance with above mentioned studies, self-reported hearing disability among older populations is highly correlated with experienced difficulties in the discrimination of phonemes, when temporal acoustical cues have to be used [27]. Thus, temporally demanding auditory tasks appear to be particularly challenging for older adults.

Separating important information from irrelevant information within complex tasks requires considerable attentional resources, as relevant signals must be enhanced, and irrelevant signals suppressed or inhibited [29]. According to declining capacity theories of attention, processing resources available for cognitive task performance deteriorate with age, particularly for tasks that require considerable attention [4]. Indeed, research on aging has demonstrated that age-related changes in the perception of speech can be partially explained by changes in information processing due to an age-related decline in the efficiency of inhibitory function-

ing, and therefore in preventing irrelevant information from entering working memory [5; 6; 13]. Thus, various lines of evidence suggest that older listeners, when attempting to recognize a sound that is embedded within a stream of rapid sequences of sounds, might be more affected by the presence of the stream sounds than younger listeners (e.g., [4]; [10]; [20]; [30]).

The findings of the above-mentioned studies in addition to a paucity of investigations on age-related changes in the auditory Attentional Blink motivated us to explore these phenomena as a function of age. The goal of the present study was to investigate age-related changes in the processing of tones and the immediate perceptual/cognitive consequences on the detection and identification of subsequent tonal stimuli embedded in a sequence of distracting tones. Previous results have demonstrated that processing information about a tone within a stream of tones presented at a rate of 11/s by young individuals can modify their perception of subsequent tones [11]. We predicted that this perceptual modification would be greater for older adults.

2. METHODS

2.1 Participants

Eleven young adults (mean = 21.2 years old) and 11 older community dwelling adults (mean = 66.8 years old) participated in the study. All subjects were screened for normal hearing (i.e., 15 dB HL or better for audiometric frequencies from 500 Hz to 8000 Hz), lack of middle ear and/or neurological problems, and Canadian English as their first and native language.

2.2 Stimuli

Stimuli were generated using SoundEdit 16 Software imple-

mented on a PowerMac computer with a sampling rate of 44 kHz. One hundred sixty eight Rapid Auditory Presentation streams of 25 tones were randomly chosen from a set of stimuli within the range of 1000 Hz to 2500 Hz, in 10 Hz multiples. Tones of frequencies 1500 Hz (pitch=low), 2000 Hz (pitch=medium), and 2500 Hz (pitch=high) were reserved for targets and probes, which in the experimental condition were increased in sound pressure level by 10 dB SPL, relative to stream tones. Furthermore, a difference between the frequency allocated to the target and probe, and the frequency of the closest preceding or following sound was at least 500 Hz. Presentation of one stream of tones lasted 2245 ms. All "stream tones" were of equal SPL. The duration of all tones was 85 ms, including 5 ms on- and off-ramping, and the Inter-Stimulus Interval (ISI) was 5 ms. The Stimulus Onset Asynchrony (SOA) therefore, was 90 ms and became a unit of the experiment at which the auditory Attentional Blink was measured. Target (T) occurred equally often at a position "n" within the stream of tones (n=5, 9, or 13). Probe (P) occurred equally often at positions n+1, n+2, ... n+5, n+6, corresponding to SOAs of 90, 180, 270, 360, 450, 540, and 630 ms respectively and never occurred at the last position of a tonal stream.

Figure 2. Experimental condition's paradigm. T- target and P-probe (only 11 are presented out of 25 stimuli)

In the experimental condition (dual-task condition), the sound pressure level of the T was increased on 50% of the trials (streams), while the sound pressure level of the P had higher level than that of stream stimuli on all trials (streams). This design enabled us to measure a rate of false alarms. The control condition (single-task condition) was identical to the experimental condition except that the sound pressure level of T was not higher on any of trials (i.e., was equal in sound pressure level to the stream tones). The frequency of T and P were never the same in any given stream, and all T/P com-
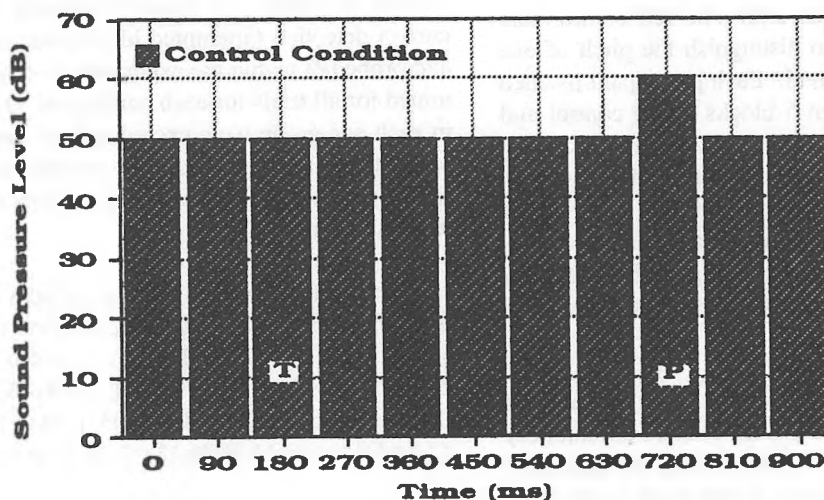

Figure 1. Control condition's paradigm. T - target and P - probe (only 11 are presented out of 25 stimuli)
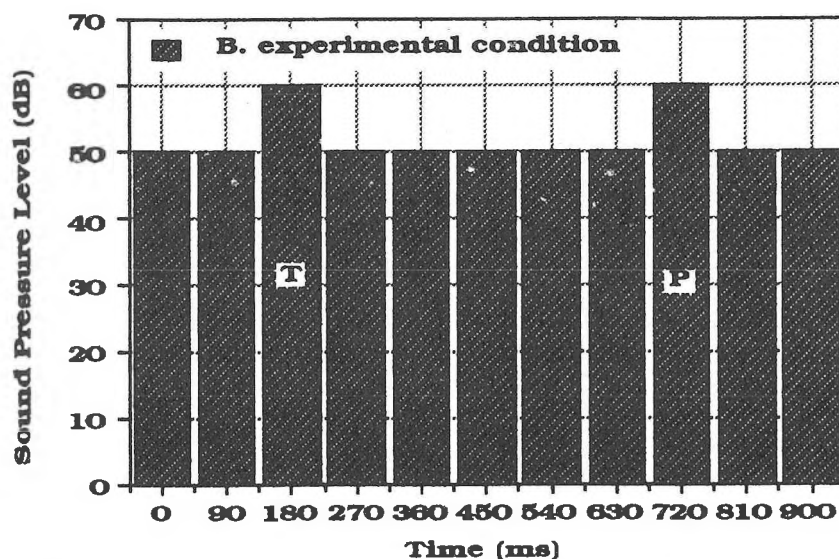
Figure 2. Experimental condition's paradigm. T- target and P-probe (only 11 are presented out of 25 stimuli)

binations of frequencies (e.g., high/low, high/medium, low/high, etc.) were counterbalanced across SOAs. The general paradigm for the control and experimental conditions are shown in Figure 1 and Figure 2, respectively. These figures depict a particular case of presentation, when a target (T) occurs at a 3rd position and the probe (P) occurs at a position # 9 of a tonal stream. Stimuli at positions #12 to #25 are not displayed.

2.3 Procedure

Stimuli were delivered by loudspeakers placed in a distance of 60 cm from behind of listeners' ears. The sound pressure level (SPL) of the stream stimuli at listener's ears was equal to 50 dB SPL, while the sound pressure level of targets and probes was 60 dB SPL, as measured by Bruel and Kjaer Sound Pressure Level Meter Type 2218. Listeners were tested individually in an acoustically shielded room. At the beginning of a testing session each participant was exposed to the target and probe sounds until s/he felt comfortable with the task, and was able to distinguish the pitch of one sound from that of another sound. Each participant listened to 84 streams divided between 5 blocks in the control and experimental condition. Both the experimental and control tasks were counterbalanced across participants. Listeners were asked to identify a pitch associated with any tone of higher sound pressure level that they heard (low, medium, high) and respond verbally after listening to the stream of tones (unspeeded response). Participants' responses were collected by an experimenter.

The same participants were exposed to visual stimuli, in order to explore the mechanisms that control the auditory and visual Attentional Blink. Visual stimuli, the procedure associated with visual task as well as obtained results were

previously described in the study by Goddard and Slawinski (1999).

3. RESULTS

3.1 Identification of Targets and Probes within the Control and Experimental Conditions.

Listeners were not able to identify targets and probes above a chance level, and thus, the percentage of correct P identification within the control condition and T and P within the experimental condition were not determined for trials when targets were detected correctly.

3.2 Detection of target within a control and experimental condition

Percentage of correct detection (attempted identification) of a probe (P) within the control condition and percentage of correct detection (attempted identification) of the target (T) and probe (P) within the experimental condition were determined for all trials for each participant. Data from one adult in each age group were excluded from data due to a higher percentage of false alarms than established criteria (10% or less of false alarms). Thus, analyzed data included 10 adults in each age group.

The three-way mixed ANOVA revealed a main effect of: Age ($F_{(1,18)}=13.02$, $p<0.05$), Condition ($F_{(1,18)}=76.25$, $p<0.05$), and SOA ($F_{(6,13)}=17.59$, $p<0.05$), and significant interactions: Condition x Age ($F_{(1,18)}=6.35$, $p<0.05$), Condition x SOA ($F_{(6,13)}=19.03$, $p<0.05$), as well as Age x Condition x SOA ($F_{(6,13)}=3.06$, $p<0.05$).

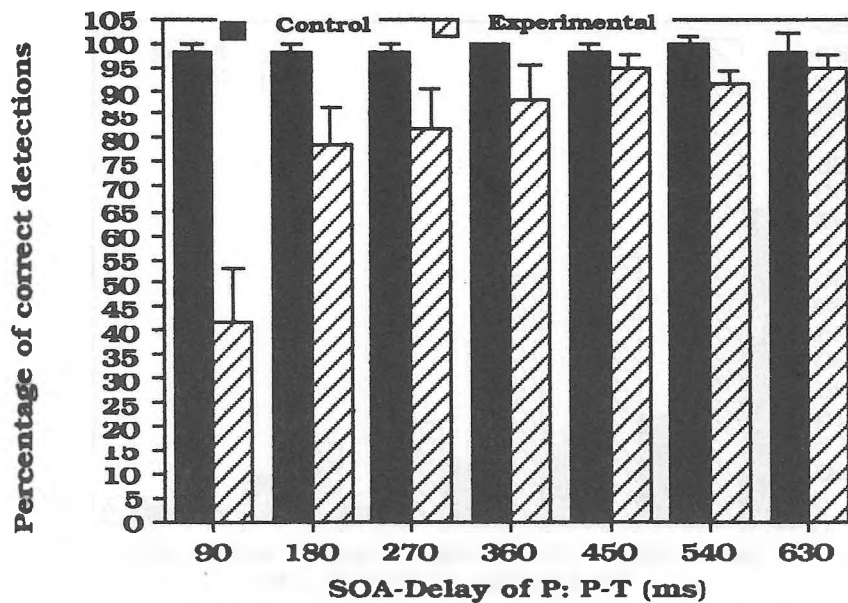Figure 3 and 4 display the mean percentage of trials

Figure 3. The mean percentage of correct detection of the probe (P)) as a function of SOA obtained by young adults within control and experimental condition (see text).

Standard errors are presented as error bars. Please notice a lacl of variability at 360 ms within the control condition.

(streams) on which participants correctly detected (attempted to identify) the probe as a function of the interstimulus SOA in the control and experimental conditions. Figure 3 displays the mean percentage of correct detection obtained by young adults, and Figure 4 displays the results for older adults.

In the control condition (single-task condition), younger adults correctly detected the probe for all interstimulus (target-probe) SOAs on 97.8% (SD = 6.4%) of trials and older

adults correctly detected the probe on 93.3% (SD = 10.3%) of all trials. While both age groups were very good at detecting a single tone of higher sound pressure level in a stream of distracters, the percent correct detection was slightly, but significantly better (t (138) = 2.89, p < 0.05) for younger adults compared to older adults. In the experimental condition (dual-task condition), by contrast, probe detection when the target was present and detected averaged 81.4% (SD = 26.5%) for younger adults, and 61.9% (SD = 32.4%) for older adults, across all interstimulus (target-probe) SOAs.
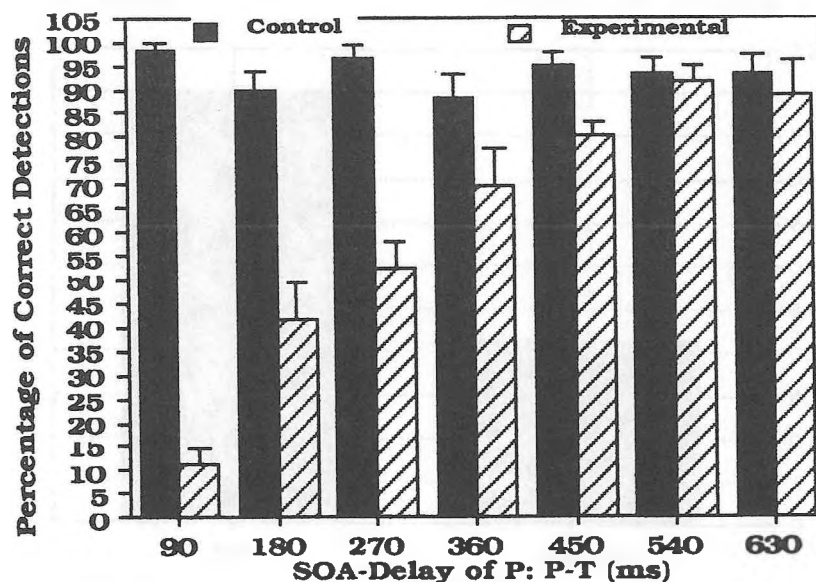

Figure 4. The mean percentage of correct detection of the probe (P) as a function of SOA obtained by old adults within control and experimental condition (see text).
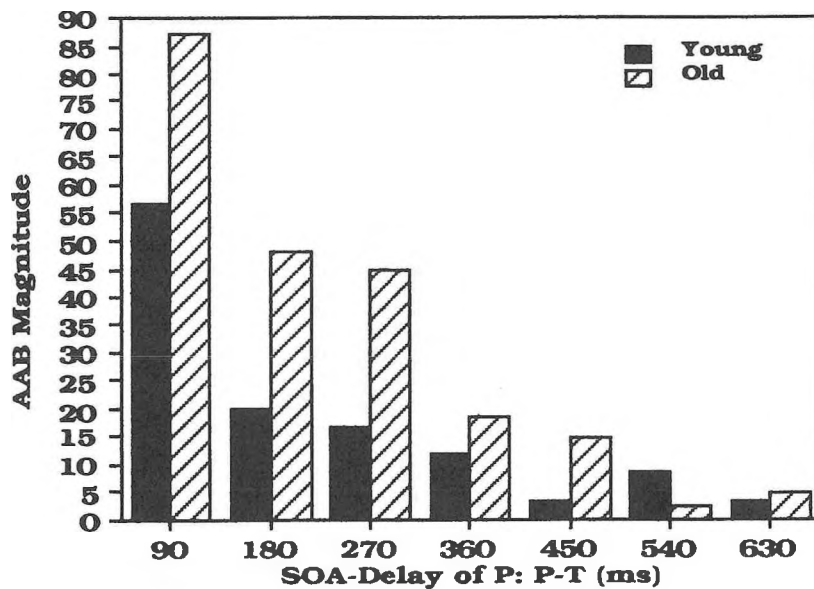
Standard errors are presented as error bars.

Figure 5. Magnitude of auditory Attentional Blink for young and old listeners.

Again, the overall percent correct detection was significantly better for younger adults than for older adults in the experimental condition (t (138) = 2.16, p<0.05). In particular, post hoc comparisons conducted at a Bonferonni adjusted alpha of 0.025 revealed a significant difference between age groups at p<0.025, and at SOA's of 90 ms (t(18)=3.91), 180 ms (t(18)=4.38), 270 ms (t(18)=2.08), 360 ms (t(18)=4.32), and 450 ms (t(18)=2.75). Multiple paired comparisons revealed that both younger and older participants' P detection was significantly lower (p's <0.05) in the experimental than in the control condition when P appeared at interstimulus (target-probe) SOAs of 90, 180, 270, and 360 ms. In addition, older adults also had significantly poorer detection

at the 450 ms SOA in the experimental rather than in the control condition.

At longer interstimulus (target-probe) SOAs, from 450 ms and 540 ms to 630 ms for younger and older participants, respectively, P detection in the experimental condition averaged 93.9% for the younger adults and 89.8% for older adults. These values did not differ significantly from either group's overall P detection in the control condition.

Thus, group differences emerged at interstimulus (target-probe) SOAs of 90, 180, 270, 360, and 450 ms. At these SOAs, younger adults' percent correct detections were sig-
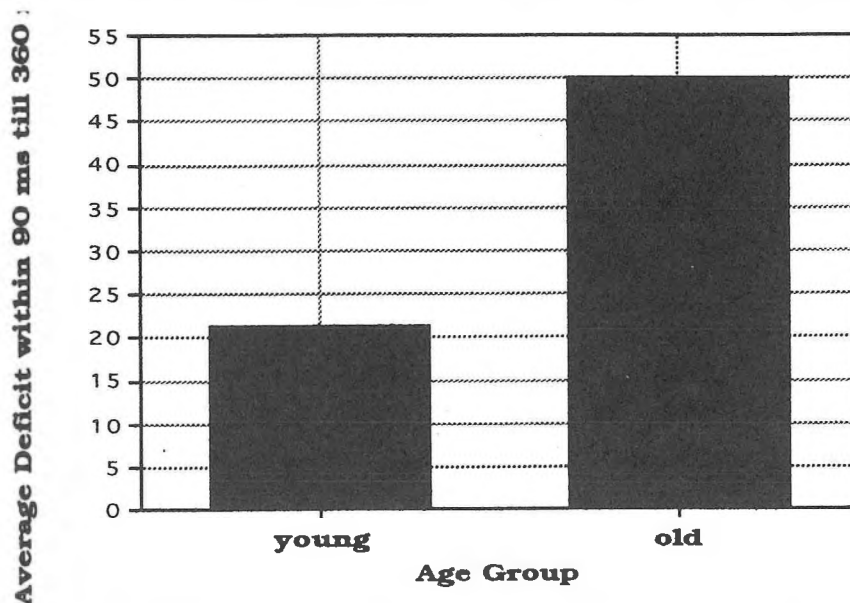

Figure 6. Information processing deficit about detection of the probe averaged across 90 ms, 180 ms, 270 ms, and 360 ms SOAs for young and old listeners.
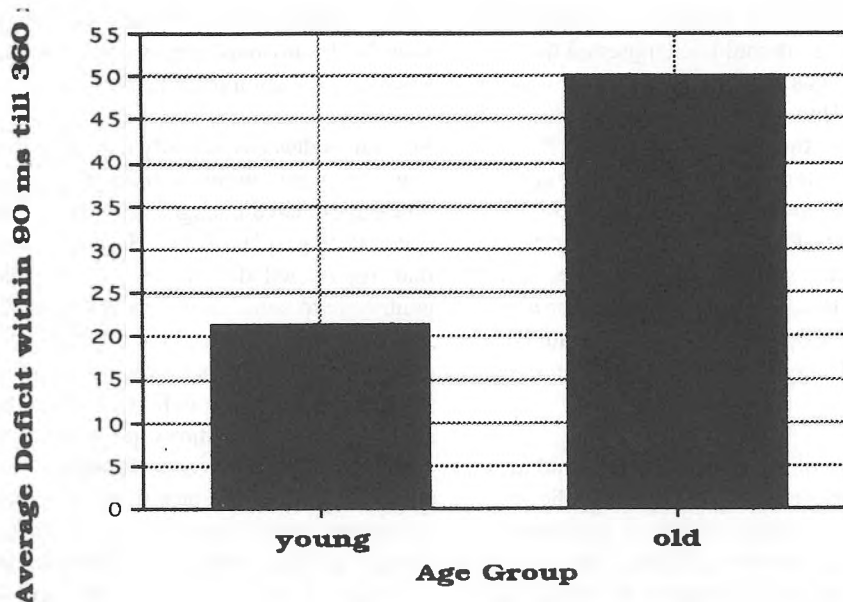
Figure 7. Variability in correct probe detection within experimental and control condition as a function of SOA. Parameters are age groups.
Please notice that variability = 0 in the control condition for the young group at SOA = 360 ms.

nificantly better than those of older adults (ps < 0.05). At the 540 and 630 ms SOAs however, the two groups' performances did not differ (ps > 0.05). False alarm rates ranged from 0% to 9% for both younger and older adults (averaging 2.3% and 1.8%, for younger and older adults respectively), and did not differ as a function of either group or condition (ps>0.05).

3.3 Auditory Attentional Blink Magnitude

Auditory Attentional Blink (AAB) magnitude for each of age group was determined by averaging the difference in percent correct detection between the single and dual task conditions for each individual in each task for SOAs of 90 ms to 630 ms inclusively. Figure 5 illustrates these differences graphically for both age-groups. A t-test (t (78)=3.50, p<0.05) revealed that older adults (M=51.7%, SD=34.4%) demonstrated a significantly "deeper" auditory Attentional Blink magnitude, averaged across four SOA's (90, 180, 270, and 360 ms) than younger adults (M = 28.3%, SD = 30.5%). Figure 6 illustrates these differences graphically for both age-groups.

3.4 Variability in Correct Target Detection

Both age groups demonstrated greater variability in correct probe detection within experimental condition relative to that within control condition. In particular greater variability was observed for SOAs 90 ms, 180 ms, 270 ms. and 360 ms. Thus, greater variability occurred at these same SOAs at which auditory Attentional Blink was observed. Figure 7 depicts this difference between conditions and age groups.

However, strict interpretations of the variability data warrant caution due to the ceiling effects in the control condition, especially for younger adults (e.g., SOA=360 ms), and for floor effects in the experimental condition for older adults.

4. DISCUSSION

This study explored the differences between young and old adults in the auditory Attentional Blink. In order to avoid potential modality differences in attentional dynamics (processing auditory stimuli while relying on their visual images) this study included stimuli that were not associated with time-compressed spoken letters and/or digit names. It has been shown that time-compressed speech can easily distort temporal acoustical speech cues and can be perceived differently by older and younger adults [27]. In the present experiment, we used pure tones to establish an auditory Attentional Blink.

Our results are consistent with Jolicoer (1999), who also found the Attentional Blink with pure tones, albeit in a cross-modal task. The identification task in this study became an attempted identification task in which participants were able to detect targets and probes but they were not able to identify them. Therefore the attempted-identification task has become a modified detection task. Thus, the subsequent discussion addresses this task as a detection task. However, a presence of the auditory Attentional Blink and potential differences that emerge between detection and identification tasks requires further clarification. The results of this study revealed an auditory Attentional Blink among both older and younger adults and confirmed the presence of a previously

demonstrated auditory Attentional Blink in a normal and congenitally blind population. It could be suggested that the auditory Attentional Blink, observed in the study was due to energy masking of P by T. However, the auditory Attentional Blink, cannot be explain by the energy masking of P by T because listeners were able to detect 2 tones at near ceiling accuracy in the absence of stream tones, even when these tones were separated by ISI of 5 ms. In addition, our previous findings that congenitally blind listeners relative to listeners with normal vision demonstrate an improved processing of stimuli efficiency reflected by a smaller auditory attentional magnitude [12] suggest that auditory Attentional Blink can be modified.

In agreement with a variety of studies that have found age-related changes in inhibitory tasks (e.g., [13], [19]) the ability to selectively attend to an auditory stimuli in the presence of similar distracting stimuli, appears to decline with age and may result from losses in the ability to inhibit the processing of irrelevant stimuli. Consequently, it might be expected that older listeners may demonstrate greater magnitudes in the auditory Attentional Blink compared to younger listeners, and as well, that the duration of the auditory Attentional Blink would be longer. Indeed, observed differences in the auditory Attentional Blink between age groups supports the notion of less efficient inhibitory mechanisms in older adults. Moreover, our previous findings [12] that congenitally blind listeners, relative to listeners with normal vision, demonstrated a smaller auditory Attentional Blink magnitude suggests that the auditory Attentional Blink is modifiable. By extension then, the efficiency with which attentional inhibition is deployed, differs across populations.

Consistent with Raymond, Shapiro, and Arnell (1992) we interpreted the auditory Attentional Blink as reflecting an inhibitory attentional mechanism, which suppresses the allocation of attention to subsequent stimuli (e.g., probe) until the target has been processed. Younger adults' detection of P was less affected by processing information about T compared to older adults and it is possible that the detection of P by younger listeners was facilitated by efficient inhibition. It might be that detection of sounds by older adults was more affected (less inhibited) by a temporal vicinity of other sounds than that of young adults. In particular, performance decrements in detection of sound immediately following the attended sound (T) was more pronounced among old than young adults.

It has been demonstrated that the greatest deficit in detection of tones for both age groups occurs in the closest temporal vicinity of the target (T). This would suggest an early selection process, which could be due to an inhibitory mechanism [25] and can reflect a deficit in perceptual processing. However, inhibitory mechanisms can operate in either modality independent or modality-specific ways, as suggest-

ed by several researchers who have studied prepulse inhibition, backward masking, negative priming and rapid serial visual presentation (e.g., [20]).

Several studies have clearly indicated that younger and older adults process auditory information in a similar fashion when age-related changes in hearing ability were taken into account, (e.g., [21]; [28]). However, while it is conceivable that age-related differences in pure-tone sensitivity could contribute to some of the observed performance differences between younger and older adults, it is unclear how differences in pure-tone sensitivity alone could account for the differential performance deficits seen in the experimental versus the control conditions, particularly at short SOAs. The current study compared performances of younger and older adults who were characterized by similar normal hearing (pure-tone sensitivity). Therefore, differences between age groups' auditory Attentional Blink which emerged when P followed T (90, 180, 270, 360, and 450 ms) cannot be explained by different hearing abilities of younger and older listeners.

The results of Jolicoer's study (1999) suggest that a cross-modal Attentional Blink occurs within a central, amodal attentional framework. The findings of his study support those of Massaro and Kahn's study (1973) in that identification of a sound can interfere with a processing of other stimulus (sound) in a close temporal vicinity and that it requires central processing.

However, the differences between these studies require a thorough consideration. Massaro and Kahn studied the influence of the attended sound on the recognition (identification) of an earlier sound. Both sounds were identical in pitch but different in quality and duration. Furthermore, both sounds were separated by a variable blank interval, and they were the only sounds to which listeners were exposed. Thus, these sounds were not embedded within any of stream stimuli, which are required in order to demonstrate the visual Attentional Blink [25]. Massaro and Kahn have also reported that identification of the attended sound (target) deteriorated in a presence of the earlier sound (probe). However, deterioration in T identification performance was not dependent upon the duration of the blank interval. Therefore, these results would suggest that the presence of other stimuli (sounds) between a target and probe is necessary in order to demonstrate the auditory Attentional Blink, although this remains an empirical question.

Attempts to address identification of T and P in the current study were not successful. Despite the near-ceiling identification observed during practice session, participants were unable to correctly identify the pitch of targets and of probes in the presence of the stream stimuli. Leek, Brown, and Dorman (1991) found that a discriminability of tones embed-

ded within a tonal stream requires a higher frequency difference limen than in a case of a single tone. In the current study relative difference limen (df/f) was, at most, between 0.2 and 0.33. In an absence of data for a given difference limen that is sufficient for the discrimination of a target and/or probe from surrounding tones on a basis of frequency, it is highly probably that the chosen frequency differences in the current study, were insufficient to identify targets and/or probes according to pitch. Thus, while the 10 dB sound pressure level difference between the sound pressure level of targets or probes and the level of tones within a stream allowed participants to discriminate the targets and probes from surrounding stream tones, it did not provide a sufficient information for target identification.

Nevertheless, even in the absence of accurate identification, all of participants demonstrated an auditory Attentional Blink. In light of both those findings, and of our previous findings which showed that a) auditory and visual Attentional Blink magnitudes are different and b) that auditory task performance was not correlated with visual task performance [11] we conclude that modality specific attentional mechanisms can govern the Attentional Blink and further, that this mechanism operates early to modify subsequent perception.

It should be noticed that the conclusions of this research were based on the results obtained for presentation rate of 11 tones per second. How the rate presentation and the frequency of T relative to the frequency of P affect performance remains an empirical question.

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