Attention to Time in the Auditory Modality

JIN, Mingxuan

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Attention to Time in the Auditory Modality

Submitted by Mingxuan Jin

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Abstract

Although attention is distributed across time as well as in space, the temporal allocation of attention has been less well studied than its spatial counterpart, especially in the auditory modality. However, temporal information is crucial to processing in audition and it is expected that attention to time may play a more important role in the auditory modality than in the visual modality. In the present thesis, I pursued three studies to gain more understanding of auditory temporal attention. In study 1, the basic temporal attention orienting was studies in the auditory modality. The results showed a cue effect indicating that it is possible to orient attention based on temporal information in the auditory modality, and that the temporal attention modulates perceptual and subsequent processing stages. In study 2, auditory attention in the temporal and spatial modalities was directly compared in one paradigm. The results showed that the temporal attention interacts with spatial attention, and temporal information is more dominant in guiding attention in the auditory modality. Temporal attention and spatial attention have some overlap in their neural correlates, such as the N1 and P2 components, but differ in the late P300

component. Finally, I extended current studies to another aspect of attention concerning attentional selection, to examine how auditory attention selects target items and suppresses or inhibits distractor items purely based on temporal information. Using the analog of a spatial flanker task, study 3 investigated the efficiency of attentional selection, and the results showed an interference effect and magnitude of temporal segregation were the primary factors that determine temporal attentional selection. In summary, the studies provide the first set of empirical evidence probing the nature of temporal attention in auditory modality.

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论文题目：

听觉通道中的时间性选择注意

提交人：金鸣轩

香港中文大学博士学位

摘　要

注意可以被选择性的投放在空间或时间维度上，但关于时间性选择注意的研究远远少于空间性的，尤其是在听觉通道中。由于听觉中的信息都是序列呈现的，时间信息在听觉中应该具有比视觉通道中更重要的指引作用。在本文中，运用行为实验和 ERP 方法，通过 3 个研究，我们试着深入理解听觉通道中的时间性选择注意。

研究一中，我们首次在听觉通道中重复时间性注意的基本范式，结果发现了线索效应，这表明在听觉中，我们可以利用时间信息来引导注意。ERP 结果发现早期 N1、P2 波以及晚期的 P300 都可以被时间性注意调制。研究二将时间性和空间性注意结合在一个范式中研究，探讨和比较两者之间的交互效应。结果表明时间信息和空间信息可以共同引导注意；在听觉通道中，时间性注意更占优。ERP 结果表明，二者在早期成分上比较相似，但在晚期成分上差异较大。最后，研究三中，我们关注时间性注意的另一方面：选择性，探讨听觉中注意是如何根据时间信息选择目标忽略干扰子的。运用 Flanker 范式，结果表明时间注意也有 flanker 干扰效应，并且，干扰量大小受到时间间隔的影响。

总之，本论文第一次系统的探讨了听觉通道中时间性选择注意的行为及脑电特征。

Thesis/Assessment Committee

Professor Alan Chun-nang Wong (Chair)
Professor John Xuexin Zhang (Thesis Supervisor)
Professor Liqiang Huang (Committee Member)
Professor Caiqi Chen (External Examiner)

INTRODUCTION

Studies of selective attention began with the well-known dichotic experiments on selective listening in the 1950s (e.g., Broadbent, 1958). Researchers soon switched to examine interest to attention about objects and space in the visual modality, partly due to ease in preparation and presentation of visual stimuli (e.g., Kahneman & Treisman, 1984). In addition to the visual search paradigm, a major approach to visual attention involves using the spatial cuing paradigm developed by Posner (1978) to examine the orienting of attention in space. After several decades of research in how attention distributes in space, a new line of research has emerged to examine temporal attention, the counterpart of spatial attention (Coull & Nobre, 1998; Miniussi, 1999; Griffin, 2001). These studies have provided preliminary evidence that orienting to attention in the temporal domain is possible. However, these studies are conducted in the visual modality using visual stimuli. None has examined the orienting of attention to time in the auditory modality. Given that auditory processing operates on streams of signals that unfold in time, temporal information may be more crucial for audition than for vision. Therefore it seems a valuable but unexplored topic to study auditory temporal attention.

In the present thesis, we studied two major aspects of temporal attention in audition, the orienting of attention to a particular temporal point, and the selection of relevant targets in the presence of detractors based on temporal information. We began with a review of research on attention to space and time in vision, and on attention to space in audition focusing on temporal attention. We then turned to specific research questions on attention to temporal information in audition.

Visual Attention

Visual attention to space

Our visual system is constantly overloaded with information from the environment. As an indication of our capacity limitations, attention restricts the contents that become available to awareness and directs resources towards task-relevant stimuli. The study of attention is a broad and active field with many different and important aspects. The selection mechanisms are one of the primary functions ascribed to visual attention. Since Posner (1980) describes the behavioral effects of orienting attention to spatial locations, there has been an enormous amount of experimentation on this issue. In a typical study, subjects made a simple reaction to the onset of a target light that appeared at one of several locations before target onset by cues such as a peripheral flash or a central arrow pointing to the likely location of the target. The well-established finding is that target detection is normally better at the cued location relative to uncued locations. These studies show that we are able to focus attention dynamically on relevant locations in space.

Visual attention to time

Although most research on attention has focused on the ability to select locations in space and the objects that occupy spatial locations, everyday experience would suggest that time also plays an important role in orienting our attention to the external world. That is, spatial and object attention might be sufficient in a static world, but not in the real world that is dynamic and consequently, time-related. A temporal perspective might also be important in terms of expecting an event and filtering events out of awareness. We also have the usual experience that focusing attention on anticipated future moments will lead to quicker responses. However, such abilities to use information about time to direct attention to future time points have not been much explored until recently. Directing attentional resources to specific moments in time, also referred as attention to temporal intervals, is a relatively novel conceptualization of attention. In the following, we review existing behavioral, electrophysiological, and brain imaging evidence on this topic.

Behavior evidence

The existing studies can be classified into three categories, based on the experimental paradigms used.

The first kind of paradigm (Coull & Nobre, 1998) is a temporal analog of the spatial orienting paradigm. In the spatial orienting task (Posner, 1980), the subjects are asked to respond as quickly as possible to visual targets appearing at peripheral locations. Immediately preceding the target is a visual cue that either correctly ("valid cue") or incorrectly ("invalid cue") predicts the location of the upcoming target. Similarly, in the temporal orienting task, Coull assessed whether stimuli that occurred at predictable cued intervals were detected more efficiently than those that did not occur at the predicted moment. The assumption is that expectancies about when an event will occur can be used to optimize behavioral responses, as the expectancies about where an event will occur.

As shown in Fig. 1, the basic trial structure consisted of a central cue and two peripheral boxes inside which the target ("x" or "+") could appear (Coull, 1998). The subjects' task was to detect the peripheral target stimuli as rapidly as possible while avoiding errors. The cue informed subjects to adjust their expectations of where or when target stimuli would appear in a trial.

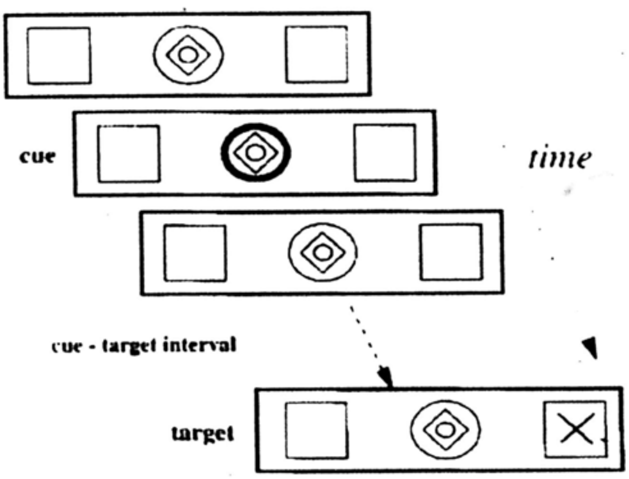


Fig. 1

A 2 x 2 factorial design was used crossing spatial cueing (S) and temporal cueing (T) and produced four types of cues, cues predicting both spatial location and onset time (ST), predicting target location only (S), predicting target onset time only (T), and neutral cues predicting neither target location nor onset time (N). The cue was a compound stimulus consisting of a diamond and two concentric circles (Fig. 2). Part of the cue would be highlighted to inform the subject to attend to either the location the target would appear (left or right) or the time interval after which the target would

(300 or 1500 msec from cue presentation). Specifically, in the S condition, the left (or right) side of the diamond would be brightened to indicate that the target was likely to appear in the left (or right) peripheral box. In the T condition, the inner circle (or the outer circle) would be brightened to indicate that the target would appear within a short 300 msec time interval (or a long 500 msec interval). In the ST condition, one of the circles and one side of the diamond would be brightened to indicate cueing of one of the four combinations of spatial location and temporal interval. In the neutral cue (N) condition, the entire cue brightened, providing no spatial or temporal cueing information. As with the spatial cueing paradigm, the cues would be valid (i.e., correctly predicting where or when the target actually appeared) for 80% of the trials and invalid for the rest 20%.

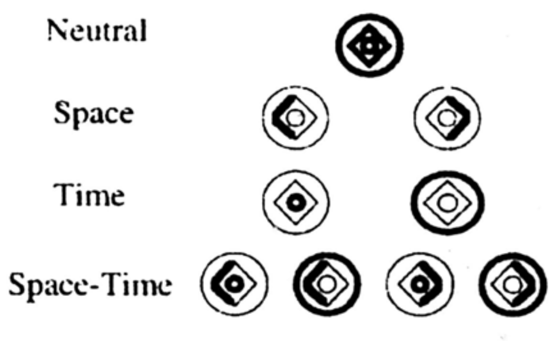


Fig. 2

The results demonstrated a response time benefit in all conditions when cues were spatially and/or temporally informative, compared with neutral cues. Furthermore, subjects showed behavioral costs for invalid cueing, as compared with valid cueing, for both spatial and temporal cues. This pattern of results shows that behavioral performance could be improved by informative cues regarding the temporal intervals preceding the presentation of peripheral targets.

There was also an interaction among task, validity, and time interval so that the response time cost associated with invalid cueing was smaller for targets presented at long intervals than at short intervals in the temporal cueing conditions. The authors explained this interaction as reflecting the fact that omission of the target at the short interval guaranteed it would occur at the long interval as there would always be a target in each trial. Subjects could then reorient attention to the later time point, reducing the impact of invalid cueing.

The Coull (1998) study provides the first empirical evidence demonstrating the possibility that when attention is paid to moments in time, it can benefit performance by speeding up responses to the target stimulus.

However, there was one problem in mixing the spatial and temporal dimensions closely in the experiment. The symbolic cues may selectively direct subjects to locations or intervals as the experimenter wanted, but the sudden appearance of a peripheral stimulus may summon attention automatically to its spatial location during temporal cueing. Similarly, target onset may summon attention automatically to its temporal interval during spatial cueing. Ideally, one would hope to separate the spatial cueing and the temporal cueing so that they did not affect each other.

Some more controlled tasks were developed to minimize the possible contribution of reflexive shifts of attention to the irrelevant stimulus dimension. This is the second type of paradigm we will describe. For example, Miniussi (1999) explored the dynamics process involved in directing attention toward temporal intervals, using a foveally selective task. The detection task they used included two kinds of central cues (narrow or wide cross), which predicted with 80% validity when a subsequent target would occur, either 600 or 1400 msec after cue onset. The task differs from the previous studies of selective attention in that all stimuli were presented foveally. Thus, there was no spatial information that could potential confounding the selection or detection of targets based on temporal cueing.

The behavioral results showed that reaction times were faster when the cues correctly predicted the cue-target interval, suggesting that subjects were indeed capable of using information about time intervals to improve their behavioral performance. Still, such kind of reaction time benefits was restricted to targets that occurred at the short interval. They, similar to what was proposed by Coull (1998), suggest that this reflects the subjects' ability to re-focus their attention to the long interval once the expected target time has elapsed beyond the short interval. The findings from this second paradigm indicate that it is possible to make use of temporal information to deploy attentional resources dynamically, even in the absence of any spatial information.

In a similar paradigm, Coull (2000) also verified whether the behavior results for temporal orienting would be consistent with his previous findings (Coull, 1998), in the absence of any spatial information. The task required detection of a visual target presented after an informative cueing stimulus. All stimuli were presented foveally at the centre of gaze. The cues were foveal concentric circles which informed subjects when the ensuing visual target would appear (SOA) with 80% validity. A factorial design was used to test the effects of cue validity (valid, invalid cues) and cue-target interval (600, 1400 msec). Results also showed that reaction times for valid trials were shorter than those for invalid trials, confirming the basic results and conclusions from Miniussi (1999).

Following these initial demonstration of the basic temporal cueing effects, some studies went further to investigate the specific mechanism of temporal selective attention. Griffin et al. (2001) reported a series of experiments designed to characterize the ability of orienting attention in the temporal domain.

The first key question they tasked was whether the reaction time benefits from temporal cueing observed reflect a rigid process, with a fixed optimal time course. In other words, they asked whether the preparatory processes underlying performance benefits on temporal attention tasks can be under flexible cognitive control.

They used the basic paradigm in previous temporal attention studies, which includes a identification task with the warning signal (cue) providing information about when a stimulus would occur, either at a short (600ms) or long (1400ms) interval. Cue and target stimuli were always presented foveally. Different from previous studies, there were 9 possible cue-target SOAs: 200, 500, 600, 700, 1000, 1300, 1400, 1500, and 1800 ms. The cues predicted the correct interval on 80% of trials. On invalid trials, the target appeared at one of the 8 remaining SOAs.

From the results (Fig. 3), we could see that the reaction times were decreased to targets appearing after an expected time interval. A comparison of targets that appeared at 600ms revealed a 100ms benefit in reaction time when subjects expected the target at this time interval, compared to when their temporal expectation was invalid (expected target at the long interval). RT costs were observed both when the target appeared 100 ms before (at 500 ms SOA) and 100 ms after the expected time point (600 ms). These results demonstrate our ability to use information about predicted time intervals to enhance behavioral performance. Furthermore, the different rather than the similar reaction time functions after the short and long cues indicate that the processes giving rise to such expectation and behavioral benefits are under flexible control, rather than having a fixed time course.

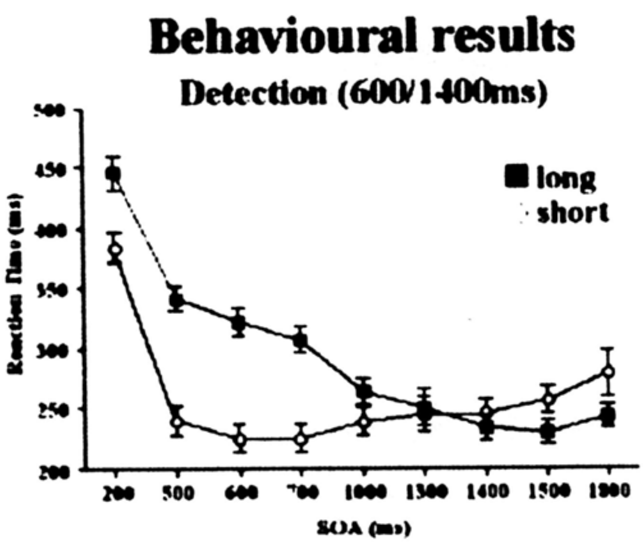


Fig. 3

The authors noted that there might be an alternative explanation for their findings. It is possible that the time interval they focused on was in fact in the range of the optimal foreperiod. Therefore, the behavioral facilitation they observed may in fact be the classical foreperiod effect rather than reflecting the cognitive control of orienting attention to time intervals. To test this possibility, they re-did their study using a different time frame around 300 ms and 700 ms. The patterns of results replicated generally that in their former experiments. Valid cueing produced reaction time benefits, with these effects being larger when subjects were cued to the short interval. The results showed that attentional resources can be allocated over time periods as short as 300ms, with benefits already being present even 100ms after the cue.

The previous two studies demonstrated decreased reaction times with selective temporal orienting of attention. This effect could be accounted for with several mechanisms. For example, it may reflect facilitated perception of stimuli occurring at the attended time point, modulation of the motor response, or some other more general mechanism not specific to sensory perception or motor responses. Griffin et al. designed two more experiments to manipulate motor variables and perception variables to distinguish these possibilities. For the motor variable manipulation, they designed a discrimination task to let subjects reacted to each target (X or +) with one finger (index or middle finger). The other aspect was same as the previous experiment. Again, results were broadly similar to previous results. There was a behavioral benefit of valid cueing, mostly over the short interval. The behavioral effects were not as strong as those seen in previous experiments, which may reflect some contribution of specific motor preparation to the effects seen in the previous experiments.

Furthermore, Griffin et al. manipulated perceptual variables within the time orienting task, by requiring subjects to make a difficult perceptual discrimination. The perceptual manipulation was used in order to test whether the requirement for more effortful visual analysis would also influence and make temporal orienting more difficult. In this experiment, subjects made choice responses according to whether a small gap was present or not in the target stimulus. The visual display of the task was slightly different to the tasks used in the previous experiments, and only two time intervals were used for target presentation.

Results were still similar to that in the previous experiments, the performance facilitation for targets at correctly predicted time intervals was observed with this difficult perceptual discrimination task (see Fig. 4). As with the previous discrimination experiment, the effects were modest and the average reaction times were longer than those seen in the earlier detection experiments. The difficult perceptual discrimination diminished but did not eliminate the effect of temporal orienting. The opportunity for additional perceptual aspects of attention did not appear to enhance the attentional effects. This supports the interpretation that the effects of temporal orienting did not occur in the perceptual stage but may be biased toward the post-perceptual aspects of information processing. However, based on these reaction-time results alone, one cannot rule out attentional modulations at the perceptual level.

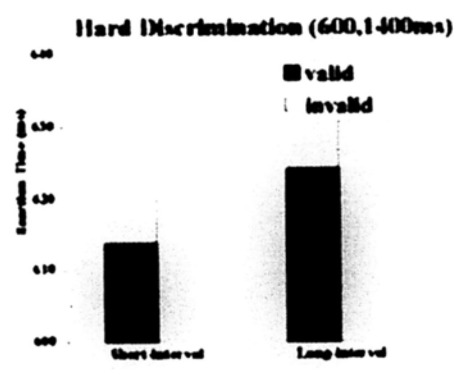


Fig. 4

As we can see here, many studies used the foveally selection paradigm to avoid confounding spatial factors. However, some researchers think there were still some problems with this paradigm. Firstly, it is hard to compare the behavior and neural mechanism of temporal and spatial selective attention, if they are not studied in the same task equating stimuli and task demands. Secondly, visual processing of foveal stimuli is already optimized in the visual system. It might therefore not be necessary or advantageous to enhance resources further for foveal stimuli. And even if perceptual selection processes matters for foveal stimuli, the facilitative effects may not be as strong as it can be for peripheral stimuli. That is, such foveal selection paradigm may undermine the real effect of temporal orienting attention.

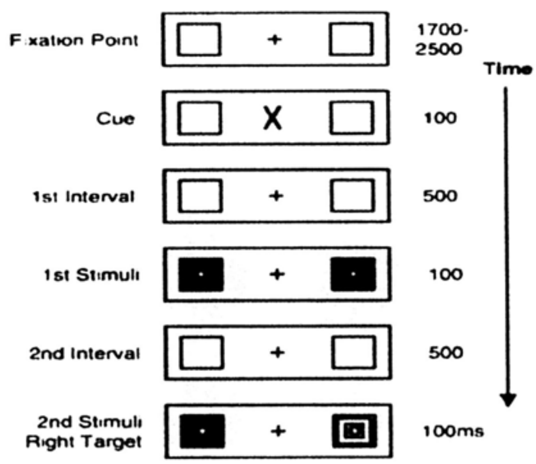


Fig. 5

Integrating the good features in former paradigms, a new paradigm with better control was developed to minimize these confounding and limitations. As shown in Fig. 5, with this paradigm, Griffin et al. (2002) presented identical central symbolic cues predicting either the spatial location or time intervals of the target stimulus. Arrays containing items in each location (left and right) were presented at each time interval (short and long), different from the previous peripheral paradigm which present one stimuli in each time and spatial location. Peripheral stimuli consisted of configurations of concentric squares. The target (with one of the inner concentric squares missing) appeared within the array at only one location and one time interval. The distribution of non-target items in both space and time helped prevent irrelevant automatic shifts of attention. The results (see Fig. 6) showed that large behavioral advantages were obtained for both spatial and temporal orienting under these conditions, suggesting that purely endogenous effects can arise in the temporal as well as the spatial domain.

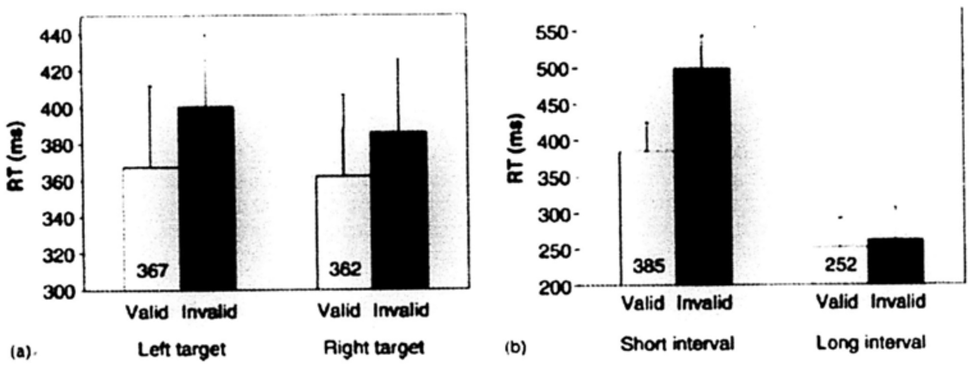


Fig. 6

To summarize, a general conclusion from these different behavioral paradigms is that we could use information about time to deploy attentional resources flexibly to optimize our response and behavior.

ERP evidence

Having established the existence of temporal orienting behaviorally, a natural next step is to enquire about the brain mechanisms of these effects. Event-related potentials (ERPs) have provided an important means of investigating attentional processing in the human brain, giving a more complete picture of stimulus processing than behavioral measures alone. Their high temporal resolution provides information about the on-line modulation of brain activity by attention, and about the level of stimulus processing at which attention acts. They also provide a measure of stimulus processing without any requirement for the subject to attend or respond to that stimulus, thus allowing comparison of the processing of both attended and unattended stimuli during conditions of focused selective attention. So, it would be useful to combined ERPs with behavioral measures to reveal the neural consequences of orienting attention to time intervals, and to compare them to the consequences of visual spatial orienting.

We all know that ERPs have played a decisive role in the study of spatial attention. However, the ERP evidence about the effects of orienting attention to time intervals is scant. The first ERP study used foveal stimuli and required the detection of a brief target that appeared after one or two predicted intervals (600, 1400ms) (Miniussi, 1999). The results showed that ERPs linked to shifts of attention in the temporal domain started several hundred milliseconds prior to the appearance of the subsequent target stimuli. These effects on ERPs elicited by orienting cues suggested differential engagement of motor preparation. But there were no effects of cue validity on the amplitude or latency measures of P1 or N1 for targets at either stimulus onset asynchrony.

This pattern of modulation is distinct from the well-characterized effects of spatial attention upon stimulus processing (Neville et al., 1987). The P300 was affected by target validity only for short SOA trials. The peak of the P300 was significantly earlier for expected validly cued targets (326 ms) than for targets that appeared unpredictably at the short interval (375ms), which may reflect changes in response preparation of decision. Like the behavioral effects described earlier, this ERP differences were restricted to targets appearing at the short interval.

These results suggested that the temporal orienting acted mainly after the early perceptual levels, by tuning decisions or response-related variables. However, as discussed earlier, one limitation of this experiment, was the use of bright transient foveal stimuli that may confound temporal orienting. Also the responses to foveal stimulation are already inherently optimized in the visual system, and it may not be necessary to enhance foveal visual processing further, which might be a possible account to why there is no earlier perception ERP component during the presentation of targets.

Similar results were obtained from Griffin et al. in their analysis of the ERPs elicited by the cueing stimuli (during the cue-target interval), which that the differential processing of cues predicting short and long intervals modulated the CNV (contingent negative variation) component. The CNV, originally named as an 'expectancy' wave, is often interpreted as an index of expectancy for an upcoming stimulus and the associated motor preparation (Brunia, 1993; Macar et al. 1999). The CNV was significantly accentuated when subjects expected targets at the short interval, starting around 280ms, which suggested that orienting attention in time modulates brain processes linked to motor preparation and expectancies.

This effect is markedly distinct from those seen during the cue-target interval in studies of spatial attention. During visual spatial orienting lateralized posterior and then anterior potentials are modulated according to the predicted location of the stimulus (Harter, 1989; Nobre, 2000). The authors think this 'striking difference' in ERP modulations in tasks of temporal and spatial orienting suggests that these two forms of selective expectancies may affect behavioral processing via very different mechanisms.

Analysis of ERPs elicited by the target stimuli further showed that temporal attention did have a modulatory effect on brain activity after the initial visual ERP components. Differences were observed in the amplitude of the N2 component, and the amplitude and latency of the P300 component, which have been linked to expectancies, decisions, and motor preparation (Kok, 1986; Mangun, 1995). Unlike studies of spatial attention (Mangun, 1995; Eimer, 1998), temporal orienting did not enhance the early visual-evoked potentials (VEPs). However, confounds associated with the fovea presentation of stimuli described earlier constrains the interpretation of the results.

To overcome this limitation and to test directly whether the optimization of behavior by spatial and temporal attention involve the same or different attentional processes, Griffin et al. used tasks to manipulate temporal and spatial orienting toward peripheral stimuli in a parallel way. The peripheral stimuli were presented simultaneously and briefly at each location and at each task-relevant time interval and the target stimulus appeared within the bilateral array at only one location and time interval. The results showed that spatial attention modulated the visual N1 component to show increased negativity on valid trials, especially over the contra-lateral scalp. This replicates many other studies of visual attention which have found N1 enhancements for valid trials over the scalp contra-lateral to the direction of attention (Eimer, 1998; Mangun, 1995), confirming the finding that spatial attention modulated early stages of stimulus processing.

However, unlike spatial orienting, there was no modulation of early VEPs by temporal attention. This clearly argues that spatial and temporal orienting has distinct early modulatory effects on stimulus processing. Temporal orienting was found to modulate the latency of the P300 component so that P300 occurred earlier when subjects attended the short interval than when they did not attend. Modulation of P300 latency was a finding similar to that in the previous two studies, in which the temporal orienting was studied with foveal stimuli. Latency modulation of the P300 component is not typically reported during spatial attention tasks. This suggests that temporal orienting may affect stimulus processing via different or additional mechanisms to that found in studies of spatial attention.

In summary, the available ERP studies indicate that spatial and temporal orienting seem to be associated with distinct modulatory effects on stimulus processing, even when probabilities of stimulus occurrence at different spatial locations or time intervals have all been matched. While spatial attention affects visual N1 component in a lateralized way and acts in an early, perceptual selection stage of analysis, temporal attention seems to show a different pattern of modulation, exerting its effects later on the latency of the P300 potential linked to decisions and responses.

Brain imaging evidence

This section reviews studies concerning the nature of the neural system that controls the orienting of attention toward specific time intervals using fMRI (functional Magnetic Resonance Imaging).

Coull et al. (1998) was the first to directly compare orienting attention to spatial locations and to time intervals using fMRI. They wondered whether there was a unitary system for allocating attentional resources that was independent of the stimulus dimension used to direct expectancies or whether functionally specialized brain regions differentially deployed these resources toward different aspects of the external world.

As described earlier, subjects detected the brief appearance of target stimuli that occurred at one of two peripheral (7 ° eccentricity) locations (left, right) and at one of two time intervals (300, 1500 ms). Across different conditions, predictive cues indicated (80% validity) the likely spatial location, time interval, or both the location and the interval of the subsequent target. In one additional condition, neutral cues provided no predictive information.

The brain imaging results showed both partial overlap and partial specialization of the neural systems for orienting attention in space and in time. However, the two patterns showed opposite hemispheric lateralization. Spatial orienting preferentially activated the right inferior parietal lobule (IPL); but temporal orienting preferentially activated the left IPL and the left inferior lateral premotor cortex (BA 6/44). The conjoint presence of spatial and temporal cueing enhanced activity in both right and left parietal regions, and additionally activated the right temporal parietal junction (TPJ). Based on previous results in the literature, the left hemispheric lateralization for temporal orienting could be explained as reflecting a left-hemisphere dominance for cognitive functions such as motor intention or preparation (Kram, 1998; Rushworth et al., 1997; Rushworth et al., 1998) or fine temporal discriminations (Fiez, 1995). Motor preparation and anticipation may thus play an important role during temporal orienting, which is consistent with the major ERP finding that temporal orienting of attention mainly is associated with modulation of late ERPs components linked to decisions and motor preparations.

However, as noted previously, the appearance of peripheral targets may have introduced reflexive spatial orienting. The partial overlap in parietal-frontal activations might therefore have been a consequence of the presence of spatial orienting across all conditions. So, in a follow-up experiment (Coull et al., 2000], researchers used fMRI to investigate brain activations during orienting to time intervals in a task using only foveal stimuli. The results showed that all trial-types activated a shared system, including frontoparietal areas bilaterally, suggesting a common network associated with attentional orienting which is not only specific to spatial orienting. In this study, the parietal-frontal involvement in the previous experiment was no longer a contamination from reflexive spatial attention to peripheral events. Posterior parietal cortex was activated bilaterally around the intraparietal sulcus. Lateral premotor/prefrontal activation also occurred bilaterally, but was mostly at regions more inferior to the frontal eye-fields.

The comparison between invalid and valid trials highlighted the effects of temporal orienting, since invalid trials preferentially tax disengagement and shifting of attentional focus from one time interval to the other. This comparison replicated the activation of a left-sided network of posterior parietal and inferior premotor/prefrontal cortex, and the selective participation of the orbitofrontal cortex during invalid trials. The findings reinforce the hypothesis that the systems for orienting attention can include sensorimotor areas with differential specialization and can interact with prefrontal areas dynamically. Brain activity in long SOA trials was preferentially enhanced in the medial premotor cortex in the anterior portion of the supplementary motor area (pre-SMA), the left putamen and bilateral thalamus, which indicated that long cue-target intervals invoke extended motor preparation, anticipation and response withholding.

The Griffin et al. (2001) study replicated the typical behavioral pattern of cue validity effects for temporal cueing mainly at the short intervals. The imaging results in the study showed that the brain system for temporal orienting appears to involve a left-hemisphere dominant frontal-parietal network. The network also interacts with areas related to motor attention and motor readiness. Such results further support the notion that modulation of motor-related variables plays an important role in temporal orienting, and activities in these areas are also coordinated with other areas subserving specific aspects of temporal orienting, such as prefrontal control and visual areas.

In another study, Coull et al. (2004) investigated the neurolanatomic basis of temporal attention using a different paradigm, the temporal conjunction search paradigm. Based on their behavioral results suggesting that temporal conjunction (TC) tasks placed a greater load on temporal allocation of attention than temporal feature (TF) tasks, the authors speculated and examined whether left parietal cortex should be activated more by the TC than the TF tasks. The fMRI data confirmed their hypothesis and showed that left parietal cortex was preferentially activated in the TC vs. TF comparison. However, the same region was also activated by the comparison of SC (spatial conjunction) to SF (spatial feature) tasks, demonstrating a lack of specificity for left parietal cortex in these temporal versus spatial search tasks.

This pattern of results suggests that selective activation in left parietal cortex by temporal attentional orienting tasks, reported previously, may not be related to temporal processing per se, but rather to processes such as motor attention which are taxed more heavily during temporal orienting than temporal search. Moreover, the comparison of TC to TF tasks activated parietal cortex in the right, as well as the left hemispheres, further demonstrating a lack of specificity of left parietal cortex for temporal selective attention. The regions selectively associated with temporal selective attention therefore, as indexed by the interaction term, were the left prefrontal cortex, frontal operculum and putamen bilaterally and right superior temporal cortex. These frontal activations concur with the results of Marois et al. (2005) who observed prefrontal activation for a temporal, but not a spatial, version of their attentional blink paradigm.

Auditory attention

Auditory attention to space

Relative to the amount of research on visual attention using the cuing paradigm, only a few investigations have been conducted on mechanisms and characteristics of auditory attention to space and not all of them demonstrate the spatial cueing effect successfully. For example, Posner (1978) asked participants to detect or discriminate the presence of a brief tone presented to the left or right ear after a visual spatial cue, an arrow indicating the most probable location. Contrary to the effects in visual attention, the speed of tone detection was independent of cue validity. In other studies, researchers also failed to find benefits to sound detection from valid cues (Scharf, Quigley, Aoki, Peachey and Reeves, 1987; Klein, Brennan, and Gilani, 1987; Buchtel and Butter, 1988; Spence and Driver, 1994).

Rhodes (1987) was the first to report a spatial cuing effect in auditory orienting. She suspected that simple detection tasks cannot demonstrate such effect because they can be performed through a non-spatial representation. She used a localization task to ensure that a spatial representation was involved in performance. When subjects had to specify the location of a target, their reaction time increased with the spatial distance between target and cue. Mondor and Bryden (1991, 1992) also demonstrated that in identification tasks, the valid cues could affect the spatial distribution of auditory attention. In their experiments, participants were presented simultaneously with two verbal stimuli, one to the right ear and one to the left ear. Before each trial, a tone cue was presented to one of the two ears. Participants were instructed to identify the syllable presented to the cued ear. Thus, these investigations provided evidence that for dichotic presentation, spatial cues do facilitate auditory perception. Most of the ERP studies on auditory attention examine intramodal stimulus selection (Naataned, 1990; Woods, 1990) where attended and unattended auditory stimuli differ from each other in spatial location, tonal frequency, or both, focusing on the negative difference (Nd) waveform between the attended and the unattended stimulus. The Nd consists of separate early and late portions, which appear to originate from auditory and frontal cortices, respectively (Naataned, 1990). Hillyard et al (1973) considered the early portion of Nd to be caused by an enhancement of the N1 component, reflecting a physical enhancement function of attention. However, more and more evidence were later reported against this view. For example, the Nd began after the peak of N1 deflection and lasted for several hundred milliseconds (Naatanen, 1980), and, the N1 distribution depends on the frequency of the eliciting stimulus, but the early Nd distribution does not (Woods, Alho, and Algazi, 1991).

These data favor a view of Nd as caused by an attention-related endogenous ERP component, called the processing negativity (PN). Naatanen (1982, 1990) has proposed that the PN component is generated by a matching process between the sensory input and an 'attentonal trace'. The attentional trace is actively formed and maintained during selective listening and each auditory stimulus is compared with the trace. This comparison lasts longer, the PN component is elicited with a longer duration and larger amplitude. This theory has gained strong support from later studies. Breifly, the Nd indicates the difference between a larger and long-duration PN elicited by relevant stimuli and a smaller and shorter-duration PN elicited by irrelevant stimuli, which overlapping with exogenous N1 components.

Auditory attention to time

So far there has been only one study examining attentional orienting to time in the auditory modality. Lange et al. (2003) presented to participants sequences of brief (50-ms) white noise bursts with every two neighboring bursts marking the onset and offset of an empty interval. The intervals could be short (600 ms) or long (1200 ms), randomly intermixed. In half of the blocks, participants were instructed to pay attention only to short intervals and ignored long intervals and to detect an infrequent deviant tone louder in intensity. In the other half of the blocks, they paid attention only to long intervals. The deviant tone would only occur at the offset of an interval, as shown in Fig. 7. The results showed that stimuli presented at the attended compared to the unattended moments in time elicited an enhanced N1 and an enhanced posteriorly distributed components in 300–370 ms, suggesting that attention can be flexibly controlled in time and that not only late but also early perceptual processing stages are modulated by attending to a moment in time. Due to the adoption of block design in this study that is well recognized to suffer from strategic factors, it is not clear their results indeed reflect flexibly allocation of attention in time, which has been usually demonstrated in spatial cueing studies with event-related designs where different types of trials were intermixed in every block. Further, there is no behavioral evidence substantiating the claim that orienting to a particular time point did occur in this study.

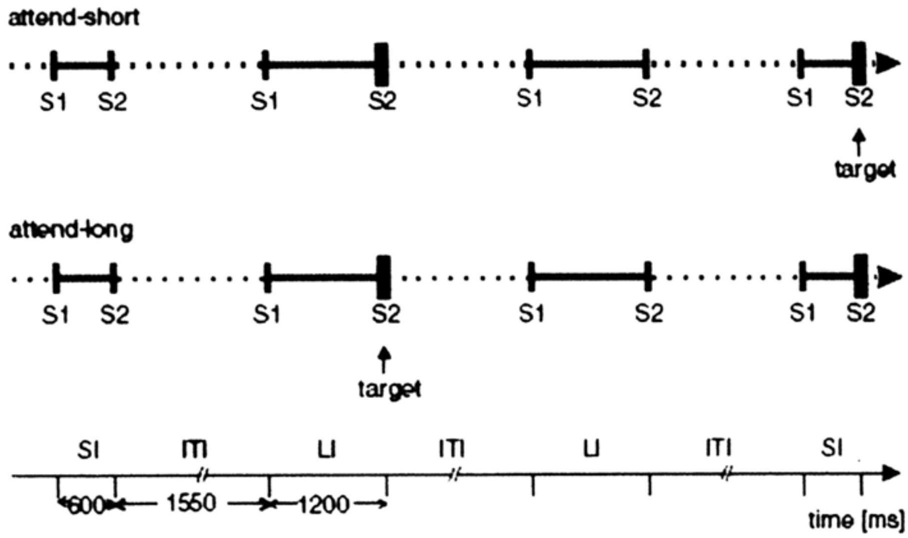


Fig. 7

EXPERIMENTAL STUDIES

Overview

The literature review shows that much of research on attention has been devoted to the study of orienting of attention in the visual and spatial domain. Even recently researchers have started to examine orienting of attention in time, the major focus is still in the visual modality with only one study on auditory temporal attention conducted 5 years ago without any follow-up studies. This seems to indicate a major blind spot in the theoretical landscape of attention. While 'vision is inherently spatial' (Charles, 1994), audition may be inherently temporal. Temporal information is crucial to processing in audition of sequences of letters, tones, words, and digits. So it is expected that attention to time may play a more important role in the auditory modality than in the visual modality. In the present thesis, we pursued three lines of research to gain more understanding of auditory temporal attention.

1. Attentional orienting to time in audition

As we pointed out, there has been only one rather isolated study in temporal attention in audition and its results are both limited in scope and not convincing due to methodological weakness. Additional foundation work are needed to establish the basic effects that voluntary and flexible orienting of attention to a particularly time point indeed occurs and can benefit performance in auditory tasks not concerned with the spatial dimension.

2. Comparison between temporal attention in vision and in audition

As one way to push forward understanding to temporal attention in audition, we also directly compared it with spatial attention to examine their similarities and differences and investigated whether there would be any interaction between orienting based on two different types of cues.

3. Temporal selective attention in audition

In many situations in everyday life, adaptive and flexible behavior requires the ability to choose among multiple response options, often in the face of conflict or uncertainty. So, besides orienting the selective attention to relevant information, the successful inhibition of distracting information is also a prerequisite for adequate behavior. It is well-known in visual attention studies that for higher-level cognitive tasks, selectivity is a more crucial aspect of attention than orienting in selecting task relevant information and resisting interference from distracting information.

However, so far, the research on temporal attention, whether in vision or audition, has studied only attentional orienting. Our goal here was to extend current studies to the second major aspect of attention to examine how auditory attention selects target items and suppresses or inhibits distractor items purely based on temporal information. The specific paradigm we used to measure selective attention is the very classical Eriksen flanker task widely used in visual selective attention research (Eriksen & Eriksen, 1974).

In a typical flanker task, participants responded to a relevant central target letter that was flanked by irrelevant distracter letters that can be compatible (associated to the same response as the target), neutral letters (associated with no response), or incompatible (associated with the response opposite to that of the target). The typical finding is that performance receives benefits when the flankers are compatible but suffers from interference when they are incompatible. Such facilitation and interference effects are taken to indicate the extent to which attention is selectively focused on the target letter not to be influenced by the distractors. We modified this paradigm to create a temporal flanker task to present three items sequentially in time and ask participants to respond only to the middle target item and ignore the other two items. Critically we measured whether performance were affected by the distractor temporally 'surrounding' the target. It could be possibly a novel way to examine attention to time, if we would demonstrate a temporal flanker effect.

Corresponding to these three goals, we did three studies to examine temporal attention in audition.

In Study I, discrimination tasks (Exp. 1) were used to demonstrate that auditory selective attention in audition can be oriented based on temporal information. Both behavioral and ERP measures were used to investigate the characteristics of temporal orienting. To rule out the fore-period account, Exp. 2 varied the length of the temporal intervals to see whether temporal attention can be voluntarily adjusted for a flexible control of orienting.

In Study II, orienting to time and space in audition was compared with the combined spatio-temporal cues to examine whether spatial and temporal orienting effects are additive to some extent (Exp. 3) and whether temporal cues are more important or effective to dominate over spatial cues in auditory attention (Exp. 4).

In Study III, we investigated whether people can use temporal information to ignore irrelevant stimuli for effective selection. Firstly, we attempted to duplicate the basic visual flanker effect in auditory modality with three items presented in a sequence (Exp. 5). Then, we in Exp. 6 adopted the same task but varied the SOAs between the target and the distractor items, just as distance is varied in the visual flanker tasks, to examine the temporal characteristics of auditory attention, specifically, its temporal resolution.

One major theory for visual selective attention emphasizes the effects of perceptual load on selective attention (Lavie, 1995). For the flanker paradigm, the theory would predict that whether the flanker items create interference or facilitation to the target processing does not only depend on how they are separated in space (here in time) but also how much processing resources participants devote to the target. Therefore, as one step to examine whether this fundamental tenet of a major theory for visual selection attention applies to auditory selective attention, we would also manipulated the task difficult in Exp. 7 to examine whether the perceptual load interacts with the temporal flanker effects.

Methodology

Study I

Experiment 1

This experiment evaluates the proposal that auditory attention could also be oriented based on temporal information, like visual temporal attention. In addition to behavioral measures, event-related potentials (ERPs) were used to reveal the neural consequences of orienting attention to time intervals in auditory modality, and to compare them to the consequences of visual temporal attention.

The paradigm in this experiment is an auditory analog of the visual temporal attention paradigm in previous research on visual attention (Coull, 1998). ERPs were recorded while participants perform a target discrimination task. A key question for us is whether there were some early ERP components in auditory temporal attention, which has important implications for a central theme in attention research concerning the level(s) at which stimulus processing can be influenced by attention. Early ERP components have been documented to be a key characteristic of spatial attention both in visual an auditory modality, but there is no clear result for visual temporal attention.

Participants

11 healthy right-handed healthy college students were recruited. All have normal or corrected-to-normal vision and normal hearing. Written informed consent was

obtained.

Stimuli

The cues were the Chinese word 'short' and 'long' with 87db intensity, which was presented with a male speech binaurally. The targets were 100-ms pure tones, either 400 Hz or 800 HZ. The frequency of distractor was 250 Hz, also with duration of 100 ms. The intensity of target was 87dB and the distracters' intensity was 67dB. All tones were presented binaurally and thus appeared to the participants to come from the mid-line of their body.

Task and procedure

Subjects comfortably seated in a dimly illuminated, sound shielded room, wearing earphones. They were asked to do a discrimination task. Before each trial, a target tone was presented to participants, indicating which tone she/he should respond to. The auditory cue then indicated when the target will be presented, after either a short (600ms) or a long interval (1200ms), with 75% validity. Two tones were presented, one in 600 ms and the other in 1200n ms. One of them was the target and the other a distractor. Participants were informed, at the beginning of the experiment, about the cue–target relationship, and they should press one key for the 400 HZ tone and another for the 800 HZ tone s soon as possible when they heard the target tone.

Experiment design

A 2×2 mixed design with factor cue (short vs. long) and validity (valid vs. invalid) was used, in which four kinds of conditions would be in random order. There were totally 240 trials and each trial lasted 3 seconds. The whole session lasted on average

15 minutes.

ERP recording

EEGs were recorded continuously from 64 scalp sites using non-polarisable tin electrodes mounted on an elastic cap (Electro-Cap Inc.), positioned according to the 10-20 International system. The montage included 8 midline sites (FPZ, FZ, FCZ, CZ, CPZ, PZ, POZ, and OZ) and 23 sites over each hemisphere (FP1/FP2, AF3/AF4, AF7/AF8, F3/F4, F5/F6, F7/F8, FC1/FC2, FC3/FC4, FC5/FC6, FT7/FT8, C3/C4, C5/C6, T7/T8, CP1/CP2, CP3/CP4, CP5/CP6, TP7/TP8, P3/P4, P5/P6, P7/P8, PO3/PO4, PO7/PO8, and O1/O2). Additional electrodes were used as ground and reference sites. ERPs were referenced to the right mastoid. Data were recorded with a band-pass filter of 0.03–100 Hz.

The epoch analysis of ERPs was performed off-line. Epochs started 100 ms before and ended 800 ms after stimulus onset. Pre-stimulus (100 ms) interval was used to calculate the baseline in order to minimize the possible contribution of tonic modulation during the cue-target interval.

Horizontal and vertical eye movements were detected by recording the horizontal and vertical EOG with bipolar electrodes placed around the eyes. Participants were asked to minimize eye movements.

Separately averaged ERP waveforms were computed for the four different types of targets (valid and invalid for short, and long cue-target interval). ERPs elicited by the two types of cues (short versus long intervals) also were computed. Trials with reaction times faster than 130 ms or slower than 1000 ms were regarded as errors, and excluded.

The EOG recordings served for offline rejection of trials with eye movements. Trials were rejected if the voltage change between two consecutive sampling points exceeds 70 mV or if the maximal absolute voltage difference exceeded 150 mV at any electrode.

Data analysis

Behavioral data Reaction times to targets and accuracy of performance were analyzed by repeated-measures analyses of variance (ANOVAs) with factors including cue-target relationship (short versus long), and validity (valid versus invalid).

Event-related potentials Identifiable ERP components were analyzed for both cue and target stimuli, and they were analyzed for the standard stimuli at electrode locations where they showed maximal intensity in the distribution. N1, P1and P2 were analyzed both for the target stimuli and cues at central electrodes paires which showed the maximal intensity, similar to the previews papers (Miniussi, 1999): CPZ, CZ, CP1 and CP2. For each subject, the peak of the N1 component were calculated at the time point of the largest negative peak between 60 and 150 ms. The peak of the P2 components were calculated at the time point of the most positive peak between 180 and 210 ms. The P300 potential was also analyzed only for the target stimuli at electrode sites which showed the maximal intensity on the mid line FZ, CZ and PZ. The P300 peak were calculated at the largest positive-going peak occurring between 250 and 350 ms. The CNV potential was analyzed only for the cue at the four central electode sites which showed the maximal intensity CPZ, CZ, CP1 and CP2. The CNV peaks were calculated at the largest positive-going peak occurring between 300 and 500 ms.

Since we deploy the Chinese word as the cue stimuli, and the language process involves the left hemisphere specific neural correlations, so here we did not compare the neural components between left and right hemisphere to avoid the mix of the effect of temporal attention specific correlations and which induced by the language processing.

Results

Behavioral results

The accuracy of all the trials was higher than 95%, and the trials with error reaction were excluded from analysis. Reaction times to targets in the behavioral experiment were analyzed (N=11). Analysis revealed a main effect of validity [$F(1, 10) = 5.89$, $P = 0.036$], and an interaction between validity and cue-target interval [$F(1, 10) = 110.52$, $P < .001$]. In the short interval condition, the reaction time was faster when the cue was valid than when it was invalid [$t(10) = 8.14$, $p<.001$]. However, the reaction time to targets at the long interval was faster when the cue was invalid than when it was valid [$t(10) = -12.63$, $p<.001$]. Fig. 8 shows the pattern of results. The pattern we got under short interval condition was similar to visual temporal attention studies that temporal cue facilitated the behavioral. However, in long interval conditions, the reaction times when the cue was invalid were much faster than when cue was valid. It can be explained by the special procedure of the present experiment.

When the participants received a short cue, the expected a target presented after a short interval, however, when the short cue was invalid, they did not received any target tone at the short time point, after that, the participants can inferred that the target must be presented at the long interval. This kind of 'shortly emphases' might be another kind of 'cue' to show the target will be presented shortly. So, there was a faster reaction when the cue was short but invalid in the long interval. We will test this hypothesis in the following ERP result part.

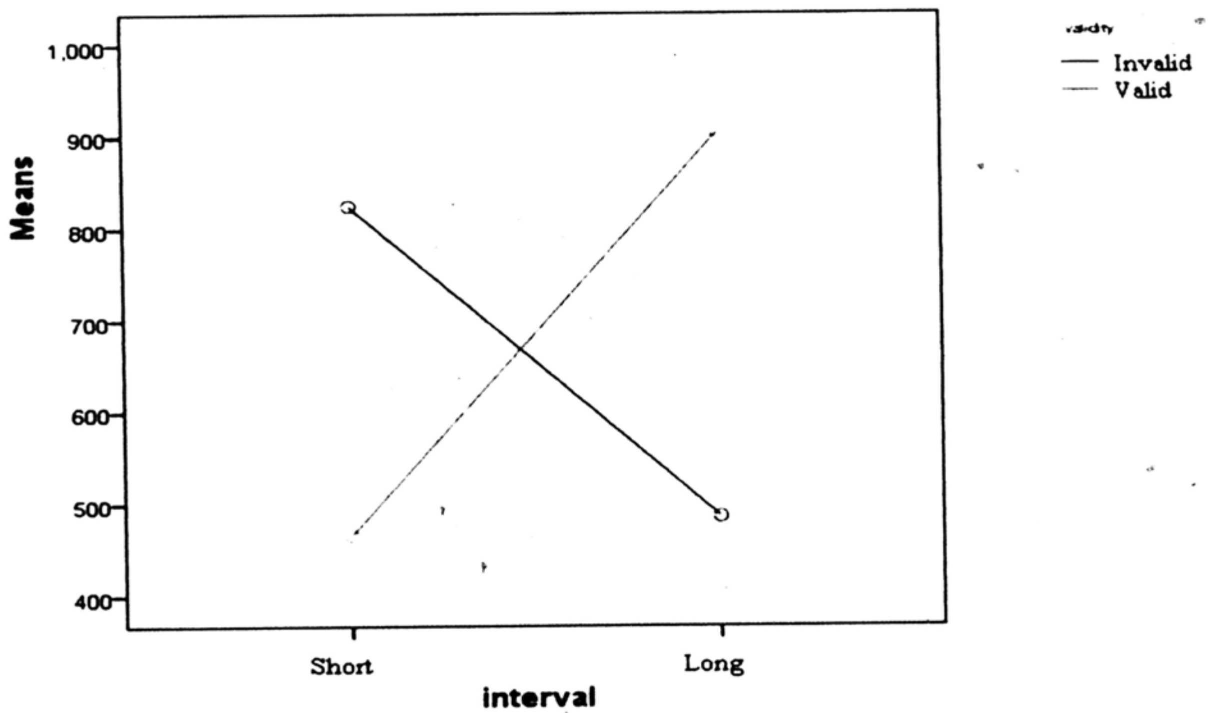


Fig. 8

ERP results

Cues

Data from 11 subjects were used to analysis ERPs elicited by cues. ERPs elicited by the two types of cues (signaling short versus long intervals) were constructed. ERPs to cues did not take into account trial validity, since this is not determined until the appearance of the target.

The ERPs were characterized by a CNV at around 300-500 ms, which were maximal over central sites, as the figure 9 showed. A t-test was used to test the difference between two types of cues (short versus long). The results showed a significant difference [t (10) =-2.80, p=0.01], that is, the CNV was significantly accentuated when subjects expected targets at the long interval. Since the CNV component has been linked to expectancies, in some content, the present results supported our hypothesis, which we used to explain the behavioral results in the long interval condition.

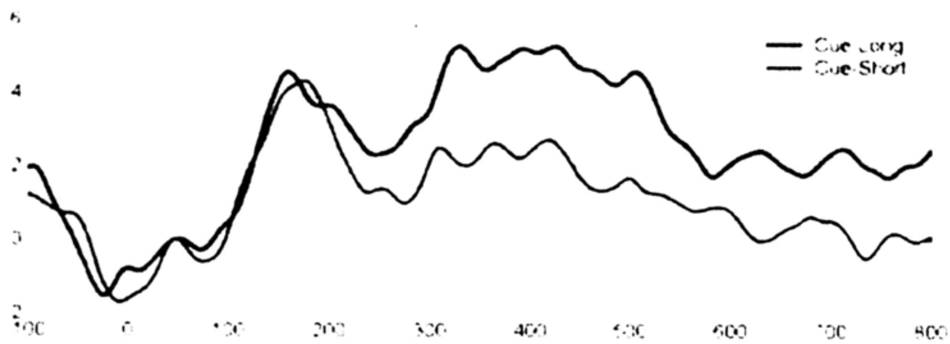


Fig. 9

Targets

Representative waveforms are shown in Fig. 10, and also, the upper figure is the results from short interval condition and the lower one is from long interval condition. A 2 x 2 ANOVA with two factors, interval and validity was done to test the effect in the components: N1 and P2. Significant interactions were found for both components [F (1, 11) = 21.07, p = 0.00; F (1, 11) = 46.86, p = 0.03]. Paired t-tests showed that there were significant differences on auditory-evoked components, N1 and P2, both in short [t (11) = 2.55, p = 0.02, t (11) = -5.35, p = 0.00 respectively] and long intervals [t (11) = -1.92, p = 0.04, t (11) = -2.90, p = 0.01 respectively]. These results suggested that selectively attending in time modulates processing stages related to perceptual processes.

In the short interval condition, the N1 component showed a more negative peak when the cue was valid, which means that the valid cue improve the sensation of the targets. However, the N1 showed a more negative peak when the cue was invalid in the long interval condition, which partly confirm our hypothesis that the target which did not presented after a short interval indicate a short cue is invalid, in this case, a target in long interval were expected and the N1 showed a more negative peak.

The amplitudes of P300 were affected by temporal attention only in the short interval condition [t (11) = -3.37, p = 0.00], which indicated a dynamic neural activity involved in orienting auditory attention to time intervals. However, there was not any P300 difference in long interval conditions [t (11) = 0.70, p = 0.50]. As showed in figure 10, the magnitude of P300 in long interval condition was similar to it in short interval when the cue was valid. This data style could be explained by our hypothesis that in the long interval condition, participants could infer the presentation of target based on the situation after a short interval. So, they have some kind of expectation both in short and long interval condition.

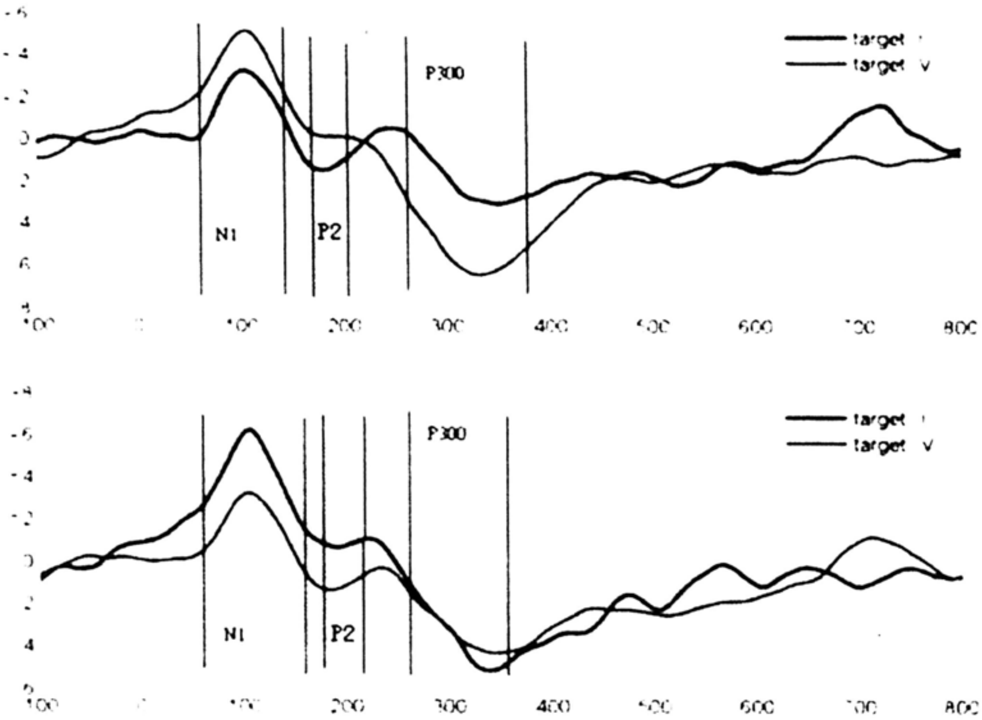


Fig. 10

Experiment 2

This experiment is identical to Experiment 1 except that the time intervals to orient were in a different range from 400 ms and 800 ms. If the results replicate what was found in Exp. 1, it would indicate that what was observed in Exp. 1 were not foreperiod effects that only operate in a specific temporal interval range but indeed reflect a flexible involuntary orienting of attention to time. To test this possibility, we re-did Experiment 1 using a different time frame around 400 ms and 800 ms.

Participants

6 healthy right-handed healthy college students were recruited. All have normal or corrected-to-normal vision and normal hearing. Written informed consent was obtained.

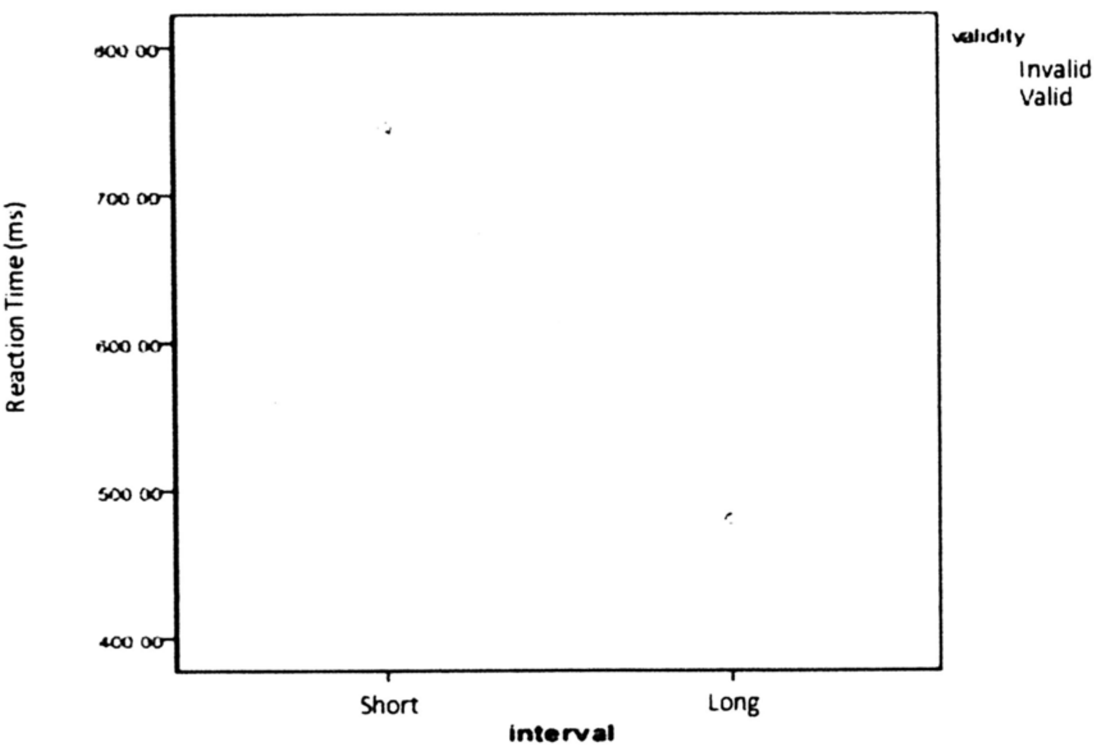
Procedure

Task and behavioral experiment design was as same as what in Experiment 1, only behavioral experiment was done and no any ERP study in this experiment. The procedures were also similar except the short and long temporal intervals were changed to 400 ms and 800 ms.

Behavioral Resuls

Reaction times to targets in the behavioral experiment were analyzed (N=6). Analysis revealed an interaction between this factor and cue-target interval [$F(1, 5) = 46.92$, $P = .001$]. Both two main effects were non-significant.

Results of paired t-test showed the significant difference both in short and long interval condition [$t(5) = 5.85$, $p < .005$; $t(5) = 7.27$, $p < .001$ respectively]. The data style and the explanation were similar to what in experiment 1.



Summary for study I

The aim of Study I was to investigate whether attention can be oriented based on temporal cues in auditory modality, and the neural correlates of temporal selective attention in audition.

The ERP recordings permitted on-line measures of shifts of attention. The differences between cue types involved modulation of CNV, suggesting the different expectation aroused by short and long cues. The CNV have a more negative peak in the long cue trials, which different from the previous studies in visual modality.

The ERP component N1, P2 and P300 of target processing were analysised. On the short cuing conditions, results showed a similar pattern to the previous studies: an accentuated modulation of the N1, P2 and P300 in the valid cuing conditions. The behavioral results showed a cue effect that the reaction time for discriminating the valid target was faster than the invalid ones was found. The cue facilitate effect were restricted to targets which occurred at the short interval, as same as the results found in visual temporal attention studies. These parts of results showed that subjects were indeed capable of using information about time intervals to improve our performance, and the early processing stage were modulated.

There were some different results got from the long cuing condition: an accentuated modulation of the N1 and P2 component in the invalid cuing conditions and no difference of P300 between the valid and invalid condition. And the behavioral data also showed a fast reaction in the invalid cuing trials. Due to the specific task setting and experimental procedure, the data type in long interval condition was different from those previous studies. Both the behavioral and ERP results showed an accentuated result in the invalid trials in long interval condition. This kind of difference could be viewed as the particularity of the temporal attention in auditory modality, which need to be further studied using paradigm with some modification.

Forperiod effect is a phenomenon that in the reaction time paradigm, when the target fall into a duration, a better reaction could be got. Many researcher believe that foreperiod reflect a kind of relationship between time and non-specific preparation (Antonino Vallesi et al., 2007). The patterns of results obtained from Experiment 2 replicated that in Experiment 1, excluding the possibility that behavioral facilitation observed in Experiment 1 was due to the classical foreperiod effect. Rather than, the effects we observed here should reflect the cognitive control of orienting attention to time intervals.

Study II

Experiment 3

In this experiment, the auditory spatial selective attentions were tested using the same paradigm used to study temporal selective attention (in experiment 1). The aim of experiment 3 was to directly compare the neural correlates of focusing auditory attention to spatial locations and to time intervals, despite the effect of different stimuli and procedure. ERP recording during task performance permitted real-time measurement of the neural effects of spatial and temporal attention on identical stimuli and process. The task was still the discrimination task, and a spatial cue was used to indicate where (left ear or right ear) the target tone would be presented.

Participants

12 healthy right-handed healthy college students were recruited. All have normal or corrected-to-normal vision and normal hearing. Written informed consent was obtained.

Stimuli

The targets were 100-ms pure tones, either 400 Hz or 800 HZ. The frequency of the distractor was 250 Hz, also with duration of 100 ms. The intensity of target was 87dB and the distracters' intensity was 67dB.

The spatial cue were the Chinese word 'left' and 'right' with 87db intensity, which was presented with a male speech binaurally to indicate where the targets would be presented.

Task and procedure

Similar to Experiment 1, subjects were asked to do a discrimination task, and a cue was presented at the beginning of each trial to indicate where the target would appear. The cue were the Chinese word 'left' and 'right' with 87db intensity, which was presented with a male speech binaurally to indicate where the targets would be presented, with 75% probability. There were two tones be sequentially presented after cue, one interval was 600ms and the other one was 1200ms. Different from the previous experiments in this thesis, the target was randomly assigned to the two time interval with 50% possibility for each. Only the location was manipulated by the cue with 75%, that is, in 75% cases, the cue was valid and can indicate the location of target. Participants need to discriminate the target and distracters by pressing 'J' or 'F' key in keyboard. Accuracy and speed were both required.

There were 400 trials, including 300 valid trials and 100 invalid trials separately. Each trial was about 3 seconds, and the total experiment was about 30 minutes long.

Data analysis

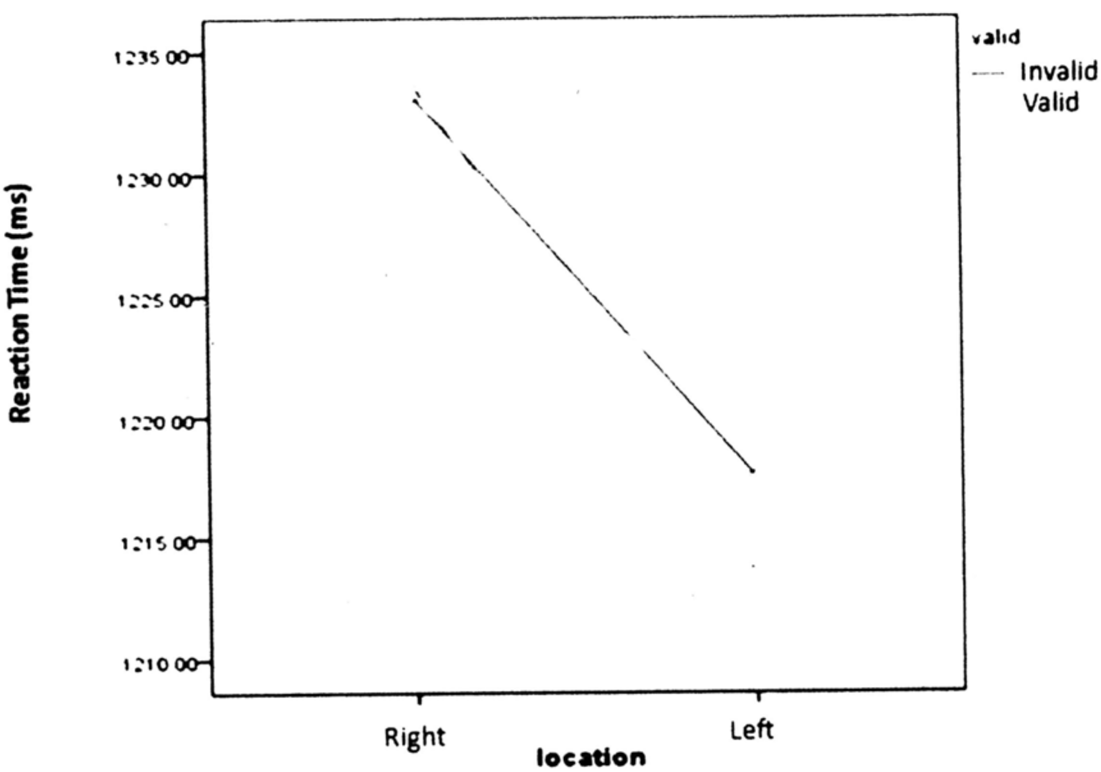
Behavioral data The accuracy of all the trials was higher than 95% and the trial with error reaction were excluded from analysis. Reaction times to targets were analyzed by repeated-measures analyses of variance (ANOVAs) with factors of cue–target relationship (short versus long, left versus right), and validity (valid versus invalid).

ERP analysis The main purpose of this experiment was to compare the modulation of spatial versus temporal attention. We did the similar ERP analysis as done in experiment 1. Identifiable ERP components were analyzed for both cue and target stimuli, and they were analyzed for the standard stimuli at electrode locations where they showed maximal intensity in the distribution. N1, P1and P2 were analyzed both for the target stimuli and cues at four central electrode pairs: CPZ, CZ, CP1 and CP2. N1 component were calculated at the time point of the largest negative peak between 60 and 150 ms. The peak of the P2 components were calculated at the time point of the most positive peak between 180 and 210 ms. The P300 potential was also analyzed only for the target stimuli at electrode sites which showed the maximal intensity on the mid line FZ, CZ and PZ. The P300 peak were calculated at the largest positive-going peak occurring between 250 and 350 ms. The CNV potential was analyzed only for the cue at the four central electode sites which showed the maximal intensity CPZ, CZ, CP1 and CP2. The CNV peaks were calculated at the largest positive-going peak occurring between 300 and 500 ms.

Results

Behavioral results

Reaction times to targets in the behavioral experiment were analyzed (N= 11). The results were somewhat unexpected. The effect of location was significant [F (1, 10) = 8.19, P = .017]; the reaction time to the auditory stimuli were faster when it was presented in left earphone, no matter the cue was valid or invalid. Neither validity nor its interaction with location was significant.



As the figure showed, the reaction time of all the four conditions were longer than 1000ms, which indicate that the spatial orienting task was more difficult than the temporal ones (reaction times were shorter than 800ms). Also, this hypothesis could be used to explain the missing of cue effect here. All the previous auditory studies which found the attention could be modulate (Hillyard et al., 1996) deployed the block design, in which, the attention were oriented to one location (for example left) in one whole block and to the other location (for example right) in another block. We viewed the mixed design used here were much more difficult than the block design since it need to shift attention very fast, so we got a long reaction time in Experiment 3.

Also, due to the difficulty of following the cue's direction, the cue effect here was weak than the other effect, for example the priority reaction to the dominant ear. The exactly evidence of what we hypothesized needs further research.

Comparison of spatial and temporal orienting

The spatial orienting and temporal orienting showed different behavioral results. In temporal conditions, the results showed a significant cue effect in short interval condition, indicating that attention can be oriented based on the temporal cues. However, in spatial condition, there was no direct evidence of any cue effect.

ERP results

Cues

Data from 11 subjects were used to analysis ERPs elicited by cues. ERPs elicited by the two types of cues (be presented from left versus right earphone) were constructed. ERPs to cues did not take into account trial validity, since this is not determined until the appearance of the target.

The ERPs were characterized by a CNV at around 300-500 ms, which were maximal over central sites, as the figure 9 showed. A t-test was used to test the difference between two types of cues (short versus long). The results showed a non-significant difference [t(10) = 1.77, p=0.10], that is, the CNV was not modulated by the location of the cue. Since the CNV component has been linked to expectancies, the results here showed that there is no difference of the extend of expectancies between two locations, that's logical.

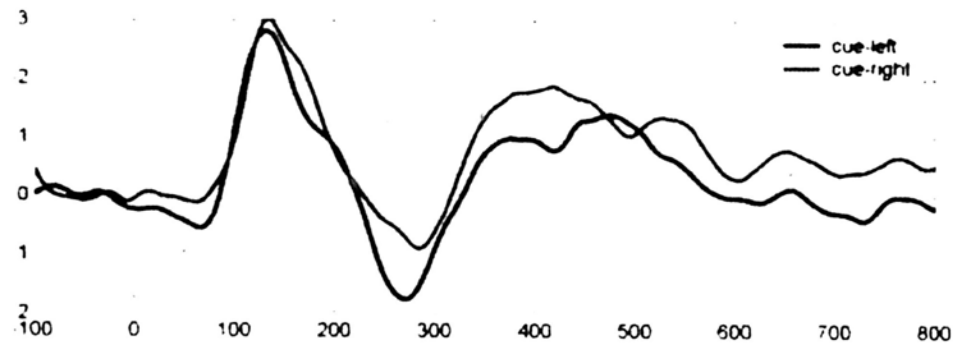


Fig. 11

Targets

Representative waveforms are shown in Fig. 12. Two-way ANOVAs with factors of validity and location were done on the N1, P2 and P300 components. The ANOVA results only showed a significant interaction on N1 [F (1, 11) = 22.517, p = 0.00], and a main effect of validity on P2 [F (1, 11) = 8.41, p = 0.01]. Then, results of paired t-test showed that there were significant differences on auditory-evoked components, N1 both in left [t (11) = 2.41, p = 0.03] and right conditions [t (11) = -3.67, p = 0.00]. However, P2 elicited by the valid cue were different from those elicited by invalid cues only in left condition [t (11) = 2.43, p = 0.03], but there was no difference in left interval condition [t (11) =1.27, p=0.23]. These results suggested that selectively attending in time modulates processing stages related to perceptual processes.

The amplitudes of P300 were not affected by spatial attention both in left and right conditions [t (11) = 1.15, p = 0.15; t (11) = 0.01, p = 0.99 respectively], which was generally consistent with other results in auditory attention study.

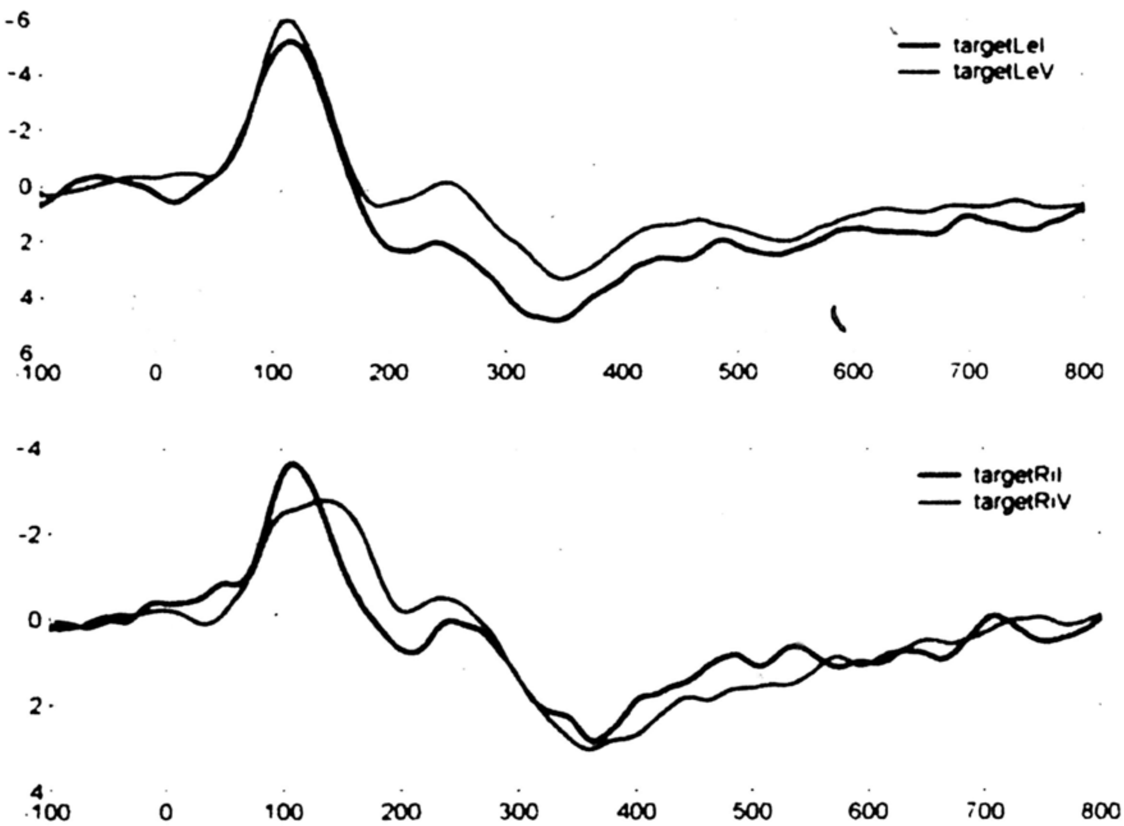


Fig. 12

Comparison of spatial and temporal orienting

Both spatial and temporal orienting exerted effects during the N1 interval, however, late effects were quite different in the two cases. Temporal orienting involved an enhancement of P300 and CNV components, but spatial one did not show these modulation differences, when comparing the invalid and valid conditions.

Experiment 4

Using behavioral experiment design, Experiment 4 combined temporal and spatial selective attentions together. Two key questions the present experiment tried to answer were that whether spatial and temporal orienting effects can be accumulated or not, and whether the temporal dimension in auditory attention is more dominant and important than the spatial one.

Task and procedure

Similar to the previous experiments, subjects were asked to do a discrimination task, at the start of each trial, there was a cue to indicate where and when the target would be presented. In the present experiment, there were three types of cues: cues predicting both spatial location and onset time (ST), predicting target location only (S) and predicting target onset time only (T). In the S condition, the cue were the Chinese word 'left' and 'right' with 87db intensity, which was presented with a male speech binaurally to indicate where the targets would be presented, without any temporal characteristic of target. In the T condition, the cue were the Chinese word 'short' and 'long' with 87db intensity, which was presented with a male speech binaurally to indicate when the targets would be presented. In the ST condition, the cue were four kinds of the combination of two Chinese word, such as 'shortleft', 'shortright', 'longleft' and 'longright', to indicate where and when the target will be presented. The cues were be valid (i.e., correctly predicting where or when the target actually appeared) for 75% of the trials and invalid for the rest 25%.

There were totally 600 trials in ST cue condition, including 450 ST valid trails (both cues were valid) and 150 invalid trails (50 S-valid trails, 50 T-valid trials and 50 both invalid trails). And there also 200 trials S cue condition and T cue condition, both included 150 valid trails and 50 invalid trails. Each trial was 3 seconds long; totally Experiment 4 was 50 minutes long.

Participants

12 healthy right-handed healthy college students were recruited. All have normal or corrected-to-normal vision and normal hearing. Written informed consent was obtained.

Data analysis and Results

The reaction times in the four different cue types were compared using a repeated measure ANOVA (N=12). The results revealed significant effects for cue type [F (3, 33) = 3.54, P = .03]. The longest RT found in both invalid condition (817ms), followed by the temporal valid and spatial valid condition (774 ms and 802ms respectively), and the shortest RT was obtained in the both valid cue condition (735ms). Figure 13 showed the data type of all the four conditions.

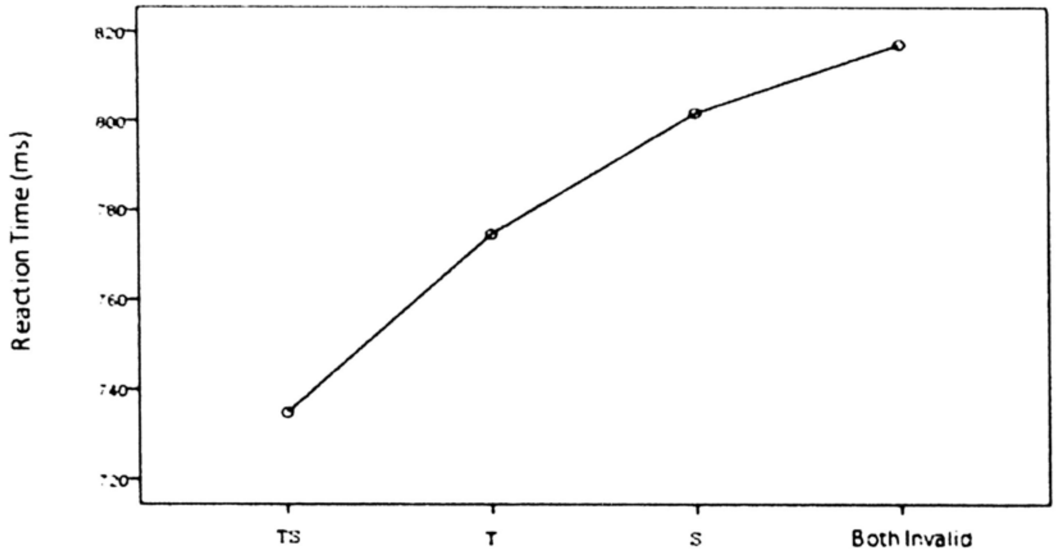


Fig. 13

Then, using within-subject contrast, the attribution of each cue types was compared. The results showed that the reaction time in the both valid condition was significantly faster than the spatial valid condition [F (1, 11) = 5.55, P = .04] and both invalid condition [F (3, 33) = 5.76, P = .04], suggesting that temporal information was important and can improve the reaction time significantly. However, there was no significant difference between both valid condition and temporal valid condition [F (1, 11) = 1.20, P = .30], which means that adding spatial information did not improve the reaction efficiency.

Summary for study Ⅱ

Although the behavioral data of auditory spatial attention in the present study did not show any cue effect, the ERP results supported that auditory attention could be oriented based on space. This issue would be returned in Discussion part. For the ERP results, spatial attention modulate the N1 and P2 components, however, there was no

CNV and P300 difference found in spatial condition. This result pattern suggested there were overlapping of the neural correlates between temporal and spatial attention, for example the early processing stage, but the spatial one did not modulate late expectation processing.

In Experiment 4, the temporal and spatial attention were put in one paradigm to test whether they are additive or not and whether the temporal dimension in auditory attention is more dominant and important than the spatial one. The results that the reaction time in the ST condition (both spatial and temporal cue were valid) was shortest suggested that the effect of attentional orienting based on space and time could be accumulated.

When comparing the reaction of ST condition (both cue was valid) and the other cue conditions, the difference between ST and S condition (spatial cue valid; temporal cue invalid), ST and N condition (both cue were invalid) were found, which means that temporal information is more important for the guidance of attention in auditory modality. However, the reaction time in ST condition and T condition (spatial cue invalid; temporal cue valid) were not different, suggesting that spatial information was not a very effective cue. These results confirmed our hypothesis that the temporal orienting is more dominant in auditory modality.

Study III

Experiment 5

The present study was to investigate the temporal interference effects in an auditory analog of Eriksen's visual flanker task. In Experiment 5, the basic temporal flanker effect in auditory modality was explored.

Participants

9 healthy right-handed healthy college students were recruited. All have normal or corrected-to-normal vision and normal hearing. Written informed consent was obtained.

Stimuli

The stimulus were the English word 'bat' and 'bed', which was presented with a male speech binaurally with 87db intensity. Each word lasted 450ms. ISI between stimuli was 200ms.

Task and procedure

Each trail contained three words presented sequentially, the second one was the target and the first and the third word were distractors. Participants were asked to do a speeded auditory discrimination response to the target words. They had to press 'F' key for 'bat' and 'J' key for 'bed'. There were two conditions: congruent and incongruent conditions. In the congruent condition, both the word before and after the target were the same as the target; and in the incongruent condition, both the stimuli before and after the target were the different one from the target.

Data collection and analysis

Reaction time and accuracy were recorded and compared using t-tests to see if there was any difference between the two conditions, which was the compatibility effect indicating the attentional selection in the auditory modality.

Results

The results showed a significant difference in the reaction time between two conditions (t (8) = 2.21, p = 0.5). Participants responded more slowly on trials where the flankers were incongruent (the mean of reaction time was 332.11ms) with the target than when they were congruent (the mean of reaction time was 272.41ms).

Experiment 6

This experiment investigated the efficiency of the temporal flanker effect by varying the ISI between the target and the flanker to see how the temporal gap affects the magnitude of the flanker interference effect.

Participants

9 healthy right-handed healthy college students were recruited. All have normal or corrected-to-normal vision and normal hearing. Written informed consent was obtained.

Stimuli and procedure

The stimuli and the task were the same as Experiment 5 with the only difference being that there were three ISIs of 100ms, 200ms and 300ms.

Data analysis

Reaction times for trials with correct responses to the target stimulus were analyzed in a two-factor ANOVA for repeated measurements on the factors of congruency and ISI.

Results

A main effect of congruence was found ($F(1, 8) = 8.67$, $p=.02$), which showed a temporal flanker effect that when the distractors were different from the target, the reaction times were slower. The ISI did not showed a significant effect ($F(2, 16) = 2.02$, $p=.17$), however, from Fig. 14, one could see a trend that when the ISI was increased, the flanker effects were decreased, which was similar to the distance effect in the classical flanker task. The interaction between congruence and ISI was not significant.

However, there could be another account to explain the results of Experiment 5 and 6, which is the repetition priming. In the congruent condition of the present study, the three words presented to participants were the same, so, the better reaction, comparing to the incongruent condition could be explained as the priming effect between the first tone and the target. So, in the next experiment, we test the auditory flanker effect with a different paradigm, to avoid the effect of the repetition priming.

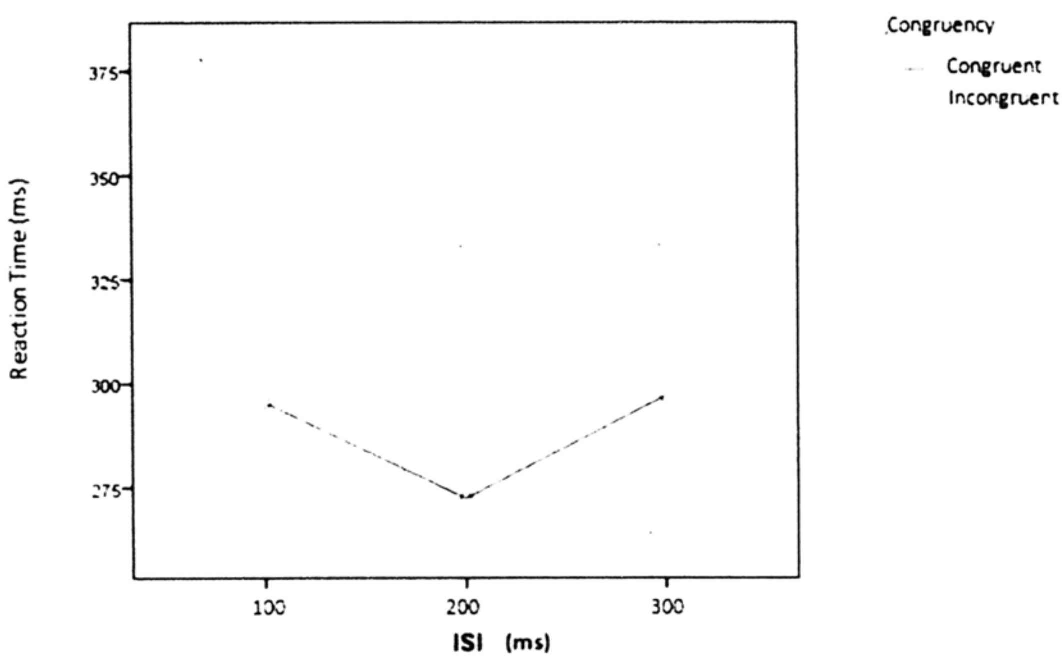


Fig. 14

Experiment 7

To avoid the effect of repetition priming, we did the experiment 7, in which, we test the auditory flanker in a different paradigm.

Stimuli

The stimulus set consists of the numerals 1-9, which will be presented with female speech binaurally with 87db intensity. ISI between stimuli was 350ms.

Task and procedure

Each trail contained three numerals presented sequentially, and the task of participants was to judge the parity (odd, even) of the middle numeral. They had to press 'F' key for even and 'J' key for odd. So, there were two conditions: in the congruent condition, both the stimuli before and after the target had the same parity as that of the target; and in the incongruent condition, both the stimuli before and after the target were of the opposite parity as that of the target.

Participants

9 healthy right-handed healthy college students were recruited. All have normal or corrected-to-normal vision and normal hearing. Written informed consent was obtained.

Data analysis and results

Reaction time in two conditions were compared using t-tests to see if there was any compatibility effect.

Accuracy of all participants was higher than 95% and all the error trials were excluded from the further analysis. The paired t-test showed a non-significant result [t

(8) = 1.44, p>.05]. The mean of reaction time in incongruent condition was 313.33ms and it in congruent condition was 303.55ms.

Even though we got a non-significant result here, we cannot draw the conclusion that there is no flanker effect in the auditory temporal attention. There was a possible reason which can explain the missing of the significant result here, that is the withholding of response. Based on the stimuli sequential, the middle one of the three numbers was the target, and by the end of the second stimuli's presentation, the participants \already could make decision about the parity of the target. However, based on the instruction to the participants, they should press the key after the presentation of the third number, so, in some trials, especially in the congruent trials, participants should withhold his/her reaction. These kinds of conflict between the instruction and experimental setting decreased the sensitive of this experiment. So, we cannot draw any conclusion just based on Experiment 7.

Summary for study Ⅲ

The aim of this study was to investigate the characteristics of attention control in temporal attention, by using the flanker task which is a good tool for examining the efficiency of attentional selection. The participants were asked to do a temporal flanker task in auditory modality. And the result showed an interference effect (Experiment 5), and temporal segregation (Experiment 6) was the factors that affect the interference effect.

Since the Experiment 5 and Experiment 6 could be explained by the other account:

repetition priming, we tried to provide the clear empirical demonstration of temporal analog of Eriksen's auditory flanker interference effect in Experiment 7. Similar to the visual flanker task, the participants were asked to do a reaction to the target which was surrounded by the distractors. Differential to the spatial surrounded in the classic flanker task, in this study, the stimuli were presented sequentially, and distractors were near closely to the target in the temporal dimension. However, the result did not show any interference effect, that is, there was no significant difference between reaction time of congruence condition and it in incongruence one. We hypothesized that the missing of a significant difference was caused by the ineffective experimental setting, which need some extend of respond withholding.

DISCUSSION

In the present thesis, we investigated how the auditory selective attention orients and selects information, using both behavioral and ERP recordings, and compared the orienting of attention to spatial locations and to temporal intervals in auditory modality. Besides that, we examined temporal attentional selection for first time.

Auditory temporal attention

The behavioral results of Study I showed that we are indeed capable of using information about time intervals to improve our behavioral performance in auditory modality. An attentional effect was found with a faster reaction time for discrimination of valid versus invalid targets. Reaction time effect was restricted to targets that occurred at the short interval. These behavioral data were very similar to the results from the visual temporal attention.

However, the behavioral results in the long interval condition showed a faster reaction time in the invalid trials. We hypothesized that there were two accounts. Firstly, because that when the cue was invalid in long interval condition, the target sound was presented at the short interval, the subjects would not expect any target at long interval at this case. So, the setting of invalid cue in long interval condition was non-effective. This point was similar to the account, which the previous studies used to explain the missing of cue effect in the long interval conditions. Secondly, it's a special characteristic of the auditory temporal attention. When the participants received a short cue, the expected a target presented after a short interval, however, when the short cue was invalid, they did not received any target tone at the short time point, after that, the participants can inferred that the target must be presented at the long interval. This kind of 'shortly emphases' might be another kind of 'cue' to show the target will be presented shortly. So, there was a faster reaction when the cue was short but invalid in the long interval. The participants were more sensitive to this kind of 'shortly emphases' might be the explanation to why the result type that in the long interval condition, the reaction time in the invalid trials were faster than which in the valid ones, only showed in auditory modality, but haven't got from the temporal attention study in visual modality.

ERP recordings during task performance permitted on-line measures of shifts of attention, as well as the assessment of temporal expectancy on auditory processing of the targets. The differences between cue types involved perceptual and later processing stages.

N1 is a kind of early sensory-evoked component and always used as a support to early selection theories of attention. In the present study, we found that the auditory temporal attention could modulate N1, reflecting an attentional mechanism of early sensory gain of temporal orienting. Also, N1 was one kind of index of discrimination processes (Vogel EK & Luck SJ, 2000). So, it is not curious to find N1 components here.

Later effects of auditory temporal orienting were related to response inhibition and preparation for the next stimuli. Auditory temporal attention modulated the P2 component. P2 enhancement has been interpreted as reflecting response inhibition. In the Go/Nogo task, enhanced P2 potentials have been found to nogo stimuli (Jode E. & Kayama Y., 1992). In our results, a more positive P2 was found in the invalid cueing condition, which would appear to fit well with these accounts.

Later effect on stimulus processing may also be a reflection of attentional orienting. Auditory temporal attention modulates P300 amplitude only in the short interval condition, increasing it when subjects attended the short interval. The P300 component reflects functional decision processed and preparation for responses (Mangun Gr., 1995), and auditory temporal attention may involved these processes. Due to the specific process setting, the participant could infer the presentation of target based on the situation after a short interval, so the magnitude of P300 in long interval condition showed a similar peak value to it in short interval when the cue was valid. This data style could be explained by our hypothesis that in the long interval condition, participants So, they have some kind of expectation both in short and long interval condition.

The contingent negative variation (CNV) components were found when comparing the short and the long cue. And the results showed an accentuated CNV when subjects expected targets at the long interval. The CNV were always described as an 'expectancy' wave. So, it can be interpreted as the auditory temporal attention modulates the motor preparation and expectation for the upcoming stimulus, and, the present results supported our 'shortly empathese' hypothesis, which we used to explain the behavioral results in the long interval condition.

In summary, the results in the present thesis demonstrated behavioral effects of auditory temporal orienting. ERP analysis revealed that these behavioral effects were a consequence of distinct modulatory effects, including the early perceptual processing and later decision making, expectation ones. In short interval condition, both the behavioral and ERP results showed a similar data type to the results showed in previous visual temporal attention studies. However, in the long interval condition, the data showed a accentuated results in the invalid trials, which is the different results from the previous visual temporal attention studies. We explained these result as the 'shortly emphases', which also could be a result to show the auditory attention was more sensitive to the temporal information.

Auditory temporal attention vs. Visual temporal attention

The results of the present thesis, both behavioral and ERP data, showed the auditory temporal attention and visual one were of the same nature. The data showed shorter reaction time in valid cueing condition, and this kind of cue effect was restricted in short interval condition, obtained from both visual temporal attention and auditory ones. Also, their neural correlates were very similar, which showed that temporal orienting could modulate the early perceptual and late decision making process.

There was some debate about whether the visual temporal attention modulates the early perceptual process, some study showed that temporal attention did not involve changes in amplitude or latency of the visual P1 and N1 (Minissi et al., 1999), but in other studies modulation of the N1 component by temporal attention was observed, with enhanced negativity when subjects attended stimuli occurring at the short interval (Griffin et al., 2002). The conflict of these results could be explained by the difference between the experiment tasks they used. The studies, which did not found the early perceptual modulations, deployed the foveal stimuli. Because the foceal stimuli were already optimized in the visual system, so it might not be necessary or advantageous to enhance resources further for them. And even if perceptual selection processes matters for foveal stimuli, the facilitative effects may not be as strong as it can be for peripheral stimuli. That is, such foveal selection paradigm may undermine the real effect of temporal orienting attention, especially in perceptual stages. In the present thesis, we used a discrimination task and unlike the visual system, the auditory system lacks a central fovea (Buchtel HA & Butter CM, 1988), so the perceptual stage modulations could be more easily exposed. In conclusion, the concept of temporal attention can be broadened to auditory modality, and the nature of orienting attention to time is similar between visual and auditory ones.

Here we want to discuss another question that, comparing to the visual attention, whether the auditory attention was more sensitive to the temporal information. Based on our results, the answer might be yes. The support evidence was the accentuated result, both behavioral and ERP results, in the long interval condition. Due to the 'shortly emphases', the reaction time in invalid trials was faster than in the valid trials; and the P300 components in the long interval (both valid and invalid trials) had similar peak value as it in the valid trials in short interval. All of these could be explained as the auditory attention was more sensitive to the temporal information.

Auditory Temporal attention vs. Auditory Spatial attention

One main aim of this thesis was to investigate and compare the neural correlates of focusing auditory attention to spatial locations and to time intervals. The ERP results of the present thesis showed the auditory temporal attention and visual one shared some neutral nature. Both spatial and temporal orienting exerted effects during the N1 interval, however, late effects were quite different in the two cases. Temporal orienting involved an enhancement of P300 components (Miniussi, 1999; Griffin, 2001), but spatial one did not show these modulation differences, when comparing the invalid and valid conditions.

In present thesis, behavioral results in the spatial orienting condition did not showed any cue effect, however, a 'side-effect' was obtained. Subjects had a more rapidly reaction to the stimuli from left earphone, no matter the cue was valid or invalid. These kinds of different result pattern from the previous studies could be explained by the different natures of the experimental tasks. As attention was focused on one side of the stimulus display for the entire block in the previous experiments, the expectation about where the target will be presented would much more stronger than in the mixed design. In the present study subjects continuously refocused their attention to either the left or right ear Comparing to the situation that the stimuli were expected from one direction during the whole block, only a cue with 75% validity might not enough for them to expect and prepare the reaction. So, comparing to the cue effect, a dominant ear showed a stronger effect, and in our experiments, is the left ear. These hypotheses were partly supported by the ERP results. Many reports in studies of spatial attention (Hillyard et al., 1996) reported P300 amplitude was larger for valid targets. However, the P300 component, which is widely accepted as the 'decision-related' potential and always can get from the attention studies, was missing under the auditory spatial attention condition. It also might be due to our experiment settings can not fully orient subjects' spatial attention. From the other aspect, we speculated that spatial attention modulates earlier perceptual processing.

For the early perceptual processing stage, auditory attention oriented in space and time showed a similar results. It has been postulated that N1 modulation reflects stimulus triggered orienting and engagement of attention to relevant stimulus locations (Luck SJ, et al; 1990). Also, in many spatial cueing tasks, when the stimuli occurred at cued locations, the N1 will be generally evoked in association with speeded reaction time (Anllo-Vento 1995; Eimer, 1997). In the present study, the auditory evoked N1 showed more negative magnitude when the cue was valid, suggesting that an allocation of attention in time can affect later stimulus processing in a manner similar to what has shown for spatial attention.

After comparing the auditory temporal attention and spatial one, we want to discuss them together. We put the temporal and spatial attention in one paradigm, the other aim was to test whether they the effect of temporal and spatial ones are accumulated or not and whether the temporal dimension in auditory attention is more dominant and important than the spatial one. The results that the reaction time in the ST condition (both spatial and temporal cue were valid) was shortest suggested that the effect of attentional orienting based on space and time were additive.

When comparing the reaction of ST condition (both cue was valid) and the other cue conditions, the difference between ST and S condition (spatial cue valid; temporal cue invalid), ST and N condition (both cue were invalid) were found, which means that temporal information is more important for the guidance of attention in auditory modality. However, the reaction time in ST condition and T condition (spatial cue invalid; temporal cue valid) has no any difference, suggesting that spatial information is not so effective cue information. This type of data confirmed our hypothesis that the temporal orienting is more dominant in auditory modality.

This view was different from the Lange's result (Lange K. et al, 2003). Lange suggested that 'perception is organized along the dimensions space and time: whereas each stimulus is characterized by the location and time of its occurrence, other features such as color or pitch are facultative and often only available to particular modalities'. However, the supporting evidence of them was that both temporal attention and spatial one could modulate perceptual neural correlations. In present paper, we supply a direct behavioral result that the temporal information is more dominant for the guidance of attention in auditory modality. This question still needs more research and understanding.

Temporal flanker effect

Many studies have used Eriksen flanker task (Eriksen & Eriksen, 1974) to investigate the limits of visual selective attention. However, the research on temporal attention, whether in vision or audition, has studied only attentional orienting. Our goal here was to extend current studies to the second major aspect of attention to examine how auditory attention selects target items and suppress or inhibit distractor items purely based on temporal information. So, in the present study, we deployed Eriksen flanker task to understanding the selectivity of auditory temporal attention.

We modified the classical paradigm to create a temporal flanker task to present three items sequentially in time and ask participants to respond only to the middle target item and ignore the other two items. We measured whether performance were affected by the distractor temporally 'surrounded' the target. However, we cannot draw any conclusion from the present three experiments (Exp 5, Exp 6 and Exp 7). Though we got expected results from the experiment 5 and experiment 6, that is, the reaction time was faster in the congruence condition than the incongruence condition, the other account 'repetition priming' could be the account too, and we can not peal off the effect of it just based on the results form these two experiments. Experiment 7 was designed to test the pure flanker effect, but we did not get significant results. There could be two possibilities, one is the respond holing decrease the effect and the other is temporal attention can discard the distractors better the spatial one. It's still need more further studies to research the characteristics of the temporal flanker effect.

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