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SELECTIVE ATTENTION AND THE AUDITORY VERTEX POTENTIAL

I: EFFECTS OF STIMULUS DELIVERY RATE

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INTRODUCTION

In a noisy environment human listeners can readily focus their attention upon a single "channel" of auditory input and reject the information arising concurrently from competing sound sources. Perhaps the most striking demonstration of auditory selective attention is the dichotic listening paradigm (Cherry 1953; Moray 1959), wherein the contents of a spoken message presented to one ear are almost completely excluded from awareness while the listener's attention is directed towards a second spoken message in the other ear. Using the technique of computer averaging the scalp-recorded evoked potentials, it has become possible to investigate the neurophysiological mechanisms of selective attention in normal human subjects in dichotic listening situations and a host of other attentive tasks. Näätänen (1975) has recently made an extensive review of this area.

The scalp-recorded auditory evoked potential (EP) in man is recognized to consist of some 15 distinct waves (Picton et al. 1974), which reflect the transmission of auditory information through the nervous system from brainstem to cortex. Among the most prominent and consistent of these components are a negative wave (N₁) peaking at 80 to 130 msec after stimulus onset, and a positive wave (P₂) peaking at a latency of 160 to 200 msec (Davis et al. 1966). The N₁ and P₂ waves are also the earliest components to be altered reliably by changes in a
subject's attentive state (Picton and Hillyard 1974).

Recent studies by Hillyard et al. (1973) and Schwent and Hillyard (1975) have reported highly significant enhancements of the auditory N1 component with selective attention to one of two or more competing channels of tone pip stimuli presented in a random sequence to preclude "differential preparation" artifacts (Naätänen 1967; Karlin 1970). In these experiments it was shown that each channel of tones elicited substantially larger N1s while being attended than when attention was directed to another channel. Two major design features were introduced in these studies which distinguish them from prior investigations that reported little or no attention-related lability for the N1 wave (Naätänen 1967, expt. II; Hartley 1970; Smith et al. 1970; Karlin et al. 1970; Wilkinson and Lee 1972): the inter-stimulus intervals (ISIs) were shorter and/or the number of stimulus channels was larger than those used in the earlier studies. Both of these factors serve to increase the number of sensory events delivered per unit time (i.e. the "information load" on the subject). As suggested earlier by Hartley (1970) and Hillyard et al. (1973), a high density of auditory input may well be required if perception is to be selectively confined to one source; at lower rates of stimulation, subjects may find it difficult to avoid attending to all of the sensory channels. This supposition is consistent with behavioral studies showing that attention is not necessarily restricted to one channel when stimuli from multiple sources are
delivered at relatively low rates (Lawson 1966; Shiffrin and Grantham 1974). In contrast, a high degree of selectively occurs with heavier processing loads such as trains of dichotic verbal stimuli (e.g. Treisman and Geffen 1967; Treisman and Riley 1969; Underwood and Moray 1972; Ninio and Kuhlen 1974).

The present study examined the effects of varying the rate of delivery of dichotic tone pip stimuli upon selective attention as measured both electrophysiologically (using auditory EP amplitudes) and behaviorally (using signal detectability scores). Inter-stimulus intervals were varied over a range that encompassed those of short duration, as used by Hillyard et al. (1973), intermediate duration like those of Wilkinson and Lee (1972) and Wilkinson and Ashby (1974), and longer ones such as used by Hartley (1970) and Karlin et al. (1970). Finally, this study examined the behavior of the late positive (P3) component that is elicited when a specific "target" signal is detected within an attended channel (Hillyard et al. 1973). The P3 was also found to be enhanced with attention but in a fashion that was dissociable from the N1, substantiating the proposition of Hillyard et al. that these two components are indices of different modes of selective attention.
METHODS

Subjects

Subjects were twelve young adults, seven males and five females. Four were laboratory personnel while the remaining eight were paid student volunteers, only three of whom had had prior experience in similar studies.

Stimulus Presentation

Subjects sat comfortably in a reclining chair inside a sound-attenuated chamber. Through stereo headphones they received two concurrent dichotic sequences of 50 msec tone pips (5 msec rise and fall times). One sequence, presented to the left ear, consisted largely of 1500 Hz tones ("standards") with occasional 1575 Hz tone pips serving as "targets" or "signals". In the right ear, a second sequence was presented consisting of 800 Hz tone pips as standards with occasional 860 Hz tones as "targets". All stimuli were presented at 60 dB SL (above threshold). The sequential order of presentation of tones to right and left ears was randomized (p=0.5 for each ear), as were the time intervals between successive tones and the occurrence of target tones within each channel.

The stimuli were presented to the subjects at three different rates in separate experimental runs. In the "short" inter-stimulus interval conditions, ISIs between tones averaged
350 msec (range 200-500 msec), in the "medium" ISI condition intervals between tones averaged 960 msec (range 400-1520 msec), and in the "long" ISI condition the mean interval was 1920 msec (range 800-3040 msec). The occurrence of a target (signal) within a channel of tones was randomized and unpredictable; during the short ISI condition approximately 10% of the tones in a channel were targets, while this proportion was increased to 20% for both the medium and long ISI conditions so that an adequate number of target EPs could be acquired in a reasonable length of time.

Procedure

Six-minute segments of tape-recorded stimulus sequences were played to each subject, twice at each of the three ISIs. The order of presentation of the ISI conditions was short/medium/long/long/medium/short. Subjects were instructed to attend to only one channel of stimuli during a run and to ignore all stimuli in the other ear. The channel (ear) attended during a run was alternated over the six runs of the experiment; half of the subjects attended to the right ear on the first run and the other half to the left ear. A two-minute rest period intervened between runs.

Subjects were required to respond to the detection of a target (signal) tone in the attended channel by pushing a button within 1.5 seconds. Hits, misses, false alarms and correct rejections were scored for responses to the attended tones. For
each experimental run, evoked potentials were averaged separately to the standard (non-signal) and target (signal) tones in each channel.

**Recording System**

Evoked potentials were recorded from central and parietal scalp locations (Cz and Pz in the international 10-20 system), referenced to the right mastoid, using Grass silver cup electrodes. The vertical electro-ocularogram (EOG) was also recorded and averaged to ensure the absence of electro-ocular artifacts. Brain potentials were amplified by Grass 7P5 preamplifiers (bandpass down 3 dB at 0.3 and 500 Hz) and recorded on FM magnetic tape for later analysis. Evoked potentials were averaged using a Nicolet 1072 signal averager in the four channel mode at analyses times of 200 msec and 800 msec (giving a resolution of 1.28 and 0.32 points/msec, respectively). The averaged EPs to the "standard" stimuli in the short, medium and long ISI conditions contained sums of 450, 160 and 80 responses, respectively. For "signals" the EPs during these three conditions were summed over the initial 40, 40 and 20 responses, respectively.

**Data Analysis**

The $N_1$ component was quantified as the most negative peak between 80-130 msec post-stimulus onset with respect to a baseline chosen as the mean voltage over the first 20 msec of
the averaging epoch (equipment limitations prevented the use of a pre-stimulus baseline). In addition, a peak-to-peak measure was taken with reference to the preceding P₁ component (P₁ being chosen as the most positive peak between 30 and 60 msec after stimulus onset). The P₃ component was quantified as the most positive peak between 300-500 msec, and its amplitude was also measured relative to an initial 20 msec baseline.

The effects of selective listening were evaluated by two measures which compared the amplitudes of N₁ and P₃ components elicited by attended stimuli with the amplitudes produced by the same stimuli when ignored. The first measure, designated the "attention coefficient", was calculated as follows:

\[
\text{Attention Coefficient} = \frac{\text{Attend amplitude} - \text{Inattend amplitude}}{\sqrt{\text{Attend amplitude}^2 + \text{Inattend amplitude}^2}}
\]

Attention coefficients were calculated separately for each subject, ISI condition, and channel (ear) of stimuli. The expected value of this coefficient is zero if no selective attention effects are present; deviations from zero were assessed using Wilcoxon signed rank tests, treating each coefficient as a weighted "difference score".

The second measure of the selective attention effect was the "percent enhancement" score, also calculated separately for each subject, ear and condition, defined as:

\[
\text{Percent Enhancement} = \frac{\text{Attend amplitude} - \text{Inattend amplitude}}{\text{Inattend amplitude}} \times 100\%
\]
RESULTS

Evoked Potentials to Standard (Non-Target) Stimuli

As shown in Figure 1 for a representative subject, the most prominent component in the averaged waveforms was the $N_1$ wave, peaking about 90 msec after tone onset (range over all subjects was 80-130 msec). The solid lines in Figure 1 depict the evoked vertex potentials under the conditions where the left ear tones were being attended, while the EPs shown by dotted lines were taken when attention was directed to the right ear. When the tone bursts were delivered at the fastest rate ("short ISI's") there was a clear difference in the $N_1$ amplitudes between attend and ignore conditions for each ear. With increasing ISI, however, one observes a marked reduction in this "attention effect" upon $N_1$ amplitude. Note too the expected increase in overall $N_1$ amplitude (and changes in voltage calibration) with the longer ISI ($F(2,22)=82.92<.001$).

---

INSERT FIGURE 1 ABOUT HERE

---

The mean $N_1$ amplitude across all twelve subjects and under all conditions are given in the left columns of Table 1 and in Figure 2. During the short ISI condition, the increase in amplitude between attend and inattend conditions averaged 19.8 per cent for the baseline to $N_1$ measure ($p<.01$ by Wilcoxon, performed on attention coefficients over both ears), and 20.5 per cent for the $P_1-N_1$ measure ($p<.001$). At medium ISIs, the
baseline-peak measure of $N_1$ showed no significant difference while $P_1-N_1$ showed a small average effect of 5.6 per cent, ($p<.02$). For the long ISIs, no significant change in $N_1$ with attention was revealed by either measure.

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INSERT TABLE 1 AND FIGURE 2 ABOUT HERE

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When the standard stimuli were examined on an 800 msec time base (Figure 3 top), no late positive ($P_3$) component was discernible in the majority of subjects. Accordingly, the $P_3$ amplitudes plotted in Figure 2 (right column) largely represent the noise level of the baseline-peak positivity in the 300-500 msec zone. Furthermore, the direction of attention was found to have no significant effect on this $P_3$ measure for the standard stimuli, as indicated by Wilcoxon tests performed on the attention coefficients for $P_3$ (Table 1).

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INSERT FIGURE 3 ABOUT HERE

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**Evoked Potentials to Target Stimuli**

In contrast with the standard stimuli, the waveform elicited by the higher pitched targets in the attended ear contained a large positive wave ($P_3$) peaking at approximately
400 msec (Figure 3 bottom). When the eliciting stimuli were not attended this $P_3$ was much smaller or absent. The mean amplitudes of the $N_1$ and $P_3$ components evoked by targets are given in Table II for the various experimental conditions. The variability of these target-evoked components was much greater than those to the standard stimuli, mainly because fewer responses were included in the averaged waveforms. Despite this variability, significant effects of attention were evident in the target-evoked baseline-$N_1$ component at the vertex in the short ISI condition (Figure 4). As with the standard stimuli at short ISIs, the $N_1$s were significantly larger in the ear being attended ($p<.01$ by Wilcoxon test performed on the attention coefficients over both ears).

In the case of $P_3$ a much smaller amplitude was recorded at Cz than at Pz, such that the $P_3$ enhancement to attended targets at Cz reached significance only for medium ISIs ($p<.01$). At the Pz electrode locations, however, $P_3$s to targets in the attended ear were significantly larger than in the opposite ear at all inter-stimulus intervals (Figure 4). In contrast with the $N_1$ component, it is evident that $P_3$ amplitudes to targets were not markedly enlarged with increasing ISI ($F(2,22)=1.25$, N.S.); this stability of $P_3$ occurred despite moderate variations
in target probability, target density in time, and target detectability (see below).

**Discrimination Performance**

From the subjects' responses to target and standard stimuli in the attended channel, the proportions of hits, misses, false alarms and correct rejections were calculated. In the cases of zero false alarm rates, estimated false alarm probabilities were calculated according to the formula used by Moray and O'Brien (1967, Page 766). Averaged over all subjects and both ears, the mean $d'$ for detecting targets in the attended ear was 4.57 ± 1.6, for the short ISI condition, 3.54 ± 1.11 in the medium ISI condition, and 3.23 ± 1.15 in long ISI condition. These differences in $d'$ over the ISI conditions were highly significant as evaluated using a 2-way repeated measures analysis of variance ($F(2,22)=45.14, p<.001$). Both $d'$ and percent correct scores are given separately for each ear in Table III.

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**INSERT TABLE III HERE**

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DISCUSSION

The previously reported enhancement of the auditory vertex potentials with selective attention to dichotically presented tone pips (Hillyard et al. 1973) was here found to be critically sensitive to the range of inter-stimulus intervals (ISIs) in use. Only at the shortest ISIs (200-500 msec) was there a clear-cut enhancement of the N1 component (latency 80-130 msec) to stimuli in the attended ear; at intermediate ISIs (400-1520 msec) a marginally significant attention effect was noted, while at the "long" ISIs (800-3040 msec) the direction of binaural attention had no influence upon the N1 wave. The relative magnitude of this attentional enhancement of N1 (ca. 20%) with short ISI's was somewhat smaller than in the closely related study by Hillyard et al. (1973, expt. II), probably because the stimulus intensities here were 10 dB louder.

In a subsequent report (Schwent et al. 1976b), we found that the auditory vertex potentials to louder stimuli are less labile with shifts of attention than are those to softer stimuli.

The present results strongly suggest that the failure of directed attention to influence the auditory vertex potential, as reported in several laboratories, was in part a consequence of the long ISIs used. In studies by Naatanen (1967, expt. III), Donchin and Cohen (1967), Hartley (1970), and Karlin et al. (1970), the randomized ISI's averaged at least
two seconds in duration and thus corresponded to the longer intervals where attentional effects were found to be minimal. In other studies where ISI's were fixed at one second (Smith et al. 1970; Wilkinson and Ashby 1974), roughly corresponding to our "medium" ISI range, attentional effects were similarly absent. The negative results of Smith et al. (1970) vis a vis the P1-N1 measure, however, may well have been due largely to the relatively loud click intensities used (82 dB SPL). Wilkinson and Ashby (1974) did not report their stimulus intensities, nor did they take a measure of N1 independent of the subsequent P2 wave; these factors, as well as a fixed ISI duration and a lack of spatial separation of stimulus channels may have contributed to the absence of attention effects on N1-P2. Finally, Wilkinson and Lee (1972) employed ISI's that were on the average shorter (673 msec) than those of our "medium" range and did obtain a 10% enhancement of the N1-P2 measure to tones in an attended channel, in spite of using rather high tone intensities (61, 72 and 78 dB SPL) and spatially congruous channels; no independent measure of N1 was reported.

Several possible explanations seem reasonable to explain why short ISI facilitate the channel-selective enhancement of the N1 wave in these binaural listening tasks. First, placing a large total information load on the subject makes it difficult or impossible for him to process the stimuli in unattended channels when his attentional resources are committed to processing
the relevant channel (Norman and Bobrow 1975). Secondly, a high density of stimulation may enable the subject to maintain a more focused state of attention upon the relevant channel, perhaps by continually reinforcing the channel-specific cues or processing steps upon which the selection is based. This idea is supported by the behavioral discrimination data showing that target tones were detected more effectively at the shorter ISIs. A third factor which may influence the magnitude of the attention effect is the marked reduction in $N_1$ amplitude that occurs at shorter ISIs because of its long recovery period. If selective attention only modulates $N_1$ over a small amplitude range, any attentional enhancement at longer ISIs may be obscured by its superposition upon a larger and more variable "baseline" $N_1$.

The present findings demonstrate a clear dissociation between the properties of $N_1$ and those of the late positive $P_3$ wave, substantiating the view that "$N_1$ and $P_3$ are signs of fundamentally different selective attention processes" (Hillyard et al. 1973). In line with their proposal that $N_1$ lability reflects a "stimulus set" mode of attention (also termed "filtering" [Broadbent 1971] or "input selection" [Triesman 1969]), the $N_1$ was enhanced (at short ISIs) to all stimuli in the attended ear (channel), standards and targets alike, in relation to when the other channel was being attended. This would be expected if $N_1$ indexes a selection mechanism which admits or
rejects stimuli on the basis of a preliminary analysis of their simple physical attributes (i.e. their channel of origin).

On the other hand, the $P_3$ wave was small or absent after all standard stimuli, attended or not, being enlarged only to targets in the attended channel. This suggests that $P_3$ reflects an attentional process which makes a further selection among stimuli within the channel that has been chosen for analysis by the stimulus set mechanism. Such a process has been designated "response set" or "pigeonholing" (Broadbent 1971) or "target selection" (Triesman 1969) and usually entails an analysis of higher order stimulus attributes through a serial comparison of inputs against stimulus representations in memory. In the present design, for example, it is reasonable to assume that the pitch discrimination between 1500 and 1575 Hz is based largely on a relational comparison of incoming stimuli with the memory traces of recently delivered stimuli (i.e. a response set), rather than an independent identification of each stimulus by its absolute physical attributes. The well-known difference in scalp distribution between $N_1$ and $P_3$ (e.g. Picton et al. 1974; Simson et al. in press) was also verified here, with $N_1$ being larger over the central scalp and $P_3$ over the parietal region.

Two further dissociations between $N_1$ and $P_3$ were produced by the manipulation of ISI. While the attentional enhancement of $N_1$ was evident only at the shorter ISIs, the $P_3$ was substantially enlarged to attended-channel targets at all ISIs,
reflecting the generally high detectability of the targets at all ISIs (Table III). Finally, the amplitude of the P3 to attended targets did not change substantially as a function of ISI, while the attended-channel N1s were markedly reduced at shorter ISIs. This observation suggests that overall stimulus load has little or no independent influence upon the P3 amplitude, which is more related to psychological factors such as decision confidence and subjective probability of target occurrence (Squires et al. 1975) than is the N1 amplitude.
SUMMARY

In a selective attention task, twelve subjects received random sequences of 800 and 1500 Hz tone pips in their right and left ears, respectively. They were instructed to attend to one channel (ear) of tones, to ignore the other, and to press a button whenever occasional "targets" tones of a slightly higher pitch were detected in the attended ear. In separate experimental conditions the randomized inter-stimulus intervals (ISI's) were "short" (averaging 350 msec), "medium" (960 msec) and "long" (1920 msec). The N1 component of the auditory evoked potential (latency 80-130 msec) was found to be enlarged to all stimuli in an attended channel (both targets and non-targets), but only in the short ISI condition. Thus, a high "information load" appears to be a prerequisite for producing channel-selective enhancement of the N1 wave; this high load condition was also associated with the most accurate target detectability scores (d'). The pattern of attention-related effects on N1 was dissociated from the pattern displayed by the subsequent P3 wave (300-450 msec), substantiating the view that the two waves are related to different modes of selective attention.
FOOTNOTES

1. This work was supported by NIH Grant MH-25544-01 to S.A. Galliard and NASA Grant NGR-05-009-198 to R. Galambos and was conducted while V. Schwent held a NSF Fellowship. Address reprint requests to second author.

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REFERENCES


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### TABLE I

Mean amplitudes (µV) of $N_1$ and $P_3$ components to standard stimuli and mean derived attention scores under the different experimental conditions (*S.E.*).

<table>
<thead>
<tr>
<th>Evoking Stimulus</th>
<th>Attended Stimulus</th>
<th>Baseline-$N_1$ (Cz)</th>
<th>$P_1-N_1$(Cz)</th>
<th>Baseline-$P_3$ (Pz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short ISI</td>
<td>Left</td>
<td>3.37±0.54</td>
<td>4.83±0.66</td>
<td>0.27±0.65</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>2.46±0.63</td>
<td>3.62±0.67</td>
<td>0.98±0.21</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>2.62±0.43</td>
<td>4.03±0.62</td>
<td>1.52±0.33</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>3.17±0.57</td>
<td>4.50±0.68</td>
<td>1.08±0.39</td>
</tr>
<tr>
<td>Percent Enhancement</td>
<td></td>
<td>19.8±10.6%</td>
<td>20.5±4.9%</td>
<td></td>
</tr>
<tr>
<td>Attention Coefficient</td>
<td></td>
<td>(.312±.114)**</td>
<td>(.222±.060)**</td>
<td>(-1.134±.528)</td>
</tr>
<tr>
<td>Medium ISI</td>
<td>Left</td>
<td>7.53±1.00</td>
<td>9.06±1.07</td>
<td>1.25±0.84</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>7.28±1.03</td>
<td>8.51±0.96</td>
<td>0.12±0.89</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>6.98±0.54</td>
<td>8.30±0.83</td>
<td>0.82±0.54</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>7.71±0.78</td>
<td>8.73±0.79</td>
<td>0.12±0.78</td>
</tr>
<tr>
<td>Percent Enhancement</td>
<td></td>
<td>1.4±6.7%</td>
<td>5.6±2.6%</td>
<td></td>
</tr>
<tr>
<td>Attention Coefficient</td>
<td></td>
<td>(0.062±.070)</td>
<td>(0.062±.026)*</td>
<td>(0.058±.790)</td>
</tr>
<tr>
<td>Long ISI</td>
<td>Left</td>
<td>8.68±0.90</td>
<td>9.52±1.01</td>
<td>0.97±1.42</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>9.02±1.26</td>
<td>10.02±1.35</td>
<td>0.07±1.26</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>9.03±0.97</td>
<td>10.72±1.13</td>
<td>0.25±1.24</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>10.19±0.92</td>
<td>12.33±1.10</td>
<td>0.55±1.47</td>
</tr>
<tr>
<td>Percent Enhancement</td>
<td></td>
<td>4.5±5.3%</td>
<td>3.8±5.6%</td>
<td></td>
</tr>
<tr>
<td>Attention Coefficient</td>
<td></td>
<td>(.074±.052)</td>
<td>(.072±.056)</td>
<td>(.058±.538)</td>
</tr>
</tbody>
</table>

*** $p<.001$
** $p<.01$
* $p<.02$
### TABLE III

Mean d' and per cent correct scores (±S.E.) averaged over all subjects under the different experimental conditions.

<table>
<thead>
<tr>
<th>ISI</th>
<th>d'</th>
<th>Per Cent Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>Attend Left</td>
<td>4.56±.16</td>
</tr>
<tr>
<td></td>
<td>Attend Right</td>
<td>4.57±.19</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>4.57±.16</td>
</tr>
<tr>
<td>Medium</td>
<td>Attend Left</td>
<td>3.57±.14</td>
</tr>
<tr>
<td></td>
<td>Attend Right</td>
<td>3.51±.14</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>3.54±.11</td>
</tr>
<tr>
<td>Long</td>
<td>Attend Left</td>
<td>3.44±.17</td>
</tr>
<tr>
<td></td>
<td>Attend Right</td>
<td>3.01±.16</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>3.23±.15</td>
</tr>
</tbody>
</table>
TABLE I

<table>
<thead>
<tr>
<th>Attention Coefficient</th>
<th>ISI (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>Short</td>
</tr>
<tr>
<td>1.038 ± 0.369</td>
<td>1.242 ± 0.522</td>
</tr>
<tr>
<td>Left</td>
<td>Medium</td>
</tr>
<tr>
<td>1.402 ± 0.546</td>
<td>1.564 ± 0.720</td>
</tr>
</tbody>
</table>

Note: The attention coefficients were measured under the different experimental conditions.
FIGURE LEGENDS

Figure 1 Averaged EP waveforms to standard stimuli from one naive subject (A.H.). Attending to the left ear tones (solid lines) enhanced the N1 amplitude to those tones in the short ISI condition only. Likewise, attending to right ear tones of 800 Hz (dotted lines) enhanced the N1s evoked by those stimuli.

Figure 2 Mean amplitudes of baseline-N1 and baseline-P3 components (at Cz and Pz, respectively) elicited by standard stimuli in right and left ears under attend-right and attend-left conditions, for each of the three ISIs. The indicated significance levels were obtained from Wilcoxon tests performed on the attention coefficients derived from these data and combined for both ears.

Figure 3 Evoked potential waveforms recorded from Pz in one subject (L.S.) to target (signal) and non-target (standard) tones during the "short" ISI condition. Responses to standard tones (N=256) show little or no significant change in the late components with the direction of attention (solid lines = attend left; dotted lines = attend right). Responses to the signal tones, however, (N=32) show the addition of a large P3 wave at 350-400 msec to stimuli in the attended ear.
Figure 4 Mean amplitudes of baseline-$N_1$ and baseline-$P_3$ components (at Cz and Pz, respectively) elicited by target stimuli in right and left ears under attend-right and attend-left conditions for each of the three ISIs.
SIGNALS

N1

\[ p < .01 \]

\[ \text{Short ISI} \]

\[ \text{Medium ISI} \]

\[ \text{Long ISI} \]

P3

\[ p < .01 \]

Amplitude (\( \mu V \))

Attend
Left
Attend
Right

Attend
Left
Attend
Right

Left Ear Stimuli

Right Ear Stimuli

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