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Temporally selective attention modulates early perceptual processing: Event-related potential evidence

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Some of the most important information we encounter changes so rapidly that our perceptual systems cannot process all of it in detail. Spatially selective attention is critical for perception when more information than can be processed in detail is presented simultaneously at distinct locations. When presented with complex, rapidly changing information, listeners may need to selectively attend to specific times rather than to locations. We present evidence that listeners can direct selective attention to time points that differ by as little as 500 msec, and that doing so improves target detection, affects baseline neural activity preceding stimulus presentation, and modulates auditory evoked potentials at a perceptually early stage. These data demonstrate that attentional modulation of early perceptual processing is temporally precise and that listeners can flexibly allocate temporally selective attention over short intervals, making it a viable mechanism for preferentially processing the most relevant segments in rapidly changing streams.

Selective attention plays an important role in perception under a wide variety of conditions. From visual scene perception to listening to a single voice in a crowded room, attention allows observers to preferentially process the most relevant information (Cherry, 1953; Duncan & Humphreys, 1989; Neville & Lawson, 1987; Posner, 1980). Spatially selective attention is particularly crucial when more information than can be processed in detail is presented simultaneously at distinct locations. However, large amounts of information can overwhelm perceptual systems even when only a single location is involved. Rapidly changing stimuli, such as the view from a speeding vehicle and the acoustic features that constitute speech, also present the problem of more information than can be processed in detail. Under these conditions, selecting stimuli for preferential processing on the basis of *when* events occur, rather than *where* they occur, may allow individuals to extract the most meaningful information from their environments.

Consistent with this hypothesis, temporal expectancies allowed listeners to detect a heavily masked sound on a much higher proportion of trials when it was presented within a span of 150 msec before to 100 msec after the most probable time of occurrence (Wright & Fitzgerald, 2004). In the visual modality, explicitly cuing the temporal relationship between the first and second targets in rapid serial visual presentations has been shown to greatly reduce the attentional blink (Martens & Johnson, 2005). Furthermore, reaction times (RTs) from studies employing a modified Posner cuing paradigm (Posner, Snyder, & Davidson, 1980) indicate that temporally selective attention affects responses to visual stimuli even when they are presented in isolation. Specifically, participants were asked to respond to targets preceded by cues indicating the more probable of two cue–target intervals. When the target was presented at the earlier time, viewers responded faster if given a valid cue (Coull, Frith, Büchel, & Nobre, 2000; Coull & Nobre, 1998; Griffin, Miniussi, & Nobre, 2002; Miniussi, Wilding, Coull, & Nobre, 1999).

In these initial cuing studies, no validity effects were observed for targets presented at the second time, leaving transiently increased alertness in response to the short-interval cue as a possible explanation for the RT differences. However, other studies showed that with more than two possible target times, valid temporal cues can improve performance at all cue–target intervals under some conditions (Correa, Lupiáñez, Madrid, & Tudela, 2006; Griffin, Miniussi, & Nobre, 2001; Milliken, Lupiáñez, Roberts, & Stevanovski, 2003). Furthermore, the presence of catch trials (during which no target occurs) reliably produces temporally selective attention effects at the longer time interval (Correa, Lupiáñez, Milliken, & Tudela, 2004; Correa, Lupiáñez, & Tudela, 2006). This finding supports the hypothesis that in studies with only two intervals and no catch trials, trials without a target at the first time may encourage participants to shift their attention to the later time regardless of the cue they were given (Nobre, 2001).

Initial studies brought into question whether temporally selective attention affects early perceptual processing. Most behavioral studies did not directly address this issue (but see Correa, Lupiáñez, & Tudela, 2005) and many of

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the event-related potential (ERP) studies that employed modified Posner cuing paradigms failed to find evidence that temporally selective attention modulates perceptual processing as indexed by the amplitude of the visual N1 (Griffin et al., 2001; Griffin et al., 2002, Experiment 2; Miniussi et al., 1999). Instead, these studies indicated that the effects of temporally selective attention were limited to later target identification or to response-related processes indexed by the P3 (Nobre, 2001). However, in one of these experiments (Griffin et al., 2002, Experiment 1) temporally selective attention effects were observed on the visual N1 when participants performed a discrimination task on peripherally presented images.

In a recent review and report of original data, Correa, Lupiáñez, et al. (2006) raised the hypothesis that temporally selective attention modulates early perceptual processing only when participants engage in perceptually demanding tasks (i.e., discrimination rather than detection). They reported an enhanced visual P1 for targets presented at the earlier of two intervals when participants were cued (75% valid) to attend to the earlier time. Further, ERP studies of temporally selective attention that use a paradigm more analogous to the Hillyard sustained-attention design (Hillyard, Hink, Schwent, & Picton, 1973) conclusively demonstrated that temporal attention affects early perceptual processing in the auditory modality (Lange & Röder, 2006; Lange, Rösler, & Röder, 2003). In these studies, listeners were instructed to attend to one of two times following an auditory cue in order to detect rare, louder targets presented at the attended time only. For both the shorter and longer cue–target intervals, nontargets presented at attended times elicited larger auditory N1s. This design has the advantage that participants are never asked to make a response to stimuli presented at unattended times, making shifts of attention during the course of a trial less likely. Taken together, these studies suggest that in order to observe effects of temporally selective attention on early perceptual processing, it may be necessary to employ a perceptually challenging task, observe the effects on auditory processing, cue participants to attend to the same time interval for blocks of trials, or use a design in which stimuli that have not been cued do not require responses. The available evidence does not yet make it possible to determine all of the combinations of these features that result in early temporally selective attention effects.

Importantly, none of the studies that have reported early perceptual effects have asked participants to attend to more than two times. As a result, the reported effects of attention on perceptual processing can be explained equally well by precise temporal selection at the perceptual level and a model in which temporal attention initially acts in a very coarse manner (i.e., information presented within about 1 sec of the cue is processed differently from information presented later) and only response-related processing as indexed in behavioral studies is actually selective in the sense of specific times. If temporal attention affects perceptual processing in a before-or-after manner and if the boundary is static at around 1 sec, it would not be particularly useful for dealing with overwhelming amounts of information presented in rapid streams. The present study was designed to test the temporal precision and flexibility of temporally selective attention effects on early perceptual processing.

The experiment shared as many features as possible with previous studies that have shown evidence of early perceptual modulation by temporally selective attention. Specifically, in blocks of trials, listeners were asked to attend to a time 500, 1,000, or 1,500 msec after the onset of a fixation point to detect a deviant (20%) sound. Participants were never asked to respond to sounds presented at unattended times, and the standard sound, a frequency modulated tone, was constructed such that attention was necessary to discriminate it from the deviant sound, a pure tone (Cusack & Carlyon, 2003). If temporally selective attention affects early perceptual processing in a precise temporal manner rather than in a before-or-after dichotomy, standard sounds presented at each of the attended times should elicit a larger amplitude N1 than should the physically identical stimuli when listeners were attending to either of the other times.

METHOD

Participants

Eighteen adults (6 women) between the ages of 18 and 35 (M = 24 years, 5 months), with normal hearing and normal or corrected-to-normal vision, provided the data included in analyses. Each reported being right-handed, taking no psychoactive medications, and having no known neurological or attention-related disorders. An additional 8 adults completed the experiment; data from 6 were excluded for poor EEG quality (further details in the ERP Method section) and from 2 for low accuracy rates (further details in the Results section). All participants provided written, informed consent before being included in any research activities and were paid $10/h for their time.

Stimuli and Procedure

Two 50-msec sounds were generated in Sound Studio 3: a 1000-Hz pure tone and a frequency modulated (FM) sound that varied between 500 and 1500 Hz in three cycles. Eight-millisecond onset and offset ramps were applied to each. The sounds were stored as mono WAV files with a 44.1-kHz sampling rate and presented with E-Prime software running on a PC with a Creative SB Audigy 2 ZS sound card over M-Audio StudioPro3 loudspeakers located on each side of a computer monitor 152 cm in front of participants. Each sound was presented at 65 dB SPL (A-weighted), as measured from the position of the participants, with the sound repeated 50 times in 5 sec.

Participants were first introduced to the two sounds by hearing multiple examples of them with the word "steady" presented on the computer monitor during the pure tone and the word "warble" during the FM sound. They were then given examples of the three time intervals employed in the study: sounds beginning 500, 1,000, and 1,500 msec after the onset of a fixation point. Finally, six practice blocks were given (two in each attention condition). Practice blocks consisted of 15 trials, at least two of which required a buttonpress, as described below. During the practice trials, the experimenter paused the experiment to provide verbal feedback any time the participant pressed a button on a nontarget trial or failed to respond on a target trial.

For the practice and test trials, participants were asked to press a button as quickly as possible if they heard the "steady" tone presented at the attended time only, 500, 1,000, or 1,500 msec after the onset of a fixation point. A visual stimulus was used to mark the onset of the intervals to avoid confounds with auditory refractory effects and potential attention-modulated refractory periods. At the beginning of each block of trials, the word "short," "middle," or "long" appeared on the monitor to indicate the time at which the participant should attend. On each trial, a fixation point appeared, followed by a single sound presented at one of the three possible times with equal probability. On 20% of the trials, the "steady" tone (deviant) was presented; the other 80% of trials included the "warble" sound (standard). Regardless of when a sound was played on a trial, the fixation point remained on the screen for a total of 2,500 msec, followed by a variable intertrial interval of 1,000–2,000 msec (M = 1,500 msec, rectangular distribution). A schematic of the trial design is shown in Figure 1.

Twenty-one blocks of 75 test trials were presented. Each test block began with the word indicating the attention interval and 2 examples of target trials. The 75 trials in each block included 5 deviant and 20 standard sounds presented at each of the three intervals. The average length of each trial was 4 sec; each block lasted 5 min. Experimental sessions required approximately 3 h, including EEG recording setup, instruction and practice, the completion of all test trials, and frequent breaks between blocks. The percentage of trials of each type (attention condition, sound onset time, and sound type) for which participants responded was calculated and submitted to planned, paired-comparison t tests.

ERP Method

EEG was recorded with a bandwidth of 0.01–80 Hz, referenced to the vertex, using EGI (Electrical Geodesics, Inc., Eugene, OR) 128-channel nets. Four sizes were available, to achieve a close fit for every participant. Scalp impedances at all electrode sites were under 50 kΩs before test trials began and were maintained under 100 kΩs throughout the experiment. After EEG was digitized (250 Hz), epochs 100 msec before to 600 msec after sound onset, and 100 msec before to 1,500 msec after fixation point onset, were defined. The 100-msec prestimulus intervals served as a baseline. Individual artifact rejection criteria were set for each of the 26 participants based on observations of blinks, eye movements, and head movements made while participants listened to instructions. Trials on which EEG amplitude exceeded individual limits at any electrode site were eliminated from analyses. Data from 5 participants included large-amplitude, low-frequency shifts at multiple channels likely caused by skin potentials in a room that was uncomfortably warm. Blinks were evident in over 50% of the data from another participant, leaving data from 20 individuals with a sufficient number of artifact-free trials.

Data from trials with correct behavioral responses (i.e., a buttonpress if the deviant was presented at the attended time; no buttonpress for all other trials) for each condition and electrode site for every individual were averaged and then rereferenced to the averaged mastoid measurements. Peak latency and average amplitude measurements were taken on the waveforms in the following time windows: after sound onset, 40–60 msec (P1), 90–130 msec (N1), 160–250 msec (P2), 250–350 msec (N2), and 250–500 msec (P3). Additional average amplitude measurements were made 350–500 msec, 500–750 msec, 750–1,000 msec, 1,000–1,250 msec, and 1,250–1,500 msec after the onset of the fixation point (baseline corrected to the prefixation interval). Measurements were made at 81 electrode sites across the scalp and combined into groups of 9 electrodes in a 3 (anterior, central, posterior—ACP) × 3 (left, medial, right—LMR) grid (Figure 2). These averaged measurements were then entered in 3 (attention) × 3 (ACP) × 3 (LMR) repeated measures ANOVAs (Greenhouse–Geisser adjusted). ANOVAs were conducted separately for ERPs time-locked to the onset of the fixation point and to the onset of a sound for trials on which the sound occurred 500, 1,000, and 1,500 msec after the fixation point, such that attention effects were always assessed for physically identical trials. All significant ($p < .05$) main effects of attention, and attention by electrode position interactions, were followed up by ANOVAs conducted with every combination of two attention conditions, or by ANOVAs conducted separately for each level of the relevant electrode position factor.

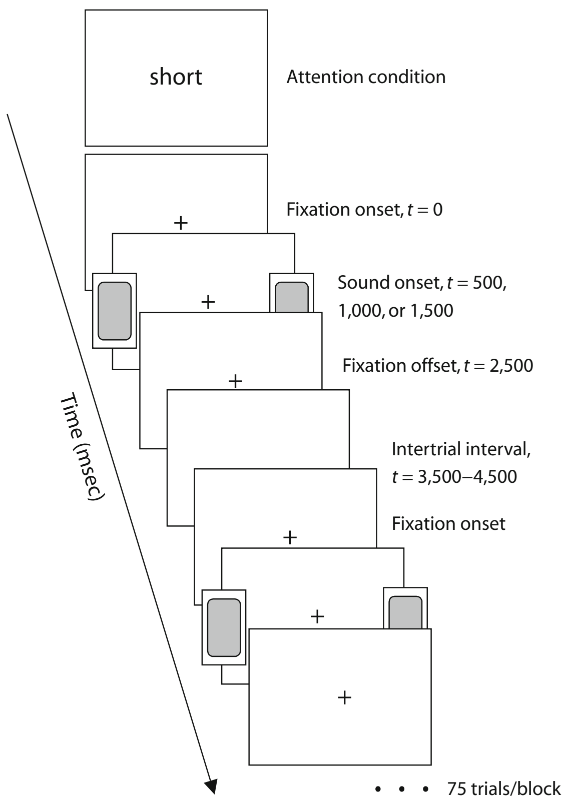

Figure 1. Schematic of trial structure. At the beginning of each block, the word "short," "middle," or "long" was shown to indicate the attention condition. The beginning of each trial was marked with the onset of a fixation point. The standard (80%) or deviant (20%) sound was played 500, 1,000, or 1,500 msec after the onset of the fixation point, which always remained on the screen for a total of 2,500 msec. The next trial began 1,000–2,000 msec later. Each of the 21 blocks (7 of each attention condition) included 75 trials.

RESULTS

Accuracy

Despite feedback during the practice trials, 1 participant responded to over 90% of deviants *and* standards presented at attended times during the test phase; a second participant showed no ability to differentiate between the 3 time intervals, and was equally likely to respond to the deviant sound when presented at the attended (77%) or unattended (81%) times. As shown in Figure 3, the remaining 18 listeners could clearly discriminate between the deviant and standard sounds and responded more often to the deviant sound when presented at an attended time (M = 88%), rather than at an unattended time (M = 19%).

More specifically, for sounds presented 500 msec after the onset of the fixation point, participants were much more likely to respond to deviants when they were attending to the short interval (M = 92%, SE = 1.1) than to either the middle [M = 13%, SE = 2.3; $t(17) = 29.0, p < .001$] or long [M = 9%, SE = 1.3; $t(17) = 49.6, p < .001$] intervals. There was also a significant difference in the percentage of responses to deviants presented at 500 msec when listeners attended to the middle and long interval [$t(17) = 2.1, p < .05$], indicating that deviants presented

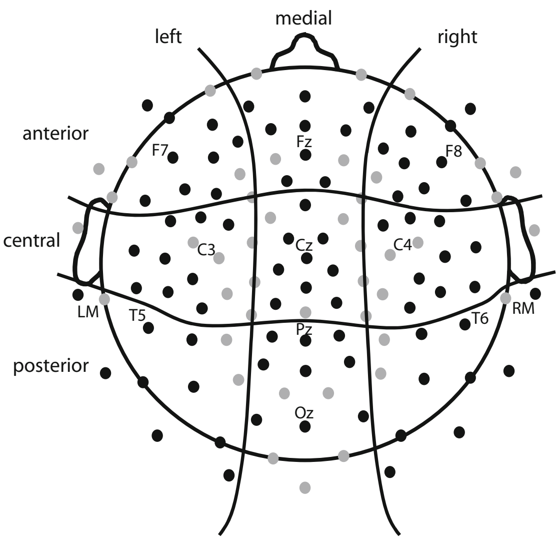

Figure 2. Approximate position of 128 electrodes. Data from the 81 electrodes shown in black were included in analyses. Nine electrodes were included in each of the three levels of the two electrode position factors: left medial right (LMR) and anterior central posterior (ACP).

at 1,000 msec were more likely to be confused with targets than were deviants presented at 1,500 msec.

Similarly, for deviants presented at 1,000 msec, participants responded more frequently when attending to this time ($M = 82\%$, $SE = 1.7$) than to the short [$M = 13\%$, $SE = 1.5$; $t(17) = 36.6$, $p < .001$] or long [$M = 30\%$, $SE = 3.0$; $t(17) = 13.7$, $p < .001$] intervals. Listeners were clearly able to distinguish both 500 msec and 1,500 msec from 1,000 msec. However, participants were less likely to respond in error to the deviant presented at 500 msec than to the deviant presented at 1,500 msec [$t(17) = 5.8$, $p < .001$], indicating that discrimination between 1,000 and 1,500 msec was worse.

Finally, for deviants presented at 1,500 msec, participants also responded more frequently when attending to the long interval ($M = 90\%$, $SE = 1.6$) than to the short [$M = 13\%$, $SE = 1.5$; $t(17) = 39.9$, $p < .001$] or middle [$M = 39\%$, $SE = 1.9$; $t(17) = 20.7$, $p < .001$] times, and more frequently when attending to the middle than to the short time [$t(17) = 12.3$, $p < .001$]. Participants were successful at distinguishing the longest interval from both of the other two, but were more likely to confuse it with the middle than with the short time.

Event-Related Potentials

The onset of the standard sound elicited a typical positive–negative–positive–negative series of peaks, all of which appeared largest in amplitude over anterior or central and medial regions. Specifically, sounds presented at each time evoked a positive response (P1) that peaked at 49 msec and a first negative peak (N1) at 110 msec. The second positive peak (P2) had a latency of 199 msec and the second negative peak (N2) a latency of 297 msec. Between 250 msec and 500 msec, deviant “steady” sounds elicited a positivity (P3) largest over central or posterior and medial positions. The P3 was absent for standard “warble” sounds at each time [500 msec, $F(1,17) = 10.3$, $p < .001$; 1,000 msec, $F(1,17) = 9.0$, $p < .001$; 1,500 msec, $F(1,17) = 8.3$, $p < .001$], although the P3 amplitude for deviant sounds was modulated by attention, as reported below.

Deviants

There were no significant effects of attention condition on P1, N1, or P2 latency or amplitude for the deviant sounds (ps $> .10$). The absence of early attention effects for deviants was attributed to low signal-to-noise ratios, since each participant observed only 35 of these trials per condition and contributed even less data once trials with incorrect behavioral responses or artifacts in EEG were excluded. However, the amplitude of the P3 elicited by

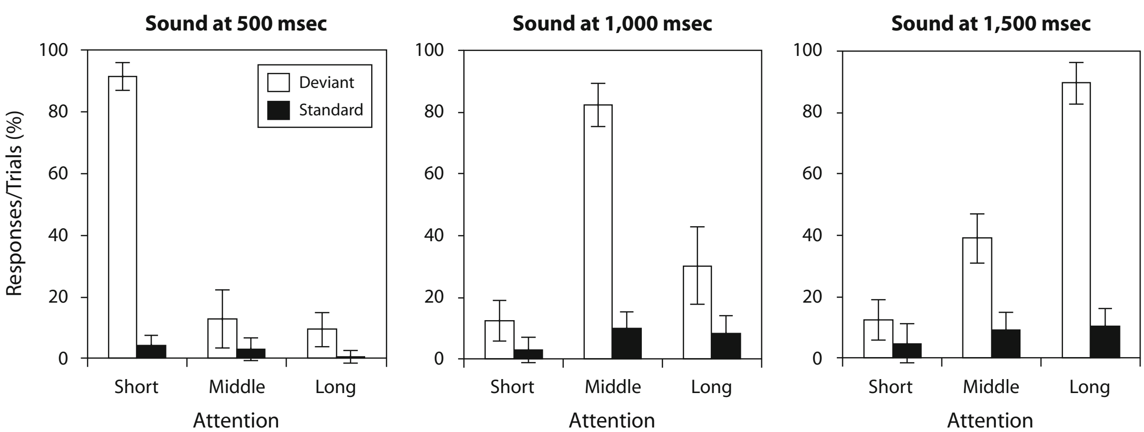

Figure 3. Percentage of trials on which participants ($N = 18$) responded to deviant (white bars) and standard (black bars) sounds for the three cue–target intervals (500, 1,000, and 1,500 msec) and the three attention conditions (short, middle, and long). In all conditions, participants were more likely to make hits (responses to deviant sounds at the attended time) than they were to make false alarms (responses to the standard sound or the deviant presented at unattended times). Error bars show standard deviations.

deviant sounds was modulated by whether or not the deviant was defined as a target by the attention condition (Figure 4). These ERP results were consistent with the behavioral data and further support the claim that participants were able to attend to the specific times that differed by only 500 msec.

When the deviant sound was presented 500 msec after the onset of the fixation point, attention affected the amplitude of the P3 [$F(2,34) = 8.8, p < .01$], such that it was larger when participants attended to the short interval than when they attended to either the middle [$F(1,17) = 9.3, p < .01$] or the long [$F(1,17) = 12.3, p < .01$] interval. The differences in P3 amplitude were largest at medial electrodes [attention × LMR, $F(4,68) = 8.2, p < .001$]. No difference was observed in the amplitude of the P3 for the deviant sound presented at 500 msec when listeners attended to the middle and long intervals ($p > .4$).

The response to deviants presented 1,000 msec after the onset of the fixation point was also modulated by attention [$F(2,34) = 13.3, p < .001$]. Again, targets (deviant sounds presented at the attended time) elicited larger P3s than did the same sound when listeners attended to either the short [$F(1,17) = 25.0, p < .001$] or the long [$F(1,17) = 7.3, p < .05$] interval. The differences in P3 amplitude were largest over medial areas [attention × LMR, $F(4,68) = 10.3, p < .001$]. There was also a significant difference in the P3 amplitude elicited by deviants presented at 1,000 msec for the two unattended conditions [$F(1,17) = 6.5, p < .05$]. Across medial electrodes, the mean amplitude between 250 and 500 msec that occurred when listeners attended to the long interval ($M = 1.32$, $SE = 0.36$) was more similar to that elicited by targets than when listeners attended to the short interval ($M = 0.19$, $SE = 0.59$). This result was consistent with the behavioral data indicating that participants were better able to distinguish between the short and middle times than between the middle and long times.

The amplitude of the P3 elicited by the deviant sound presented 1,500 msec after the fixation point was affected by attention [$F(2,34) = 10.1, p < .001$]. Deviants presented at the attended time elicited a larger P3 than when listeners attended to either the short [$F(1,17) = 37.4, p < .001$] or middle [$F(1,17) = 5.3, p < .05$] interval. The P3 differences were largest over medial and central or posterior areas [attention × ACP, $F(4,68) = 6.9, p < .01$; attention × LMR, $F(4,68) = 7.8, p < .001$]. The results of the P3 analysis for deviants at the long time indicate that listeners were better at discriminating between the long and short intervals than between the long and middle intervals [$F(1,17) = 4.7, p < .05$].

Standards

Both accuracy and ERPs elicited by the deviant sound indicate that listeners were able to perform the task. However, neither of these measurements was designed to determine whether temporally selective attention modulated early perceptual processing for each of the three time windows. The temporal precision and flexibility of selective attention effects on perceptual processing were assessed by ERPs evoked by standard sounds, which were never defined as targets. No effects of attention were observed on the latency or amplitude of the P1 or on the latency of the N1 peak ($ps > .15$). However, temporally selective attention resulted in larger amplitude N1s for standards presented at the short, middle, and long time intervals (Figure 5).

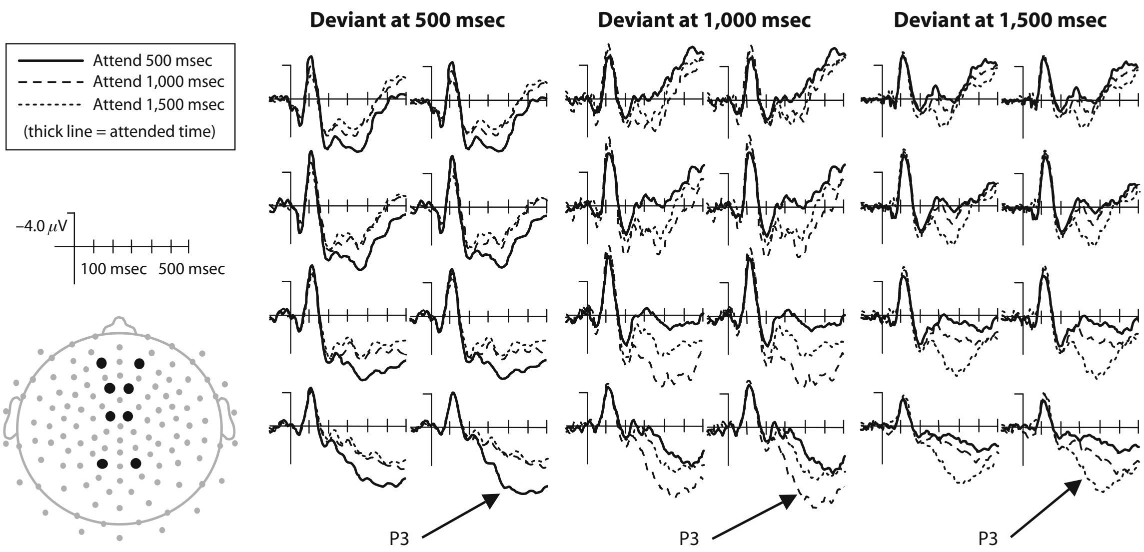

Figure 4. Auditory evoked potentials elicited by deviant sounds. Data are shown at eight electrode sites indicated in black on the electrode map, with more anterior positions shown at the top. ERPs for deviants presented at each time are shown for attend short (solid line), attend middle (dashed line), and attend long (dotted line) conditions; waveforms for targets (deviants presented at attended times) are shown with a thicker line. Deviants presented at attended times elicited larger P3s than did deviant sounds presented at unattended times.

Attention affected the amplitude of the N1 elicited by standards presented 500 msec after the onset of the fixation point [$F(2,34) = 15.4, p < .001$]. Specifically, N1 was larger in amplitude when listeners attended to the short as opposed to the middle [$F(1,17) = 17.9, p < .001$] or the long [$F(1,17) = 36.0, p < .001$] time. The N1 amplitude differences were larger over anterior and central regions [attention × ACP, $F(4,68) = 7.5, p < .001$], as was the N1 component itself. No significant difference was found in the N1s elicited by standards at the short time when listeners attended to the middle and long times ($p > .20$).

Similarly, temporal attention affected the amplitude of the N1 elicited by standard sounds presented at 1,000 msec [$F(2,34) = 11.6, p < .001$], such that N1 amplitude was larger when listeners attended to the middle time than to either the short [$F(1,17) = 18.8, p < .001$] or the long [$F(1,17) = 11.8, p < .01$] time. Unlike the P3s elicited by deviants, the N1 responses to standards at 1,000 msec did not significantly differ for the two unattended conditions ($p > .15$). The N1 attention effects for standards presented at 1,000 msec did not interact with either electrode position factor (ps $> .20$)

Finally, attention modulated the response to standards presented 1,500 msec after the onset of the fixation point [$F(2,34) = 8.9, p < .01$]. N1 amplitude was larger when listeners attended to the long time as opposed to the short time [$F(1,17) = 16.2, p < .001$], and when they attended to the long time as opposed to the middle time [$F(1,17) = 7.9, p < .05$]. There was no significant difference in N1 amplitude for the two unattended conditions ($p > .10$). As was true for standards presented at 500 msec, these attention effects were largest over anterior and central locations [attention × ACP, $F(4,68) = 5.4, p < .01$].

P2 latency did not differ by attention condition (ps $>$ .15). However, P2 amplitude was larger across central electrodes when listeners attended to the short time for standards presented 500 msec after onset of fixation [attention × ACP, $F(4,68) = 4.3, p < .05$; central electrodes only, attention, $F(2,34) = 3.6, p < .05$]. There was a tendency for P2 amplitude to be smaller when listeners attended to the short time for standards presented 1,500 msec after onset of fixation [attention × ACP, $F(4,68) = 5.3$, $p < .01$], but the attention effect did not reach significance at any subset of electrodes. No other effects of attention were evident on P2 amplitude.

N2 latency was shorter for standards presented 1,500 msec after fixation when participants attended to that time interval [$F(2,34) = 5.4, p < .05$]; these latency differences were not evident for sounds presented at other times (ps $> .4$). The N2 was also smaller in amplitude for standards presented at 1,500 msec when participants attended to that time [$F(2,34) = 13.8, p < .001$]. This effect was largest over central and medial areas [attention × ACP, $F(4,68) = 8.2, p < .01$; attention × LMR, $F(4,68) = 6.1$, $p < .01$], as were the P3 effects for deviants, suggesting that the measurements in these overlapping time windows (N2: 250–350; P3: 250–500) may have been partially indexing the same process. Consistent with this idea, ERPs in the P3 time range were numerically more positive for standard sounds presented at 1,500 msec when listeners were attending to the long interval than when they were attending to the middle interval, and more positive when listeners were attending to the middle interval than when they were attending to the short interval. However, neither the main effect of attention ($p > .10$) nor the comparisons of any two attention conditions (ps $> .10$) was significant.

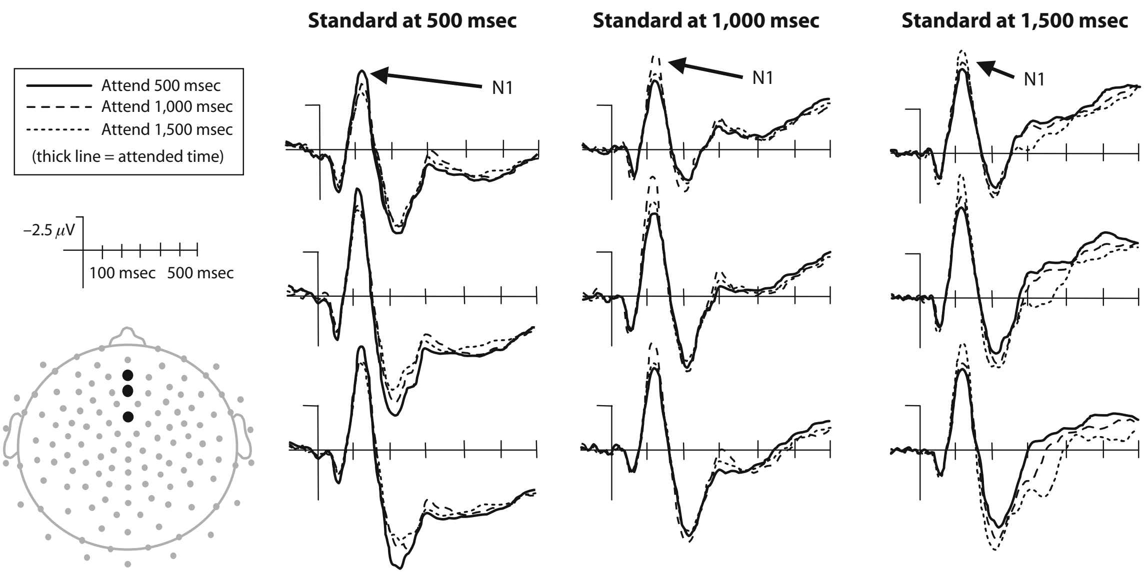

Figure 5. Auditory evoked potentials elicited by standard sounds. Data are shown at three electrode sites indicated in black on the electrode map, with more anterior positions shown at the top. ERPs for standards presented at each time are shown for attend short (solid line), attend middle (dashed line), and attend long (dotted line) conditions; waveforms for standards presented at attended times are shown with a thicker line. For each interval, sounds presented at attended times elicited larger N1s.

Fixation

Auditory evoked potentials were measured using 100 msec before sound onset as a baseline, such that the effects of attention on those components could be measured directly. However, participants were using the onset of the fixation point to mark the onset of the interval. The response to that fixation point prior to any sound onset was also modulated by temporally selective attention (Figure 6). Specifically, a broadly distributed negativity increased in amplitude immediately before the attended time and dropped back to a level equal to the other conditions after that attended time passed without a sound being played.

For trials on which a sound was played at 500 msec, the mean amplitude between 350 and 500 msec after the onset of the fixation point was more negative for the attend short than for the attend long condition at anterior electrodes [attention × ACP, $F(2,34) = 4.4$, $p < .05$; anterior electrodes only, attention, $F(1,17) = 4.5$, $p < .05$]. For this same time period and subset of electrodes, the mean amplitude tended to be more negative for the attend short than for the attend middle condition [$F(1,17) = 3.6$, $p = .077$]. In contrast, there was no evidence of a difference between the attend middle and attend long condition, in this time range ($ps > .5$).

For trials on which a sound was played at 1,000 msec, the mean amplitude between 500 and 750 msec was more negative when participants attended to the middle time than when they attended to the long time over anterior regions [attention × ACP, $F(2,34) = 3.8$, $p < .05$; anterior electrodes only, attention, $F(1,17) = 5.7$, $p < .05$], but there was no difference between the attend short and attend middle conditions ($ps > .15$). In the subsequent 250 msec (750–1,000 msec), the negativity in response to the temporal cue for the attend middle condition continued to develop, such that it was larger in amplitude than that for the attend short condition [$F(1,17) = 9.9$, $p < .01$] and for the attend long condition [$F(1,17) = 7.7$, $p < .05$]. These differences in amplitude were largest over anterior and central regions [attention × ACP, $F(4,68) = 4.8$, $p < .01$]. During the same time window, mean amplitude did not differ for attend short and attend long conditions ($ps > .15$), suggesting that this was a relatively unattended time for both of these conditions.

The increase and decrease of this broad negativity around the attended time could be observed most clearly on the trials in which the standard sound was not presented until 1,500 msec after the onset of the fixation point. Between 1,000 and 1,250 msec, attention affected the broadly distributed negativity [$F(2,34) = 14.0$, $p < .001$], such that it was still present in the attend middle, compared with the attend short, condition [$F(1,17) = 13.2$, $p < .01$], and was building in the attend long compared with the attend short condition [$F(1,17) = 24.7$, $p < .001$]. There was no difference in mean amplitude for the attend middle and attend long conditions ($ps > .4$). The attention effects were largest over central and medial regions [attention × ACP, $F(4,68) = 3.7$, $p < .05$; attention × LMR, $F(4,68) = 2.7$, $p < .05$]. By 1,250–1,500 msec, the attention effect [$F(2,34) = 15.4$, $p < .001$] further developed, such that the negativity was larger not only for attend long than for attend short [$F(1,17) = 24.1$, $p < .001$] but also for attend long than for attend middle [$F(1,17) = 12.6$, $p < .01$]. The difference in amplitude for attend middle and attend short was also significant [$F(1,17) = 5.1$, $p < .05$]. These attention effects were also broadly distributed, but larger at central and medial electrode sites [attention × ACP, $F(4,68) = 4.2$, $p < .05$; attention × LMR, $F(4,68) = 3.3$, $p < .05$].

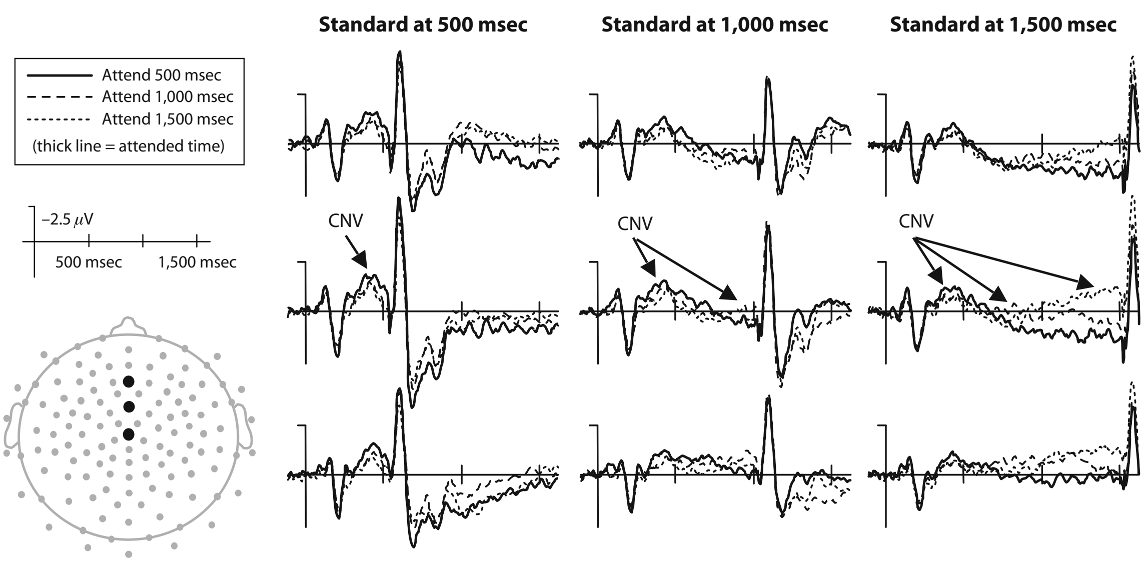

Figure 6. ERPs time-locked to the onset of the fixation point. Data are shown at three midline electrode sites indicated in black on the electrode map. ERPs for trials on which the standard sound was presented at each time are shown for attend short (solid line), attend middle (dashed line), and attend long (dotted line) conditions; waveforms for standards presented at attended times are shown with a thicker line. A broadly distributed negativity (CNV) developed around the attended time before the presentation of a sound.

DISCUSSION

Behavioral data indicate that listeners were able to discriminate between the standard and deviant sounds, and among sounds presented at the three different times. Temporal discrimination was better between 500 and 1,000 msec than between 1,000 and 1,500 msec. All sounds elicited P1, N1, P2, and N2 components; the deviant sounds also elicited a P3. P3 amplitude was larger for targets than for deviants presented at unattended times. Temporally selective attention also affected neurosensory processing of standards as indexed by N1 amplitude. Standards presented at attended times elicited larger N1s. Temporally selective attention was also evident in ERPs time-locked to cue onsets, such that a larger negativity developed around the attended time in the absence of a sound. The results of this study provide an important replication of the finding that temporally selective attention affects early perceptual processing. They also provide the first demonstration that these early effects are truly selective and flexible. By employing three rather than two attended intervals, this study provides strong evidence that attention affects perception of stimuli presented at specific times rather than before or after a static boundary. Listeners showed preferential processing of sounds presented at attended rather than at unattended times, regardless of the specific cue target interval. The rapid modulation of temporally selective attention, along with impacts on early perception, may make it a viable tool for helping individuals process the most relevant information when their perceptual systems are overwhelmed by rapidly changing stimuli.

Previous studies indicate that under some conditions selective attention can act in a relatively coarse manner at initial stages of processing and in a more selective manner at later stages. One example of this distinction has been reported for visual spatial processing; early visual perception sometimes reflects coarse spatial selection, such that all images presented in the same quadrant as a cued location elicit a larger visual P1, whereas only images presented very near cued locations elicit a larger amplitude N2 (Bush, Sanders, & Cave, 2007; Eimer, 1999; Kasai, Morotomi, Katayama, & Kumada, 2003; Shedden & Nordgaard, 2001). Previous studies of temporally selective attention that have reported effects on early perceptual processing (Correa, Lupiáñez, et al., 2006; Griffin et al., 2002, Experiment 1; Lange & Röder, 2006; Lange et al., 2003) have not distinguished between extremely coarse selection (anything presented before a temporal boundary, rather than anything presented after) and precise temporal selection. In the present article, if early selection had been acting in a before-or-after manner, ERPs elicited by sounds presented at 1,000 msec when listeners were attending to that interval would have been similar to those presented when listeners were attending to the short or to the long interval. The finding that temporally selective attention affects early perceptual processing at all three intervals indicates that these effects are temporally precise. Furthermore, the previous studies that have shown effects of temporally selective attention on early perceptual processing have asked participants to attend to times that straddle a border of around 1 sec (600 and 1,200 msec, or 450 and 1,450 msec). Therefore, it was also possible that the early perceptual effects reflected a static selection boundary; participants could either attend to anything before 1 sec or anything after 1 sec. In the present study, such a static boundary would not have allowed for attention effects in all three time windows. Instead, the results indicate that even the early stages of selection indexed with amplitude of the auditory N1 are flexible.

The shortest latency[1] temporal attention effects were evident on the N1 (90–130 msec) for standard sounds. The latency of these effects is similar to what was reported previously for auditory stimuli (100–140 msec in Lange & Röder, 2006; Lange et al., 2003) and for the interaction of temporal and spatial expectancies on visual processing (110–130 msec in Doherty, Rao, Mesulam, & Nobre, 2005). These effects also fall into the same range as typical auditory spatially selective attention effects in studies with a similar design (e.g., Hansen & Hillyard, 1980; Hillyard et al., 1973; Hillyard, Woldorff, Mangun, & Hansen, 1987; Näätänen, Teder-Sälejärvi, Alho, & Lavikainen, 1992), suggesting that both spatial and temporal selection criteria can be applied at the same level of auditory processing. In contrast, the earliest visual temporally selective attention effects that have been reported (130–170 msec in Correa, Lupiáñez et al., 2006; 120–200 msec in Griffin et al., 2002) are somewhat later than the P1 amplification (90–130 msec) typically observed in studies of visual spatially selective attention (e.g., Clark & Hillyard, 1996; Griffin et al., 2002; Heinze, Luck, Mangun, & Hillyard, 1990; Woldorff et al., 1997). The different latencies of the earliest attention effects across studies suggest that spatial selection may affect earlier visual processing than temporal selection does. This hypothesis is consistent with the argument that spatial information has special status in the visual system and temporal information in the auditory system (Bregman, 2002; Garner, 1987; Kubovy, 1981; Sanders & Poeppel, 2007).

Differences in P2 and N2 amplitude for standards presented at attended and unattended times were not as consistent across presentation intervals as the N1 effects. Significant attention effects in the P2 range were found only for standards presented 500 msec after fixation onset (larger P2 when attending to that interval), and attention effects in the N2 range were limited to standards presented 1,500 msec after fixation onset (smaller N2 when attending to that interval). The pattern of P2 and N2 amplitudes was similar for standards presented at other times, but was not consistent enough across participants to reach statistical significance. A past debate in the literature on spatially selective attention focused on whether attention amplifies exogenously driven perceptual processing (Hillyard, 1981; Hillyard, Vogel, & Luck, 1998; Hillyard et al., 1987; Talsma & Woldorff, 2005) or results in additional endogenous processing that can be indexed with a negative processing difference (Nd) in ERPs (Näätänen, Gaillard, & Mäntysalo, 1978; Näätänen et al., 1992). There is also continuing debate on the best way to distinguish between these mechanisms (Luck, 2005). However, in the present study, the findings that the timing and distribution of the

N1 attention effects were similar to the N1 component itself, and that the P2 was never smaller in amplitude (i.e., more negative) for sounds presented at attended times, suggest that temporally selective attention was modulating the auditory onset components.

The deviant sound elicited a P3 that differed in amplitude by attention condition. Because deviant sounds presented at attended times were defined as targets that required a response, it is not possible to determine whether the P3 differences were driven by attention or, more likely, by processes related to target detection or response preparation. The standard sounds did not elicit a P3, and amplitude in the P3 time range (250–500 msec) was not modulated by attention condition.[2] As in the present study, the P3s reported in Lange et al. (2003) were larger for deviant than for standard sounds. However, in that study, P3s were also larger for standards presented at the attended than at the unattended time. The differences in P3 results may be related to the relative difficulty of the temporal discrimination and discriminating standards from deviants; that is, when the temporal discrimination is more difficult than the standard/deviant discrimination, as the behavioral data suggest it was in the present study, listeners may begin and terminate response preparation when deviants are presented at unattended times, but not when standards are presented at attended times. When discriminating between standards and deviants is more difficult than discriminating between the possible times of presentation, listeners may begin response preparation for any sound presented at the attended time. Whether or not discriminability predicts the presence of P3 effects, the lack of P3 differences for standards presented at attended and unattended times in the present study supports previous interpretations that temporally selective attention effects evident on the P3 are related to target detection or motor preparation (Nobre, 2001; Nobre & O'Reilly, 2004).

We and others (Correa, Lupiáñez, et al., 2006; Lange et al., 2003) report a negativity that is time-locked to the onset of the cue and is largest leading up to and extending beyond the attended time. This negativity is similar in distribution and amplitude to what has been described elsewhere (e.g., Macar & Vidal, 2004; Pouthas, Garnero, Ferrandez, & Renault, 2000; Roth, Ford, Lewis, & Kopell, 1976; Ruchkin, McCalley, & Glaser, 1977) as the contingent negative variation (CNV). Bendixen, Grimm, and Schröger (2006) pointed out that the CNV has been hypothesized to be composed of at least four distinct negativities: an early wave associated with warning signals; an anterior and central negativity related to motor programming; a stimulus preceding negativity that is largest over more posterior regions; and a timing component that, like the negativity related to motor programming, is largest at anterior and central electrodes. In the present study, the latency of the CNV was related to the attended time rather than to the fixation point onset. Furthermore, if the lack of a P3 in response to standards presented at attended and unattended times is interpreted as the participants' initiating motor preparation for the deviant sounds only, the motor-related component of the CNV might be reduced or absent. Since the CNV in the present study was largest at anterior and central electrodes, it is tempting to conclude that it was largely driven by the timing estimates that participants needed to make (Macar & Vidal, 2004). However, the stimulus preceding negativity has been shown to originate from regions involved in processing the expected stimulus (Van Boxtel & Böcker, 2004). Therefore, it would be expected to have a more posterior distribution for visual stimuli but to be larger at the anterior and central electrodes, where auditory onset components were most evident in the present study.

As described in the introduction, this experiment was designed to include all of the features that have been identified as potentially important for being able to observe effects of temporally selective attention on early perceptual processing: (1) Sounds rather than images were presented, consistent with the argument that temporal information is particularly important in the auditory modality (Kubovy, 1981); (2) participants were never asked to make a response to sounds presented at unattended times, giving them no reason to intentionally allocate any resources to processing those sounds (Lange et al., 2003); (3) the time to be attended was manipulated across rather than within blocks, since RT effects are larger with this design (Correa et al., 2004); (4) participants were given a discrimination task that required them to detect the lack of a feature, frequency modulation, in deviant sounds, since perceptually demanding tasks result in earlier attention effects in visual cuing paradigms (Correa, Lupiáñez, et al., 2006). Since none of these characteristics were actually manipulated in the present study, it is not possible to draw conclusions about which characteristics, if any, are necessary to observe early temporal attention effects. A comparison of studies that have and have not reported such effects suggests that any one of these experiment features might be sufficient to detect modulation of perceptual processing by temporally selective attention.

Deviant sounds presented close to attended times (sounds at 500 and 1,500 msec in the attend middle condition) were more likely to elicit false alarms and larger P3s than were deviants presented at more distant times (sounds at 500 msec in the attend long condition and at 1,500 msec in the attend short condition). This result is consistent with the idea that temporally selective attention is applied in an asymmetric graded manner (Wright & Fitzgerald, 2004), such that stimuli presented closer to attended times are processed in greater detail. However, the data are also consistent with temporal attention being applied in an all-or-nothing manner on each trial, and with listeners being better at discriminating both between more distant times (500/1,500 msec better than 500/1,000 msec) and between equidistant times for shorter intervals (500/1,000 msec better than 1,000/1,500 msec). This pattern of discrimination abilities has been reported for duration judgments under a broad range of conditions (see Grondin, 2001, for a review) and can fully account for the accuracy and P3 differences between time windows in the present study. However, no direct comparison of attention effects on processing of sounds presented at different times was made, because the design of the present study cannot distinguish among multiple interpretations (including temporal discriminability, foreperiod effects, or interactions with visual onsets) of any attention × time of sound presentation interactions.

The accuracy of duration judgments for the interval between the cue and attended time was also likely decreased by the use of an onset marker and target stimulus in different modalities (see Grondin, 2003, for a review). A visual onset was selected to indicate the beginning of the intervals to avoid refractory effects (1) that would have resulted in much smaller auditory onset components for sounds with short as opposed to long cue–target intervals, (2) that might have differed for the standard and deviant sound, and (3) that potentially also could be modulated by attention. The temporal precision of selective attention may be higher under conditions in which temporal judgments are more accurate. However, it is also important to note that duration judgments are not directly related to onset and offset perception in a straightforward way (Bendixen et al., 2006).

The results of the present study indicate that the early perceptual effects of temporally selective attention are temporally precise at a subsecond time scale, and that temporal selection is flexible at early stages of processing. These characteristics of temporally selective attention make it exactly the type of tool that might be useful in processing rapidly changing visual or auditory stimuli such as speech; in fact, the effects of temporally selective attention on auditory evoked potentials are very similar to the differences in ERPs to acoustically similar word onsets and word-medial syllable onsets in continuous speech (Sanders & Neville, 2003; Sanders, Newport, & Neville, 2002). One hypothesis concerning this word-onset effect is that listeners may selectively attend to the times in speech streams that are least predictable. Because word onsets are typically less predictable than are second or third syllables (i.e., lower transitional probabilities), listeners who are able to predict when these word onsets are likely to occur may selectively attend to the speech stream at those times. Additional research is needed to determine whether people employ temporally selective attention to effectively process the most relevant portions of rapidly changing streams, as they employ spatially selective attention to preferentially process important information in complex spatial arrays. The data presented here suggest that doing so would improve processing in perceptually challenging situations.

AUTHOR NOTE

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REFERENCES

Bendixen, A., Grimm, S., & Schröger, E. (2006). The relation between onset, offset, and duration perception as examined by psychophysical data and event-related brain potentials. *Journal of Psychophysiology*, **20**, 40-51.

Bregman, A. (2002). The auditory scene. In D. J. Levitin (Ed.), *Foundations of cognitive psychology: Core readings* (pp. 213-248). Cambridge, MA: MIT Press.

Bush, W., Sanders, L., & Cave, K. (2007, May). *Spatial distribution of visual attention across cued and uncued locations: An ERP study*. Poster presented at the annual meeting of the Cognitive Neuroscience Society, New York.

Cherry, E. (1953). Some experiments on the recognition of speech, with one and with two ears. *Journal of the Acoustical Society of America*, **25**, 975-979.

Clark, V., & Hillyard, S. (1996). Spatial selective attention affects early extrastriate but not striate components of the visual evoked potential. *Journal of Cognitive Neuroscience*, **8**, 387-402.

Correa, A., Lupiáñez, J., Madrid, E., & Tudela, P. (2006). Temporal attention enhances early visual processing: A review and new evidence from event-related potentials. *Brain Research*, **1076**, 116-128.

Correa, A., Lupiáñez, J., Milliken, B., & Tudela, P. (2004). Endogenous temporal orienting of attention in detection and discrimination tasks. *Perception & Psychophysics*, **66**, 264-278.

Correa, A., Lupiáñez, J., & Tudela, P. (2005). Attentional preparation based on temporal expectancy modulates processing at the perceptual level. *Psychonomic Bulletin & Review*, **12**, 328-334.

Correa, A., Lupiáñez, J., & Tudela, P. (2006). The attentional mechanism of temporal orienting: Determinants and attributes. *Experimental Brain Research*, **169**, 58-68.

Coull, J., Frith, C., Büchel, C., & Nobre, A. (2000). Orienting attention in time: Behavioral and neuroanatomical distinction between exogenous and endogenous shifts. *Neuropsychologia*, **38**, 808-819.

Coull, J., & Nobre, A. (1998). Where and when to pay attention: The neural systems for directing attention to spatial locations and to time intervals as revealed by both PET and fMRI. *Journal of Neuroscience*, **18**, 7426-7435.

Cusack, R., & Carlyon, R. (2003). Perceptual asymmetries in audition. *Journal of Experimental Psychology: Human Perception & Performance*, **29**, 713-725.

Doherty, J., Rao, A., Mesulam, M., & Nobre, A. (2005). Synergistic effect of combined temporal and spatial expectations on visual attention. *Journal of Neuroscience*, **25**, 8259-8266.

Duncan, J., & Humphreys, G. (1989). Visual search and stimulus similarity. *Psychological Review*, **96**, 433-458.

Eimer, M. (1999). Attending to quadrants and ring-shaped regions: ERP effects of visual attention in different spatial selection tasks. *Psychophysiology*, **36**, 491-503.

Garner, W. (1987). Location and color as cuing dimensions in contingent classification. *Perception & Psychophysics*, **41**, 202-210.

Griffin, I., Miniussi, C., & Nobre, A. (2001). Orienting attention in time. *Frontiers in Bioscience*, **6**, 660-671.

Griffin, I., Miniussi, C., & Nobre, A. (2002). Multiple mechanisms of selective attention: Differential modulation of stimulus processing by attention to space or time. *Neuropsychologia*, **40**, 2325-2340.

Grondin, S. (2001). From physical time to the first and second moments of psychological time. *Psychological Bulletin*, **127**, 22-44.

Grondin, S. (2003). Sensory modalities and temporal processing. In H. Helfrich (Ed.), *Time and mind II: Information processing perspectives* (pp. 61-77). Ashland, OH: Hogrefe & Huber.

Hansen, J., & Hillyard, S. (1980). Endogenous brain potentials associated with selective auditory attention. *Electroencephalography & Clinical Neurophysiology*, **49**, 277-290.

Heinze, H.-J., Luck, S., Mangun, G., & Hillyard, S. (1990). Visual event-related potentials index focused attention within bilateral stimulus arrays: I. Evidence for early selection. *Electroencephalography & Clinical Neurophysiology*, **75**, 511-527.

Hillyard, S. (1981). Selective auditory attention and early event-related potentials: A rejoinder. *Canadian Journal of Psychology*, **35**, 159-174.

Hillyard, S., Hink, R., Schwent, V., & Picton, T. (1973). Electrical signs of selective attention in the human brain. *Science*, **182**, 177-179.

Hillyard, S., Vogel, E., & Luck, S. (1998). Sensory gain control (amplification) as a mechanism of selective attention: Electrophysiological and neuroimaging evidence. *Philosophical Transactions of the Royal Society of London: Series B*, **353**, 1257-1270.

Hillyard, S., Woldorff, M., Mangun, G., & Hansen, J. (1987). Mechanisms of early selective attention in auditory and visual modalities. In R. J. Ellingson, N. M. F. Murray, & A. M. Halliday (Eds.), *The London Symposia* (pp. 317-324). Amsterdam: Elsevier.

Kasai, T., Morotomi, T., Katayama, J., & Kumada, T. (2003). Attending to a location in three-dimensional space modulates early ERPs. *Cognitive Brain Research*, **17**, 273-285.

Kubovy, M. (1981). Concurrent-pitch segregation and the theory of indispensable attributes. In M. Kubovy & J. Pomerantz (Eds.), *Perceptual organization* (pp. 55-98). Hillsdale, NJ: Erlbaum.

Lange, K., & Röder, B. (2006). Orienting attention to points in time improves stimulus processing both within and across modalities. *Journal of Cognitive Neuroscience*, **18**, 715-729.

Lange, K., Rösler, F., & Röder, B. (2003). Early processing stages are modulated when auditory stimuli are presented at an attended moment in time: An event-related potential study. *Psychophysiology*, **40**, 806-817.

Luck, S. (2005). *An introduction to the event-related potential technique*. Cambridge, MA: MIT Press.

Macar, F., & Vidal, F. (2004). Event-related potentials as indices of time processing: A review. *Journal of Psychophysiology*, **18**, 89-104.

Martens, S., & Johnson, A. (2005). Timing attention: Cuing target onset interval attenuates the attentional blink. *Memory & Cognition*, **33**, 234-240.

Milliken, B., Lupiáñez, J., Roberts, M., & Stevanovski, B. (2003). Orienting in space and time: Joint contributions to exogenous spatial cuing effects. *Psychonomic Bulletin & Review*, **10**, 877-883.

Miniussi, C., Wilding, E., Coull, J., & Nobre, A. (1999). Orienting attention in time: Modulation of brain potentials. *Brain*, **122**, 1507-1518.

Näätänen, R., Gaillard, A., & Mäntysalo, S. (1978). Early selective-attention effects on evoked potential reinterpreted. *Acta Psychologica*, **42**, 313-329.

Näätänen, R., Teder-Sälejärvi, W., Alho, K., & Lavikainen, J. (1992). Auditory attention and selective input modulation: A topographical ERP study. *NeuroReport*, **3**, 493-496.

Neville, H., & Lawson, D. (1987). Attention to central and peripheral visual space in a movement detection task: III. Separate effects of auditory deprivation and acquisition of a visual language. *Brain Research*, **405**, 284-294.

Nobre, A. (2001). Orienting attention to instants in time. *Neuropsychologia*, **39**, 1317-1328.

Nobre, A., & O'Reilly, J. (2004). Time is of the essence. *Trends in Cognitive Sciences*, **8**, 387-389.

Posner, M. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, **32**, 3-25.

Posner, M., Snyder, C., & Davidson, B. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, **109**, 160-174.

Pouthas, V., Garnero, L., Ferrandez, A.-M., & Renault, B. (2000). ERPs and PET analysis of time perception: Spatial and temporal brain mapping during visual discrimination tasks. *Human Brain Mapping*, **10**, 49-60.

Roth, W., Ford, J., Lewis, S., & Kopell, B. (1976). Effects of stimulus probability and task-relevance on event-related potentials. *Psychophysiology*, **13**, 311-317.

Ruchkin, D., McCalley, M., & Glaser, E. (1977). Event related potentials and time estimation. *Psychophysiology*, **14**, 451-455.

Sanders, L., & Neville, H. (2003). An ERP study of continuous speech processing. I. Segmentation, semantics, and syntax in native speakers. *Cognitive Brain Research*, **15**, 228-240.

Sanders, L., Newport, E., & Neville, H. (2002). Segmenting nonsense: An event-related potential index of perceived onsets in continuous speech. *Nature Neuroscience*, **5**, 700-703.

Sanders, L., & Poeppel, D. (2007). Local and global auditory processing: Behavioral and ERP evidence. *Neuropsychologia*, **45**, 1172-1186.

Shedden, J., & Nordgaard, C. (2001). ERP time course of perceptual and post-perceptual mechanisms of spatial selection. *Cognitive Brain Research*, **11**, 59-75.

Talsma, D., & Woldorff, M. (2005). Selective attention and multisensory integration: Multiple phases of effects on the evoked brain activity. *Journal of Cognitive Neuroscience*, **17**, 1098-1114.

Van Boxtel, G., & Böcker, K. (2004). Cortical measures of anticipation. *Journal of Psychophysiology*, **18**, 61-76.

Woldorff, M., Fox, P., Matzke, M., Lancaster, J., Veeraswamy, S., Zamarripa, F., et al. (1997). Retinotopic organization of early visual spatial attention effects as revealed by PET and ERPs. *Human Brain Mapping*, **5**, 280-286.

Wright, B., & Fitzgerald, M. (2004). The time course of attention in a simple auditory detection task. *Perception & Psychophysics*, **66**, 508-516.

NOTES

1. Although 90–130 msec captured the earliest effects that were statistically significant, it is interesting to note that the P1 peaks (49 msec) were numerically larger when listeners were attending to the time a sound was presented than when they were attending to either of the other times. Just as there was not sufficient power to detect significant N1 attention effects for the deviant sounds (the peak amplitude patterns were identical to those for the standards), there may be temporally selective attention effects earlier than 90 msec after sound onset that did not reach statistical significance with the present design.

2. As described in the Results section, standard sounds presented at 1,500 msec did elicit a smaller N2 (250–350 msec) over central and parietal regions when listeners attended to that interval as opposed to the other time intervals. The smaller negativity for attended sounds could be interpreted as a larger positivity for standards presented at the attended time.

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