Inattentional Amnesia to Words in a High Attentional Load Task

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Abstract

■ We investigated the dependence of visual word processes on attention by examining event-related potential (ERP) responses as subjects viewed words while their attention was engaged by a concurrent highly demanding task. We used a paradigm from a previous functional magnetic resonance imaging (fMRI) experiment [Rees, G., Russel, C., Frith, C. D., & Driver, J. Inattentional blindness vs. inattentional amnesia for fixated but ignored words. *Science, 286*, 2504–2506, 1999] in which participants attended either to drawings or to overlapping letters (words or nonwords) presented at a fast rate. Although previous fMRI results supported the notion that word processing was obliterated by attention withdrawal, the current electrophysiological results demonstrated that visual words are processed even under conditions in which attentional resources are engaged in a different task that does not involve reading. In two experiments, ERPs for attended words versus nonwords differed in the left frontal, left posterior, and medial scalp locations. However, in contrast to the previous fMRI results, ERPs responded differentially to ignored words and consonant strings in several regions. These results suggest that fMRI and ERPs may have differential sensitivity to some forms of neural activation. Moreover, they provide evidence to restore the notion that the brain analyzes words even when attention is tied to another dimension. ■

INTRODUCTION

The dependence of information processing on attentional resources has been an issue of central importance in the field of selective attention (for reviews, see Luck & Vecera, 2002; Driver, 2001). However, research has not offered a clear answer to the question of whether the brain is able to process information without attending to it. Early selection theorists have marshaled substantial evidence that information can indeed be selected at an early perceptual processing stage (e.g., Hillyard, Teder, Saelejaervi, & Muente, 1998), whereas many other reports (e.g., Ruz, Madrid, Lupiañez, & Tudela, 2003; Luck, Vogel, & Shapiro, 1996) suggest that ignored or unconscious stimuli can have access to high-level nonperceptual analyses, supporting late selection theories. In recent years, Lavie (1995) (see Lavie & Tsal, 1994, for a review) proposed an integrative approach that potentially accounts for many of the disparate results obtained in experiments examining the locus of selection. Her perceptual load framework states that the presence or absence of automatic processing of unattended irrelevant stimuli may be accounted for by assuming that there is limited capacity for perceptual processing. When task demands are low, resources are available to allow perceptual processing to be applied to ignored information. Under such conditions, the processing of unattended stimuli can be described as automatic in the sense that the processes are initiated and progress without intentional control of the individual. However, when perceptual task demands increase to the point at which these resources are no longer available, irrelevant stimuli are not processed.

Research on the fate of irrelevant stimuli encountered under different processing demands has traditionally faced some methodological limitations such as clearly distinguishing whether ignored information was processed and quickly forgotten (a case of *inattentional amnesia*) or never processed at all (*inattentional blindness*; see, e.g., Wolfe, 1999; Holender, 1986). Whereas behavioral tests present fundamental limitations in differentiating between these two outcomes, neuroimaging techniques afford the possibility of recording brain activation at the time information processing is taking place without the need for an overt response, proving invaluable in helping to solve this debate. Indeed, in recent years functional magnetic resonance imaging (fMRI) reports have stressed the relevance of task demands on the resources devoted to ignored information. For example, Rees, Frith, and Lavie (1997) reported that blood oxygen level dependent (BOLD) activation in V5 generated by irrelevant moving stimuli was modulated by the degree of perceptual load on a different task. When task demands were low, irrelevant background

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motion generated a large BOLD response in area V5. However, in blocks where task demands were high, motion-related activation in this area was absent. Crucially, a study by Rees, Russell, Frith, and Driver (1999) suggested that word reading, a process thought to become highly automatic due to extensive training (e.g., Dehaene et al., 2001; Posner, 1978; Deutsch & Deutsch, 1963), was obliterated when fully focusing attention in another dimension. In this study, participants saw overlapping drawings and letter strings and, in different blocks, they were asked to attend either to the drawings or to the letters and to simply detect stimulus repetitions in the attended domain. The stimuli were shown at a fast presentation rate, which maximized the attentional load associated with encoding and evaluating the attended stimuli. The design involved blocks of nonwords versus blocks that were mixed containing 60% words plus 40% nonwords, and the critical question involved how this stimulus contrast was modulated by attention. When the task required attention to letters, word stimuli activated several language-related areas, such as the left inferior frontal, left posterior temporal, and left posterior parietal regions, providing evidence that the lexical and semantic status of words had been processed. However, when participants attended to drawings, the stimulus contrast of word blocks versus nonword blocks demonstrated no such activations, leading the authors to conclude that when attention is fully withdrawn, "word processing is not merely modulated, but is abolished" (Rees et al., 1999).

These results made a strong case for the dependency of word recognition on attentional resources and thus argued against the automatic nature of this highly practiced skill. Taken at face value, the fact that the fMRI BOLD response did not differentiate blocks with and without words under the drawings focus condition suggests that words are not processed in absence of attention. This conclusion, however, rests very strongly on the assumption that a lack of any effect in the BOLD measure *necessarily* indicates a lack of neural sensitivity to this contrast. Indeed, it is possible that perceptual mechanisms respond differentially to familiar words versus novel consonant strings when attention is directed elsewhere, yet these transient responses fall below the sensitivity range of the BOLD response. It may also be possible that other imaging techniques that are more sensitive to rapid transient information are more effective in detecting such signals.

Event-related potentials (ERPs) have been fruitfully used to study the effects of attention on word processing. Looking specifically at contrasts between words and consonant strings, several reports have demonstrated sensitivity to the N200, P300, and N400 components (i.e., Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; McCandliss, Posner, & Givon, 1997; Compton, Grossenbacher, Tucker, & Posner, 1991). These ERP effects have been further examined with respect to attentional modulation, varying, for example, the depth of processing applied to the stimuli (i.e., Bentin et al., 1999; McCandliss et al., 1997; Bentin, Kutas, & Hillyard, 1995; Holcomb, 1988). In terms of detecting neural responses, the high temporal resolution of ERP complements the fMRI approach to attentional modulation of visual word processing. The addition of ERP opens the possibility of uncovering rapid, transient automatic activations to visual words that were not found in the Rees et al. (1999) study. To date, no ERP study has examined the degree to which responses thought to be automatic might be negated under conditions in which attention is occupied with another highly demanding task.

The central issue of the current study was whether fully engaging attention to a different stimulus dimension obliterates ERP effects commonly found for visual words. Such a finding would provide an important replication of the previously reported fMRI result, and together these findings would limit previous claims concerning the automaticity of processes associated with word recognition. Conversely, to the extent that results demonstrate visual word processing under conditions in which attention is engaged in a demanding task, such results would call into question the conclusions of Rees et al. (1999). In order to investigate these issues, we recorded high-density ERP (HDERP) correlates of words in the paradigm Rees et al. devised as is illustrated in Figure 1.

RESULTS

Behavioral

Mean repetition detection was 74.8% when participants attended to letter strings and 76.2% when they re-

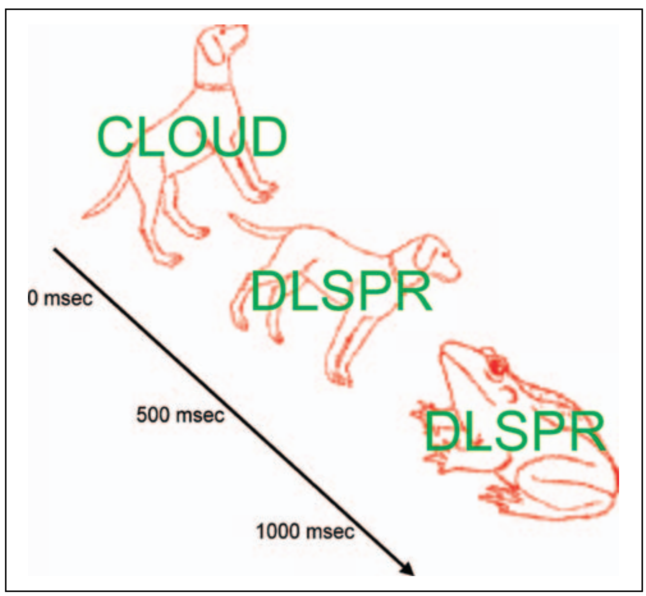

Figure 1. Representation of the stimulus display in the repetition detection task.

sponded to drawings. An ANOVA with factors for Attention (attended letters vs. attended drawings) and Lexical Status (words vs. nonwords) showed no effect of Attention, $F(1,11) = 1.501, p > .244$, or Lexical Status, $F < 1$, and a lack of interaction between the two factors, $F(1,11) = 1.255, p > .286$. Furthermore, mean response time (RT) was 398.7 msec for letter strings and 403.4 msec for drawings. When the same ANOVA as above was calculated for RT, the variable Attention had no effect ($F < 1$), but both Lexical Status and the interaction between Attention and Lexical Status were significant, $F(1,11) = 12.37, p < .005$; $F(1,11) = 8.7, p < .05$. In explanation, RT for words (426.2 msec) was longer than for nonwords (371.1 msec) when letter strings were attended, $F(1,11) = 11.24$; $p < .01$ and this was not true when participants attended to drawings (401.2 vs. 405 msec), $F < 1$. Finally, in the surprise memory test, word recognition accuracy was high for attended words (78% of "yes" responses; *MSE*, 0.18) and significantly different from that of ignored words (12%), *MSE*, 0.16; $F(1,11) = 117.27, p < .001$, or Foils (12%), *MSE*: 0.09; $F(1,11) = 155.9, p < .001$. Responses to ignored words and foils were the statistically equivalent, $F < 1$ (see Figure 2).

Electrophysiological

Attentional instructions generated widespread and long lasting effects in several areas of the scalp topography (see Figure 3). Attended drawings generated more positive ERPs at medial scalp locations than attended words, from 30 to 210 msec, $F(1,11) = 24.6, p < .001$, and the reverse was true from 100 to 300 msec in the left and right posterior scalp, $F(1,11) = 14.18, p < .01$, and in left and right anterior locations from 175 to 275 msec, $F(1,11) = 34.3, p < .001$ (see Figure 3).

When attention was directed to letters, ERPs for words and nonwords differed in several scalp locations. Words were more negative than nonwords in left frontal channels from 120 to 190 msec, $F(1,11) = 12.48, p < .01$, and in left posterior locations from 195 to 300 msec, $F(1,11) = 9.06, p < .01$. Also, the peak of the N170 component was more negative for nonwords than words in medial posterior electrodes, $F(1,11) = 11.6, p < .01$. From 240 to 315 msec, words were more positive than nonwords in anterior medial scalp sites, $F(1,11) = 12.47, p < .01$, and the reverse was true from 250 to 350 msec in left posterior electrodes, $F(1,11) = 12.44, p < .01$. An N400 effect was present from 350 to 425 msec, $F(1,11) = 8.23, p < .05$. Finally, words were more positive than nonwords from 460 to 690 msec in left medial locations, $F(1,11) = 15.18, p < .001$, and more negative in left frontal electrodes from 450 to 750 msec, $F(1,11) = 21.5, p < .001$ (see Figure 4).

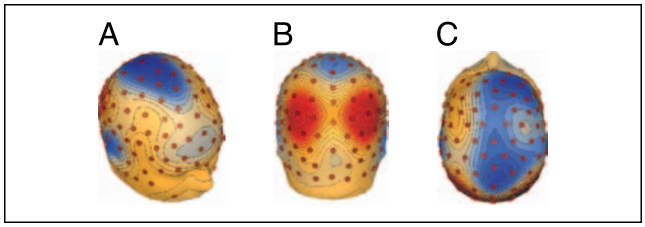

Figure 3. 3-D current source density maps of the main effects of Attentional instructions. (A) Attended drawings generated more positive ERPs at medial scalp locations than Attended words from 30 to 210 msec, (B) and the reverse was true from 100 to 300 msec in the left and right posterior scalp, (C) and in the left and right anterior locations from 175 to 275 msec.

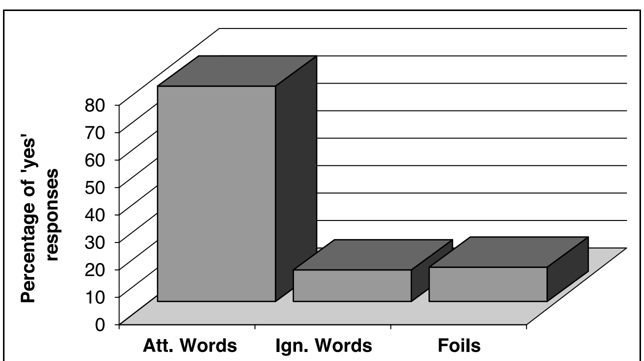

Figure 2. Percentage of "yes" responses to words presented during the surprise memory test in the Experiment 1. Whereas word recognition accuracy was very high for attended words, responses to ignored words were the same as responses to foils.

When these same contrasts (with the same groups of electrodes and temporal windows) were applied to ignored words versus ignored nonwords, the ANOVAS showed words more positive than nonwords from 460 to 690 msec in left medial locations, $F(1,11) = 10.80, p < .01$. This difference held for left frontal electrodes as well, from 450 to 750 msec, $F(1,11) = 6.5, p < .03$ (see Figure 5). Moreover, when additional contrasts were performed on ignored words versus nonwords, words were more positive than nonwords in left posterior sites from 350 to 550 msec, $F(1,11) = 7.31, p = .02$, and more negative in anterior medial electrodes in the same temporal window, $F(1,11) = 9.33, p = .01$ (see Figure 5).[1]

DISCUSSION

The fundamental result of this experiment is that words, in contrast to consonant strings, produce distinct patterns of ERP responses even under conditions in which attention is directed away from such processing by a highly demanding task. Using a nearly identical design as that of Rees et al. (1999) yet achieving different findings for unattended words might raise questions about whether the current instantiation of the paradigm was equivalent to the one originally employed. Several facts suggest that this replication effort was successful. These data tightly replicated the initial pattern of behavioral

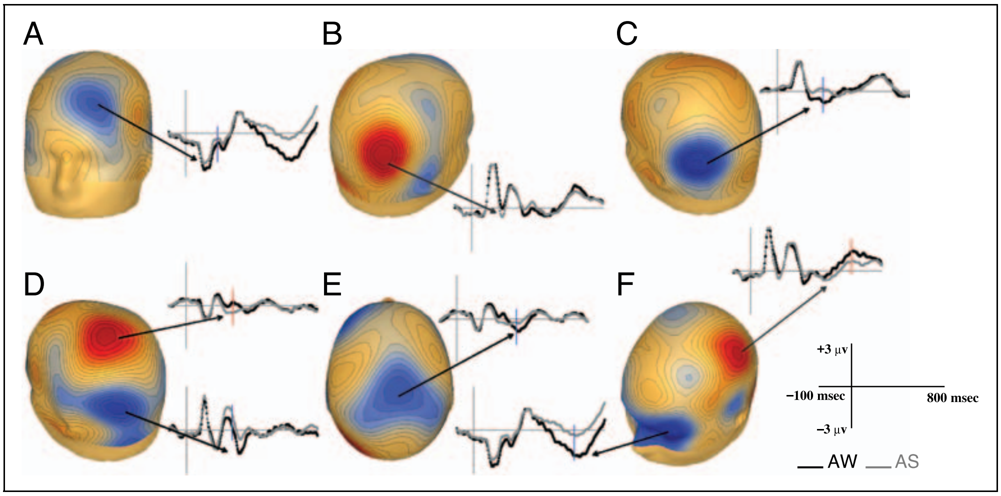

Figure 4. 3-D current source density maps of attended words versus attended nonwords effects. When letters were attended to (A) words were more negative than nonwords in left frontal channels from 120 to 190 msec (C) and in left posterior locations from 195 to 300 msec. (B) Also, the peak of the N170 component was more negative for nonwords than words in medial posterior electrodes. (D) From 240 to 315 msec, words were more positive than nonwords in the anterior medial scalp sites and the reverse was true from 250 to 350 msec in left posterior electrodes. (E) A N400 effect was present from 350 to 425 msec. (F) Words were more positive than nonwords from 460 to 690 msec in left medial locations, and more negative in left frontal electrodes from 450 to 750 msec. AW = attended words; AS = attended strings.

data. Results from the surprise memory test show that participants remembered more than 75% of the attended words, whereas the percentage of yes responses to ignored words (12%) was the same as that to foils. Furthermore, the HDERP results demonstrated a main effect of instructions, which provides further support that our instantiation of the paradigm was effective in directing participants' attention to the letter and the drawings modality.

When letters were attended, ERP responses to words and nonwords differed in several regions, including left frontal, left posterior, and medial scalp locations, consistent with the Rees et al. (1999) results and replicating previous reports in the literature of ERP word processing (e.g., Bentin et al., 1999; Badgaiyan & Posner, 1997; Kutas & Hillyard, 1987). When participants attended to drawings, ERP responses were dramatically influenced by this difference in attentional focus, yet, crucially, we still found ERP differences between unattended words and nonwords in left posterior, anterior medial, left medial, and left frontal sites (see Figure 5). Therefore, this stimulus contrast lends support to the notion that

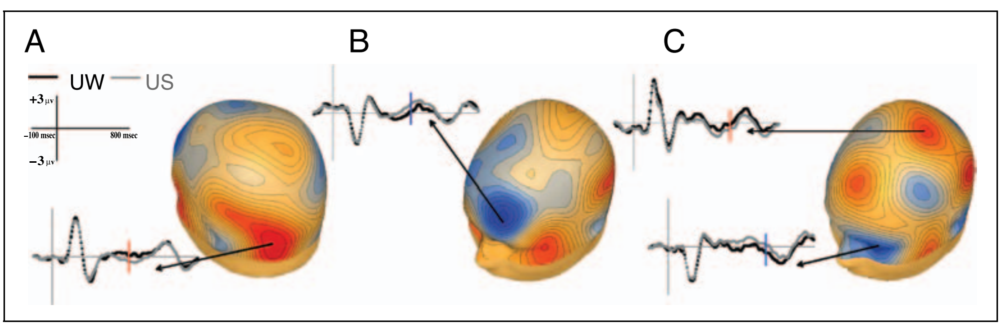

Figure 5. 3-D current source density maps of unattended words versus nonwords. (A) Words were more positive than unattended nonwords in left posterior sites from 350 to 550 msec (B) and more negative in anterior medial electrodes in the same temporal window. (C) In addition, in the same way as in blocks where letters were attended, ignored words were more positive than nonwords from 460 to 690 msec in left medial locations. This difference was also true in left frontal electrodes from 450 to 750 msec. UW = unattended words; US = unattended strings.

even under conditions of high attentional load, words engage a form of processing that differentiates them from nonword letter strings.

Interestingly, the difference between words and consonant strings was not identical under the two attentional conditions, suggesting that at least some of the observed ERP effects are dependent on attentional processes. Much of the activity extant in blocks where letters were attended was missing in blocks where participants focused on the drawings, whereas some remained. Moreover, unattended words produced activations at different times than attended ones. Taken together, this suggests that performing a highly demanding task substantially modifies the way in which the brain registers differences between words and nonwords. We will discuss these results together with Experiment 2 in the General Discussion section.

Experiment 2

Results from Experiment 1 show that even in conditions in which attention is engaged in a separate highly demanding task, the brain detects some difference between irrelevant words and nonwords. However, it is unclear from these data whether item repetition, a key manipulation in Experiment 1, is needed in order to observe this effect. That is, it could be the case that only when ignored items are repeated several times does the brain detect them. To rule out this scenario, we ran a second experiment in which letter strings were presented only once during the repetition detection task. In addition, in contrast to Experiment 1 in which some blocks of trials contained 60% words and some blocks contained 100% nonwords, in Experiment 2 all blocks contained 50% words and nonwords randomly intermixed to prevent any strategic effects due to block composition predictability. Finally, this new experiment represented a replication effort of findings in Experiment 1.

Results

Behavioral

When participants attended to letter strings, mean repetition detection was 71.5% and 68.5% when they responded to drawings. An ANOVA with the factors Attention (attended letters vs. attended drawings) and Lexical Status (words vs. nonwords) showed no effect of Attention, $F < 1$, or Lexical Status, $F(1,11) = 1.827, p > .2$, and a lack of interaction between the two factors, $F < 1$. Mean response time was 388 msec for letter strings and 324 msec for drawings. The ANOVA yielded Attention as the only significant variable, $F(1,11) = 20.66, p < .001$. In the surprise memory test, word recognition accuracy for attended words (37% of yes responses, *MSE*: 0.17) was significantly higher than that of ignored words (31%; *MSE*: 0.18; $F(1,11) = 8.555, p < .05$) or Foils (30%; *MSE*: 0.18; $F(1,11) = 12.09, p < .01$). Responses to ignored words and foils were the same, $F < 1$.

Electrophysiological

Attention to drawings generated more negative deflections at left and right posterior areas from 250 to 350 msec, $F(1,11) = 6.8, p < .05$. In addition, in the same temporal window attended drawings ERPs were more positive at anterior locations, $F(1,11) = 9.4, p = .01$. When letters were attended, words were more negative in left posterior locations from 275 to 325 msec, $F(1,11) = 18.127, p < .001$, and more positive than nonwords in left frontal channels from 300 to 550 msec, $F(1,11) = 6.515, p < .05$. The N400 effect was significant from 350 to 425 msec, $F(1,11) = 7.28, p < .05$. Finally, words were more positive than nonwords from 350 to 450 msec in left medial locations, $F(1,11) = 9.36, p = .01$. Unattended words, on the other hand, were more negative than nonwords in left posterior channels from 275 to 325 msec, $F(1,11) = 5.18, p < .05$, and more positive in left frontal areas from 300 to 550 msec, $F(1,11) = 7.83, p < .05$. In addition, unattended words were more negative than nonwords in left posterior channels from 625 to 725 msec, $F(1,11) = 14.33, p < .005$.

Discussion

Experiment 2 replicates the previous experiment in showing that unattended words are differentiated from nonwords when attention is engaged in a demanding task in another dimension. Similar to Experiment 1, attention to different modalities modulated the ERPs at left and right anterior and posterior locations. When participants attended to letters, lexical category of stimuli produced effects at left posterior and frontal sites, as well as an N400 effect, together with modulations in left medial areas. Most crucially, unattended words once again modulated left posterior and frontal channels although parietal effects (N400 and left medial) were missing. Behavioral results replicated the original memory effect for attended words that was absent for ignored ones, although the size of this effect was small (7%). Presumably presenting a large set of words only once during the task decreases the likelihood of incidental learning.

GENERAL DISCUSSION

The current ERP findings show that the brain differentiates between lexical and nonlexical stimuli even in conditions in which attention is focused in a highly demanding task unrelated to language. This takes place when words are repeated several times as in Experiment 1 as well as when items are briefly presented only once, as is the case in Experiment 2.

Attention had a large effect in the ERP waveforms. Instructional main effects manifested as widespread and long-lasting modulations of the ERP signal in both posterior and anterior scalp locations. These effects accord well with the Rees et al. (1999) results and add to many others supporting the notion that attentional focus substantially modulates the brain regions recruited to perform a task, a phenomenon that has been demonstrated in several domains (e.g., Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1990). On the other hand, attention substantially modulated word processing in both experiments by changing some of the regions responding differentially to words and nonwords and the timing of their activations.

In both Experiments 1 and 2, attention to letters was associated with word–nonword differences in left posterior, frontal, and medial areas, as well as an N400 effect. Based on previous evidence (e.g., Abdullaev & Posner, 1998), left posterior effects could reflect activations of the posterior region of the reading network, potentially fusiform and middle temporal areas known to be selective for visual word forms (McCandliss, Cohen, & Dehaene, 2003). Frontal modulations may result from activity in left prefrontal areas known to tap syntactic and semantic codes of words (e.g., Luke, Liu, Wai, Wan, & Tan, 2002) and left medial effects may reflect activations near Wernicke's area (Abdullaev & Posner, 1998). When attention was focused on the drawings (and thus letters were ignored), some of the abovementioned ERP effects were missing, whereas some remained and others underwent a temporal shift. For instance, in both experiments the classical N400 effect appeared when letters were attended and was not present in inattention conditions, which is consistent with previous literature (i.e., McCarthy & Nobre, 1993) The sensitivity of the N400 to attentional manipulations has been previously documented (i.e., Holcomb, 1988; see Kutas & Van Petten, 1994, for a review) and several reports have shown N400 effects absent when attention is directed away (i.e., Bentin et al., 1995; McCarthy, & Nobre, 1993; although see Kiefer, 2002). In contrast, left posterior and left frontal effects persisted in the inattention conditions of both experiments, suggesting that brain regions generating these modulations, arguably left fusiform and frontal areas, still detect word–nonword differences when attention is focused away from letters.

Intriguingly, unattended word–nonword differences appear late in time in both experiments. Although the onset and time course of ERP effects differs between the two (most likely due to massive item repetition in Experiment 1), both experiments exhibit late unattended contrast effects (at 350 and 275 msec in Experiments 1 and 2, respectively). Although some relevant studies describe unattended unconscious processing early in time (e.g., Dehaene et al., 2001), this is not the case in the present experiments. However, the specially challenging characteristics of the present task (composed of a highly rapid succession of complex stimuli requiring attention focused in one modality and suppression of foveated stimuli in the other modality), which was not designed to investigate word processing per se, offer a plausible explanation for this temporal peculiarity. As previous reports have shown (McCann, Remington, & Van Selst, 2000), language-related features such as word frequency can be delayed in time in conditions in which processing is occupied by another task. In inattention conditions of the present task, participants were responding to drawings presented at a very fast rate and letters were completely irrelevant. This would put differential pressure on the cognitive system, giving priority to certain processes over others, causing word–nonword differential activations to be delayed in time—an effect similarly reported for processes sensitive to word frequency in the experiment of McCann et al. (2000), which were delayed by several hundred milliseconds when attention was occupied in a unrelated task.

As discussed, our central finding—word processing enduring attention withdrawal—is in conflict with the results of Rees et al. (1999), who demonstrated no such effect. Although several incidental disparities between the two studies cannot be ruled out as the source of departure, a likely explanation for the contradictory result is the differential sensitivity of fMRI and ERPs to certain kinds of brain activity. Indeed, some authors (e.g., Logothetis, 2003; Logothetis et al., 2001; Nunez & Silberstein, 2000) note differential sensitivity of various neuroimaging techniques to different types of brain activity, which could lead to contradictory results when using more than one methodology to study the same cognitive process. Furthermore, Nunez and Silberstein (2000) argue that there are some cases in which either technique could offer a positive result while the other one shows no brain activation. One of the factors driving these different measurement outcomes is related to the temporal sensitivity of the measured responses. ERPs can show stimulus-specific brain responses less than 100 msec after stimulus onset, whereas BOLD response usually needs 4 to 6 sec to reach its maximum levels. These temporal factors are especially important when dealing with block fMRI, in which brain activity is collapsed over blocks lasting several seconds (40 sec in the case of Rees et al., 1999).

The present study shows that HDERP data can provide positive evidence of transient processing of ignored or unattended words in a high attentional load task. Our results indicate that the brain processes to some extent stimuli associated with some forms of extensive visual expertise, such as words, automatically. Indeed, recent behavioral investigations have shown that certain kinds of biologically relevant stimuli, such as human faces, may be processed regardless of task demand (Jenkins et al., 2003; Lavie, Ro, & Russell, 2003; see also Mack, Pappas, Silverman, & Gay, 2001). Whether this form of automaticity is associated with general properties of stimuli for which humans have obtained advanced levels of perceptual expertise or is specific to a special class of stimuli with adaptive significance is a matter of debate (i.e., Gauthier & Nelson, 2001). In any case, both faces and words are extensively processed throughout life and elicit distinct patterns of activity in extrastriate regions.

Results from the present study show that word processing can take place under conditions in which attention is tied to a different dimension. However, the focus of attention on a different task modified the set of effects indexing word processing, as well as their temporal onset, raising the question of whether our results can be taken as a proof of automatic word processing. Since the early days of the automatic controlled dichotomy (Shiffrin & Schneider, 1977; Posner, 1975), several authors have noted the nonunitary nature of processes labeled as automatic (e.g., Bargh, 1992; Logan & Cowan, 1984), in the sense that most of them do not fulfill all criteria that have been suggested as indexes of this kind of processes such as being nonintentional, uncontrollable, unconscious, and impervious to attention. Even when it can be assumed that in the present experiments participants did not have the intention to process the letters when they were attending to drawings, and thus it is unlikely that they had any conscious control over it, attention had the marked effect on ERP effects and their latency. This suggest that the kind of automaticity that our results point to is one in which word processing is influenced by the allocation of attention but unintentionally persists in an unconscious manner even in conditions of high attentional demands in another dimension.

METHODS

Experiment 1

Subjects

Twelve paid subjects (5 men, mean age, 23) gave written consent to participate in the study. All were right-handed, reported normal or corrected-to-normal vision and had English as their first language.

Stimuli and Apparatus

Sixty five-letter words were selected from the Kucera and Francis (1967) database (60 mean frequency), 70 strings of five consonants were created, and 100 drawings were selected from the Snodgrass and Vanderwart (1980) set. Words were divided into four lists matched in mean frequency that were used as attended words, ignored words, and foils for the recognition memory test. The same stimuli (drawings, words, and nonwords) were presented 11.5 times, on average, across the repetition detection task. All material was counterbalanced across subjects and conditions.

Participants saw a rapid stream of sequentially presented stimuli which were presented for 250 msec every 500 msec (with a jitter of $\pm$100 msec between presentations), each consisting of red drawings and overlapping green uppercase letters of approximately 5° of visual angle (see Fig. 1). Between-modality uncorrelated stimulus repetition occurred in both drawings and letters once every six items, on average. Four pseudorandom stimulus orderings were generated to use in the four blocks of the experiment and were counterbalanced across subjects and attention conditions. Drawings were randomly rotated 30° clockwise or counterclockwise from trial to trial and they were always shown in a different orientation when an immediate repetition took place. Stimulus presentation was done using a PC running E-Prime v1.0 (PST, Pittsburgh, PA) with a screen refresh rate of 60 Hz.

EEG was continuously recorded during the repetition detection task with a 128-channel geodesic sensor net (Tucker, 1993) connected to an AC-coupled high-impedance amplifier (EGI, Eugene, OR). Individual electrode impedances were adjusted until they were below 50 mΩ. Amplified analog voltages (0.1–100 Hz band pass) were digitized at 250 Hz and recordings were initially referenced to Cz. To improve signal-to-noise ratio, EEG was low-pass filtered off-line from 30 Hz and then segmented 300 msec before stimulus onset and 800 msec afterward, according to the Attention condition (attended letters or ignored letters) and the syntactic category of the letter (words or nonwords). Segments containing artifacts were rejected off-line. Individual segments were averaged by condition to create ERPs and were then baseline corrected with reference to a −200- to 0-msec interval. An average-reference transformation was then applied to more accurately estimate the distribution of activity on the scalp (Bertrand, Perrin, & Pernier, 1985). Mean voltages were calculated for each group of channels and conditions showing potential effects and then introduced into ANOVAS comparing words versus nonwords in each Attention condition (attended letters and attended drawings). Bonferroni-corrected degrees of freedom were used in all those cases in which there were no a priori predictions regarding the site of ERP modulations.

Procedure

In four different blocks lasting 4 min 48 sec each, participants were instructed to attend either to the drawings or to the letters and to press a button every time a stimulus repeated in the attended dimension. Each block was composed of eight 36-sec interleaved task and rest periods. Half of the task periods contained only nonwords, whereas the other half had 60% words and 40% nonwords in the letter dimension. In all cases, the first eight trials always contained nonwords. Immediately after the repetition detection task, participants performed a surprise memory test. Sixty words (attended and unattended words together with 30 foils) were presented in the center of the computer screen after a 1000-msec fixation point and participants were asked to respond by a button press whether they thought they had seen that word during the repetition detection task or not. The response of the participant erased the word from the screen and initiated the next trial.

Experiment 2

The following sections describe differences between Experiment 1 and 2. All other methodological details were the same.

Subjects

Twelve participants (5 men; mean age, 21.9) gave written consent to participate in the study.

Stimuli and Apparatus

Four hundred words of from 4 to 5 letters were selected from the Kucera and Francis (1967) database (67.7 mean frequency) and 264 consonant strings (from 4 to 5 letters) were created. Four hundred drawings were used from the Snodgrass and Vanderwart (1980) database. Words were divided into four lists matched in mean frequency, which were counterbalanced across attention conditions and tasks.

Procedure

The repetition detection task was composed of 544 trials divided into eight blocks of 68 trials lasting 32 sec each. The first eight trials in every block were composed of nonwords. During the surprise memory task, 320 words were presented to the participants in the same way as in Experiment 1. Half of them were new and the other half had appeared in the previous task. From the old ones, half of them had been attended and the other half were ignored words. Only words not repeating in the previous phase were included in the memory test. Participants performed 16 blocks of 20 words each.

Acknowledgments

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Note

1. As pointed out by one of the reviewers, the short ISI (500 msec) used in this study, together with the fact that the words and nonwords proportion was different (60% vs. 40%) in Experiment 1, raises the question of whether late effects observed in the unattended condition are due to lexical interactions between pairs of word stimuli or to processing of the first stimulus per se. We performed an additional analysis eliminating word–word pairs from the average ERPs to answer this question. When the same ANOVAS as before were carried out in the unattended letters condition, all effects remained significant: left medial effect, $F(1,11) = 5.632$, $p < .05$; left frontal electrodes, $F(1,11) = 24.798$, $p < .001$; left posterior sites, $F(1,11) = 10.776$, $p < .01$; anterior medial electrodes, $F(1,11) = 21.698$, $p < .001$. Thus, these effects are due to genuine word processing rather than to lexical interactions between items.

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