Difficulty of Discrimination Modulates Attentional Capture by Regulating Attentional Focus

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Abstract

■ Attentional capture for distractors is enhanced by increasing the difficulty of discrimination between the standard and the target in the three-stimulus oddball paradigm. In this study, we investigated the cognitive mechanism of this modulation of attentional capture. Event-related brain potentials were recorded from participants while they performed a visual three-stimulus oddball paradigm (frequent standard, rare target, and rare distractor). The discrimination difficulty between standard and target was manipulated in the central location. Distractor stimuli were presented in the central or surrounding locations. The P3a component was elicited by distractor stimuli and was used as a measure of attentional capture. The results revealed that discrimination difficulty had opposite effects on the P3a response between central and surrounding locations. With an increase in the difficulty of discrimination, the P3a response was enhanced when distractor stimuli were presented in the central location. In contrast, the P3a response was reduced when distractor stimuli were presented in a surrounding location. This finding suggests that spatial attention was focused by the difficulty of discrimination, and deviant processing was increased within its focus but decreased outside its focus. Therefore, attentional capture for deviant distractors is modulated by top–down controlled attentional focus. ■

INTRODUCTION

In the external environment, we are faced with a vast amount of information. Our cognitive function, however, is limited with regard to its processing capacity, and thus, it is crucial to select the important information of a scene before further processing. Selective attention plays a critical role in such situations and it can be broadly considered to comprise "top–down" and "bottom–up" processes (Corbetta & Shulman, 2002; Kastner & Ungerleider, 2000; Yantis & Egeth, 1999; Egeth & Yantis, 1997; Desimone & Duncan, 1995; Theeuwes, 1991a). The top–down process controls attention to select information based on task goals (e.g., task-relevant location, color, and shape). Sensory processing, reaction time, and accuracy of target detection can be improved by the top–down mechanism (Giesbrecht, Woldorff, Song, & Mangun, 2003; Hopfinger, Buonocore, & Mangun, 2000; Mangun, 1995; Mangun & Hillyard, 1988, 1991; Eriksen & St. James, 1986; Posner, 1980). On the other hand, the bottom–up process controls attention to select information based on the properties of stimuli themselves (e.g., salience, novelty, and rarity) regardless of task goals. Thus, attention is preferentially allocated to deviant information which usually possesses stimulus salience (Theeuwes, 2004; Friedman, Cycowicz, & Gaeta, 2001).

Two Types of Attentional Capture

Attentional allocation for deviant information is well known as "attentional capture": attention is allocated to information which deviates in a spatial context (i.e., spatial attentional capture) or in a temporal context (i.e., temporal attentional capture) regardless of whether deviant information is relevant to ongoing activity. Because attentional capture of deviant information enables us to be aware of significant changes in our external environment, such processing is a fundamental cognitive function for successful adaptation to a changing environment (Sokolov, 1963).

Many studies on visual attention have long investigated spatial attentional capture by using the visual search paradigm. Spatial attention is captured by the presence of an irrelevant singleton distractor, such as a unique red stimulus among green stimuli (Theeuwes, 1991a). The most critical factor of attentional capture is stimulus salience, and visual search for the target is distracted when such salient stimuli are irrelevant to the demanded task (e.g., Theeuwes, 1991a, 1994). In the literature, there is a debate concerning the degree to which top–down attentional control modulates attentional capture. One view is that attentional capture is entirely determined by the physical properties of the

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stimuli: Deviant stimuli capture attention involuntarily regardless of any top–down attentional control (e.g., Hickey, McDonald, & Theeuwes, 2006; Theeuwes, 2004). The other view is that attentional capture is dynamically modulated by top–down attentional control, and several evidences in support of this view have been reported as discussed below.

First, attentional capture is dependent on the size of the attentional focus/window to search a target. When observers have knowledge about where a target is likely to appear, attention is sharply focused on that location. Consequently, a distractor could be ignored even though it has a high stimulus salience (Theeuwes, 1991b; Yantis & Jonides, 1990). Furthermore, when a target stimulus becomes less salient, participants engage in serial search with a small size of attentional focus, and the distraction effect is attenuated (Theeuwes, 1991b, 2004; Theeuwes & Burger, 1998). The size of attentional focus is controlled by top–down processes according to task demands, and a distractor captures attention only when parallel search with widely distributed attention is attempted to detect a target.

Second, attentional capture is determined by top–down attentional settings. The distractor captures attention only when a property of the eliciting stimulus (e.g., abrupt onset or color) matches with the top–down attentional setting of the participants (Folk & Remington, 1998, 1999; Folk, Remington, & Wright, 1994; Folk, Remington, & Johnston, 1992) or when participants adapt ''singleton search mode,'' in which attention is strategically set to respond to a deviation in general (Lamy & Egeth, 2003; Bacon & Egeth, 1994).

Finally, attentional capture is influenced by cognitive load. The load theory of attention (Lavie, 1995, 2005; Lavie, Hirst, de Fockert, & Viding, 2004; Lavie & Tsal, 1994) proposes that distractor processing depends on the type (perceptual or cognitive) and level (low or high) of load involved in task-relevant processing. According to this theory, perceptual load determines the processing of distractor stimuli at the early perception stage and relates to space-based distractor filtering. On the other hand, cognitive load determines the efficiency of selective attention by top–down attentional control and relates to the attentional capture modulation. When cognitive load rises with increasing task demand on working memory, task-relevance-based top–down attentional control becomes ineffective, and attentional capture of distractors is enhanced (Lavie & de Fockert, 2005).

For temporal attentional capture, there are two related research streams. One is a series of studies using a rapid serial visual presentation (e.g., Shih & Reeves, 2007; Dalton & Lavie, 2006; Maki & Mebane, 2006), in which distractor and target stimuli appear in a rapidly presented stimulus stream and the attentional capture for the distractor is measured by behavioral performance on the target stimuli following the distractor stimuli. It has been demonstrated that an irrelevant singleton distractor that occurs at the same spatial location as the target, but at a different temporal position, can produce attentional capture (Dalton & Lavie, 2006).

The other line of research is based on a series of studies, which will be discussed in detail after the next section, using a three-stimulus oddball paradigm (e.g., Sawaki & Katayama, 2007; Katayama & Polich, 1998) and investigating the neural response in such a situation by recording event-related brain potentials (ERP). The three-stimulus oddball paradigm is based on the random occurrence of rare target and rare distractor stimuli that are embedded in a train of frequent standard stimuli. In the visual modality, each stimulus is discretely presented at the center of a display, and the participant has to respond to the target by pressing a button or by silent counting. Although these two research streams utilize a different paradigm and measure of attentional capture, both have confirmed that a spatial attentional shift is not necessary for producing attentional capture. In contrast to spatial attentional capture, there are few studies, which have investigated cognitive mechanisms of temporal attentional capture, in particular the involvement of bottom–up and top–down attentional control. The present study focused on attentional capture in the three-stimulus oddball paradigm.

Temporal Attentional Capture in the Three-stimulus Oddball Paradigm

In the three-stimulus oddball paradigm, target stimuli elicit a ''P3'' or ''P300,'' which is a large positive-going ERP that has a maximum amplitude over central/parietal or parietal electrode sites with a peak latency of about 300–600 msec, depending on the stimulus modality and task difficulty (Kok, 2001; Verleger, 1997; Picton, 1992; Sutton, Braren, Zubin, & John, 1965). This type of P3 is usually called ''P3b'' or ''target P3'' and is thought to reflect the neural response regarding a context updating process triggered by task-relevant information (Donchin & Coles, 1988; Donchin, 1981). The P3b response is reduced and delayed when target stimuli are similar to standard stimuli or when they have a high stimulus probability (Polich, 1986; Courchesne, Hillyard, & Courchesne, 1977; Duncan-Johnson & Donchin, 1977). Under certain conditions, distractor stimuli also elicit P3, but with a more anterior distribution than the target P3b (Sawaki & Katayama, 2006a; Simons, Graham, Miles, & Chen, 2001; Katayama & Polich, 1996a, 1996b, 1999; Spencer, Dien, & Donchin, 1999; Knight, 1984; Pfefferbaum, Ford, Roth, & Kopell, 1980; Courchesne, Hillyard, & Galambos, 1975). This type of P3 is usually called ''P3a'' or ''distractor P3'' to distinguish it from the target P3b. Although the observed P3 waveform results from the spatial and temporal overlapping of several latent components (Debener, Makeig, Delorme, & Engel, 2005; Dien, Spencer, & Donchin, 2004; Goldstein, Spencer, & Donchin, 2002; Spencer, Dien, & Donchin, 2001;

Spencer et al., 1999), the present study will use the labels of P3a and P3b as the observed P3 waveform for distractor and target, respectively.

Previous studies using the three-stimulus oddball paradigm have reported that novel distractor stimuli (e.g., a nonrepeated and unrecognizable colorful slide) produce a large P3a response because they have high physical salience. In contrast, when distractors were simple and nonnovel stimuli (e.g., repeated and recognizable simple figures), they usually produce a small P3a response compared to novel distractors (Sawaki & Katayama, 2006a; Debener et al., 2005; Goldstein et al., 2002; Spencer et al., 2001; Daffner et al., 2000; Grillon, Courchesne, Ameli, Elmasian, & Braff, 1990; Courchesne et al., 1975). However, recent research has demonstrated that simple distractor stimuli can also be made to produce a large P3a response by manipulation of the stimulus context (Sawaki & Katayama, 2006b, 2007; Combs & Polich, 2006; Hagen, Gatherwright, Lopez, & Polich, 2006; Goldstein et al., 2002; Demiralp, Ademoglu, Comerchero, & Polich, 2001; Comerchero & Polich, 1998, 1999; Katayama & Polich, 1998). With an increase in the difficulty of discriminating between standard and target stimuli, simple distractor stimuli elicit a large P3a (Katayama & Polich, 1998), and its amplitude and scalp distribution are highly similar to those elicited by novel distractor stimuli (Polich & Comerchero, 2003).

Several possible accounts regarding the functional significance of P3a have been proposed, such as the inhibition account or novelty account (e.g., Dien et al., 2004; Goldstein et al., 2002). However, as far as the P3a enhancement by discrimination difficulty is concerned, Sawaki and Katayama (2007) clarified that the P3a response is associated with attentional capture. The attentional capture account for P3a[1] is supported by the finding that a large P3a is elicited by distractors with an abrupt onset, one of the best known stimulus attributes inducing attentional capture (Sawaki & Katayama, 2008). Furthermore, Daffner et al. (1998, 2000) reported that the magnitude of P3a is related to the subsequent viewing time allocated to deviant stimuli. In the three-stimulus oddball paradigm, distractor stimuli appear in the sequence of standard stimuli with a low probability. As a result, distractor stimuli deviate in the temporal context. Under this antecedent condition, temporal attentional capture occurs for distractor stimuli and attention is allocated to them even though they are not a target for the demanded task. This neural response is reflected by the P3a (Sawaki & Katayama, 2007; Polich & Criado, 2006; Rushby, Barry, & Doherty, 2005; Friedman et al., 2001; Escera, Alho, Winkler, & Näätänen, 1998; Knight, 1997; Squires, Squires, & Hillyard, 1975), which has been reported in the visual (Courchesne et al., 1975), auditory (Squires et al., 1975), and somatosensory modality (Yamaguchi & Knight, 1991). The degree of attentional allocation increases when attentional capture is enhanced, which is reflected by an enlarged P3a response. The association between the magnitude of P3a and the subsequent viewing time allocated to deviant stimuli suggests that, as a consequence of attentional capture, deviant information is provided further evaluation as a potentially important signal (Daffner et al., 1998, 2000).

The effect of discrimination difficulty on P3a response reflects that the degree of attentional capture for distractor stimuli is dynamically modulated by the difficulty of discriminating between standard and target stimuli. This modulation of attentional capture was found in the auditory modality (Katayama & Polich, 1998), and several studies have confirmed it in the visual modality (Sawaki & Katayama, 2006b, 2007; Comerchero & Polich, 1998, 1999).

Cognitive Mechanisms of Temporal Attentional Capture Modulation

Recent studies have examined the cognitive mechanism of this modulation of attentional capture in the visual modality. It has been demonstrated that the processing of simple distractors qualitatively differs with changes in the difficulty of discrimination between standard and target stimuli (Sawaki & Katayama, 2006b). A more difficult discrimination task enhances attention toward a particular set of stimuli (i.e., standard and target). Increasing the contextual deviation of the irrelevant stimuli (i.e., simple distractors) even though there is no increase in physical novelty (Sawaki & Katayama, 2007). However, although previous studies have reported that simple distractor stimuli have high contextual deviance, and thus, attentional capture is enhanced in the difficult discrimination task, the essential mechanism of the modulation of attentional capture is not yet entirely clear. In particular, it has not yet been confirmed how a top–down mechanism is involved in this modulation, even though the modulation of attentional capture may be affected by some top–down influences, because bottom–up factors, such as the physical characteristics of distractor stimuli and the degree of the physical difference between distractor and standard stimuli, are the same in the easy and difficult tasks.

Many studies of visual attention have demonstrated that top–down attentional control regulates the focus of spatial attention according to task demands, such as in the ''spotlight,'' ''zoom lens,'' or ''gradient'' models of visual attention (e.g., Müller, Bartelt, Donner, Villringer, & Brandt, 2003; Eriksen & St. James, 1986; Shulman, Wilson, & Sheehy, 1985; Posner, 1980; Eriksen & Hoffman, 1972). A distributed spatial attention is tightly focused on a selected location to improve stimulus processing, and the processing of stimuli falling within this focus is significantly facilitated, whereas processing is impaired for stimuli that fall outside this focus. Thus, attentional focus confers a processing benefit inside the focus and a processing cost outside the focus relative to when attention is widely distributed.

One of the determinants of attentional focus is perceptual load (Lavie, 1995; Lavie & Tsal, 1994). When the perceptual load of task-relevant information is low, only a portion of the attentional resources is necessary for task-relevant information processing. Under these situations, spatial attention is distributed and residual attentional resources are involuntarily allocated to perception of the task-irrelevant distractors in the surrounding location. In contrast, when the perceptual load of task-relevant information is high, spatial attention is narrowly focused on location of task-relevant information and there are no residual resources, and thus, surrounding task-irrelevant distractors are not allocated attentional resources and their perceptual processing is restricted. In the three-stimulus oddball paradigm, increasing the difficulty of perceptual discrimination between the standard and target stimuli would increase the perceptual load. Therefore, it is plausible that spatial attention is focused on the location of a standard/target stimulus sequence in the difficult task. Such focused spatial attention may increase deviant processing within its small focus and facilitate deviant evaluation, which may enhance attentional capture within the focus. However, the involvement of attentional focus could not be directly confirmed because in the typical three-stimulus oddball paradigm all stimuli appear in the same central location. To clarify this issue, we will examine whether there is a difference in the P3a response for a distractor according to whether it is presented at the location of the standard/target stimulus sequence (i.e., central) or outside this location (i.e., surrounding).

In addition to this prediction of attentional focus involvement, we could make a possible alternative prediction: Attentional capture is enhanced by the same manner as proposed for the spatial attentional capture enhancement. As we noted earlier, it has been argued that the spatial attentional capture is enhanced when attention is strategically set to react to deviation in general (Bacon & Egeth, 1994; Folk et al., 1992). In the three-stimulus oddball paradigm, not only the distractors but also the targets are deviated from the standard stimulus sequence. The degree of deviation of the target is smaller in the difficult task than in the easy task, therefore, participants may need to exert more effort to detect the target deviation. If the attentional capture modulation is provided by a top–down attentional setting toward deviation, this may enhance attentional capture in both central and surrounding locations because participants would increase their sensitivity to deviation in general. In addition, it has been reported that high cognitive load prevents top–down attentional control from selecting task-relevant information, and thus, spatial attentional capture by irrelevant distractors is enhanced (Lavie & de Fockert, 2005). In the difficult task of the three-stimulus oddball paradigm, target stimuli are highly similar to standard stimuli. As a result, the accurate representation of target stimuli may be continuously activated in working memory. Such a demand on working memory would induce increased cognitive load. If attentional capture modulation is determined by the degree of cognitive load, the high cognitive load may enhance attentional capture for distractors in both central and surrounding locations because cognitive load would affect stimulus processing, irrespective of stimulus location.

Present Study

In the present study, ERPs were recorded from participants while they performed a visual three-stimulus oddball paradigm (frequent standard, rare target, and rare distractor). The critical experimental manipulation in the present study was that target and standard stimuli were discriminated (easy or difficult) at the *central* location and distractor stimuli were presented at the *central* or *surrounding* location. In all task conditions, the standard stimulus was a combination of a central circle and surrounding triangles. For the target stimulus, the central circle was replaced by a considerably smaller circle in the easy task and a slightly smaller circle in the difficult task. Because the surrounding triangles were identical for the standard and the target, the target could be discriminated from standards based on the physical size of the circle in the central location. For the distractor stimulus, the central circle was replaced by a square in the *central* conditions and the surrounding triangles were replaced by squares in the *surrounding* conditions. Therefore, the distractor was presented in the central location for the central conditions but in the surrounding location for the surrounding conditions. The stimulus type of distractor stimuli (central or surrounding) and the difficulty of perceptual discrimination between central standard and target circles (easy or difficult) were manipulated orthogonally. If top–down attentional control regulates the focus of spatial attention and the attentional capture of distractors is modulated corresponding to top–down attentional focus, the P3a response for distractor stimuli will be enhanced in the central location but reduced in the surrounding location with an increase in the difficulty of discriminating between standard and target stimuli. In contrast, if attentional capture is modulated by the same mechanisms as spatial attentional capture (i.e., a top–down attentional setting to deviation or cognitive load), the P3a response for distractor stimuli will be enhanced with an increase in the discrimination difficulty, regardless of distractor location.

METHODS

Participants

Twelve young adults (7 men, 5 women) with normal or corrected-to-normal visual acuity and normal color vision served as participants (M = 23 years, SD = 1.9 years, age range = 21–26 years). All participants reported being free of neurological or psychiatric disorders and provided written, informed consent.

Stimuli and Procedure

Participants performed 360 trials for each condition (see below), consisting of standard, target, and distractor trials with probabilities of .70, .15, and .15, respectively. At a viewing distance of 1 m, stimuli were presented in a random series, once every 1.2 sec with a 120-msec duration on a gray background. Four task conditions were defined by a combination of stimulus location of distractor stimuli (central or surrounding) and discrimination difficulty between standard and target stimuli (easy or difficult). The stimuli in each task condition are summarized in Figure 1. The standard stimulus was a combination of one central black circle (1.32° wide × 1.32° tall) and four surrounding blue triangles (1.32° × 1.15°) in all task conditions. For the target stimulus, the central black circle was replaced by a much smaller (0.57° × 0.57, easy task) or a slightly smaller (1.12° × 1.12°, difficult task) black circle, surrounded by the same triangles as in the standard stimulus. For the distractor stimulus of central condition, the central black circle was replaced by a central red square (1.72° × 1.72°), whereas the surrounding blue triangles were the same to the standard. Therefore, P3a response would be induced by the central stimulus because the central stimulus deviated from standard stimulus sequence, whereas the surrounding stimuli did not have a change in the sequence. In contrast, for the distractor stimulus of surrounding condition, the central black circle was the same as the standard, whereas the surrounding blue triangles were replaced by surrounding red squares (1.42° × 1.42°). Therefore, P3a response would be induced by the surrounding stimuli in the surrounding condition. The surrounding stimuli (both the triangle and square) were placed with their center 2.12° to the left and right of the vertical meridian, and 2.12° above and below the horizontal meridian.

The participants were asked to respond to the target stimuli by pushing a button with the right thumb as quickly as possible. A practice series was presented before each task condition. The order of the four task conditions was randomized across participants.

Recording and Analysis

Electroencephalographic (EEG) activity was recorded with an electrode cap using Ag/AgCl electrodes from 30 electrode sites at Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, and O2, according to the modified 10–20 system. Voltage changes caused by eye movements and blinks were monitored with EEG recordings from forehead sites (Fp1 and Fp2). A common reference electrode was placed at the nose tip, and impedance was kept at 10 kΩ or less. The EEG signals were amplified with a bandpass of 0.05–100 Hz and were digitized at 500 Hz.

The EEG was digitally low-pass filtered off-line at 30 Hz (6 dB/octave) with a finite impulse response (FIR) analog simulation filter. Averaging epochs were 900 msec, beginning 100 msec before stimulus onset. Waveforms were averaged, such that trials with a response error or those in which the EEG exceeded ±100 μV were rejected automatically. P3 was defined as the largest positive-going peak that occurred within the time window between 300 and 700 msec after stimulus presentation. To estimate the reliable peak amplitude and peak

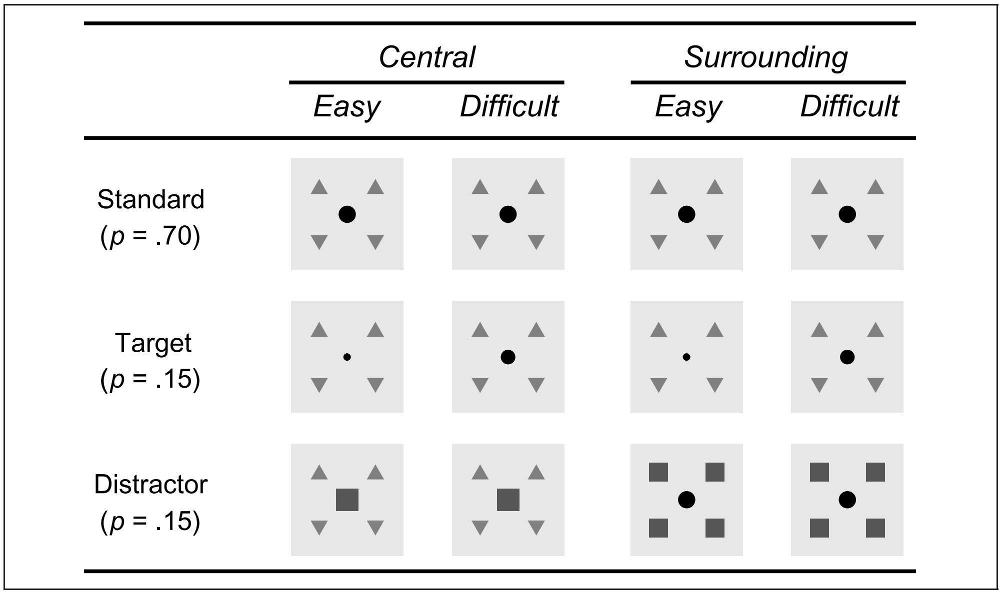

Figure 1. Stimulus characteristics (probability and shape) for each task condition. Presented circles were black, triangles were blue, and squares were red.

latency, averaged waveforms were digitally low-pass filtered at 8 Hz (24 dB/octave) with an FIR zero-phase filter. Peak latencies were measured from the time of stimulus onset at Pz for target P3b and Cz for distractor P3a. Peak amplitudes were measured relative to the prestimulus baseline at the Pz (target) and Cz (distractor) peak latency points. To reduce the number of statistical comparisons, the data from three midline electrodes (Fz, Cz, Pz) were analyzed statistically. All analyses of variance (ANOVAs) used Greenhouse–Geisser corrections to the degrees of freedom, and only the corrected probability values are reported.

RESULTS

Behavioral Results

The behavioral data are summarized in Table 1. A two-factor (2 Condition types × 2 Discrimination difficulties) analysis of the reaction time found that the reaction time in the easy task was shorter than that in the difficult task [$F(1, 11) = 52.0, p < .001$]. The same analysis found that the hit rate was higher in the easy task than in the difficult task [$F(1, 11) = 27.2, p < .001$]. These results indicate that RT and hit rate differed with changes in the difficulty of discrimination between standard/target stimuli. A three-factor (2 Condition types × 2 Discrimination difficulties × 2 Stimulus types) ANOVA of the false-positive rate in response to the standard and distractor revealed no significant effects.

ERP Results

Figure 2 shows the grand averaged ERPs from the three midline electrodes at frontal (Fz), central (Cz), and parietal (Pz) sites for each stimulus type. Figure 3 shows topographic maps taken at the latency of the peak P3 amplitude for the target and distractor stimuli in each task condition.

P3 Amplitude

The P3 amplitude data from the midline electrodes (Figure 4) were assessed with a four-factor (2 Condition types × 2 Discrimination difficulties × 2 Rare stimulus types × 3 Electrodes) ANOVA. Main effects of condition type, discrimination difficulty, and electrode were obtained. Significant Condition type × Discrimination difficulty, Condition type × Rare stimulus type, Discrimination difficulty × Rare stimulus type, Rare stimulus type × Electrode, and Condition type × Discrimination difficulty × Rare stimulus type interactions were also obtained. Table 2 summarizes the results of this analysis.

Post hoc comparisons revealed that the target and distractor P3s had a distinct scalp topography. The P3 amplitude was larger for target than for distractor at Pz electrode sites ($p < .003$), whereas there was no significant difference at the Fz and Cz electrode sites. These results showed that P3 for target had a parietal distribution, whereas P3 for distractor had a more anterior distribution compared to that of P3 for target. Therefore, it was confirmed that the P3 elicited by target was P3b, and that elicited by distractor was P3a.

Target P3b and distractor P3a showed different patterns for the effect of discrimination difficulty. For targets in both conditions, the P3b amplitude was larger in the easy task than in the difficult task (central condition: $p < .02$; surrounding condition: $p < .001$). In contrast, for distractor in central conditions, the P3a amplitude was larger in the difficult task than in the easy task ($p < .004$), whereas for distractor in surrounding conditions, the P3a amplitude was smaller in the difficult task than in the easy task ($p < .02$). Therefore, for distractor stimuli, the difficulty of discrimination had a contrasting effect on the distractor P3a amplitude between central and surrounding conditions (Figure 4).

In addition, we also found that the distractor P3a in the difficult task only had an effect of condition type. For targets in both conditions, there was no significant

Table 1. Mean (*SD*) Reaction Times, Performance Rates, and P3 Peak Latencies for Target (Pz) and Distractor (Cz) Stimuli for Each Task Condition

	Central		*Surrounding*	
	Easy	*Difficult*	*Easy*	*Difficult*
Reaction time (msec)	390 (43)	495 (72)	388 (61)	490 (99)
Hit targets (%)	100 (0.0)	83.1 (12.5)	99.8 (0.5)	86.7 (8.4)
False-positive rate (%)				
Standard	0.1 (0.2)	0.3 (0.5)	0.1 (0.2)	0.0 (0.1)
Distractor	0.2 (0.5)	0.2 (0.6)	0.0 (0.0)	0.2 (0.5)
P3 peak latency (msec)				
Target	397 (17)	477 (90)	402 (34)	498 (75)
Distractor	363 (22)	364 (17)	369 (19)	388 (43)

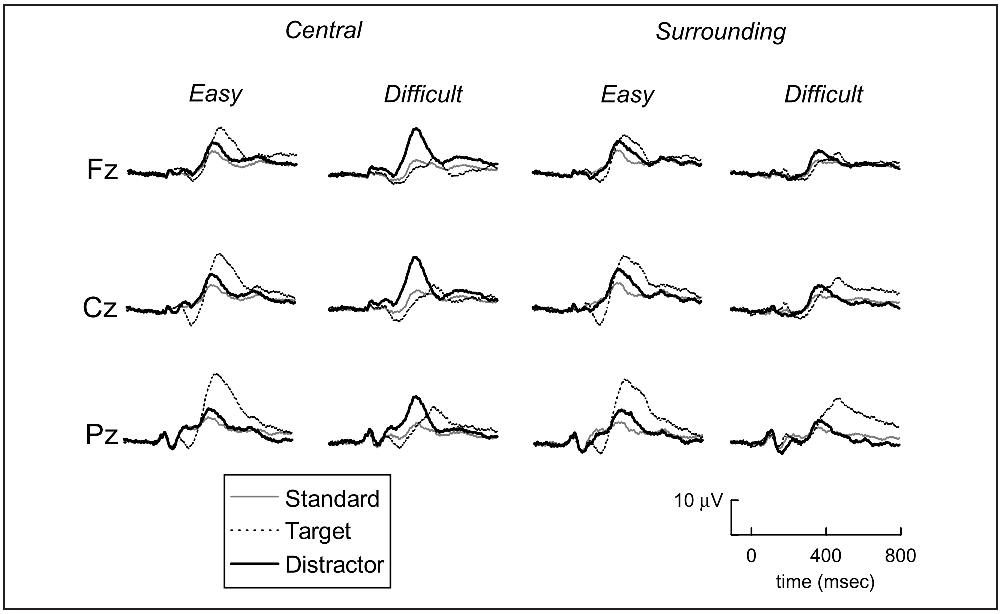

Figure 2. Grand-averaged ERPs for each condition from three midline electrodes at frontal (Fz), central (Cz), and parietal (Pz) sites (n = 12). For the central task, the distractor P3a was enhanced in the difficult task. In contrast, for the surrounding task, the distractor P3a was reduced in the difficult task. The target P3b was reduced in the difficult task of both conditions.

difference in P3b amplitude between central and surrounding conditions. In contrast, for distractors, the P3a amplitude in the difficult task was larger for the central condition than for the surrounding condition ($p < .001$), whereas there was no such difference for P3a amplitude in the easy task. These results also support the notion that an increase in the difficulty of discrimination had a contrasting effect on the distractor P3a amplitude between central and surrounding conditions (Figure 4).

P3 Latency

P3 latencies from the target and distractor in each task condition are summarized in Table 1. A three-factor (2 Condition types × 2 Discrimination difficulties × 2 Rare stimulus types) ANOVA of the latency found significant main effects of discrimination difficulty [$F(1, 11) = 19.4$, $p < .001$] and rare stimulus type [$F(1, 11) = 34.0$, $p < .001$]. There was also a significant two-way interaction between discrimination difficulty and rare stimulus type [$F(1, 11) = 12.3$, $p < .005$]. Post hoc comparisons revealed that the target P3b latencies were longer in the difficult tasks than in the easy tasks ($p < .002$), whereas there was no such difference for distractor P3a latencies.

In addition, the target P3b latencies were longer than distractor P3a latencies in the easy conditions (target: 399 msec vs. distractor: 366 msec, $p < .001$), and this

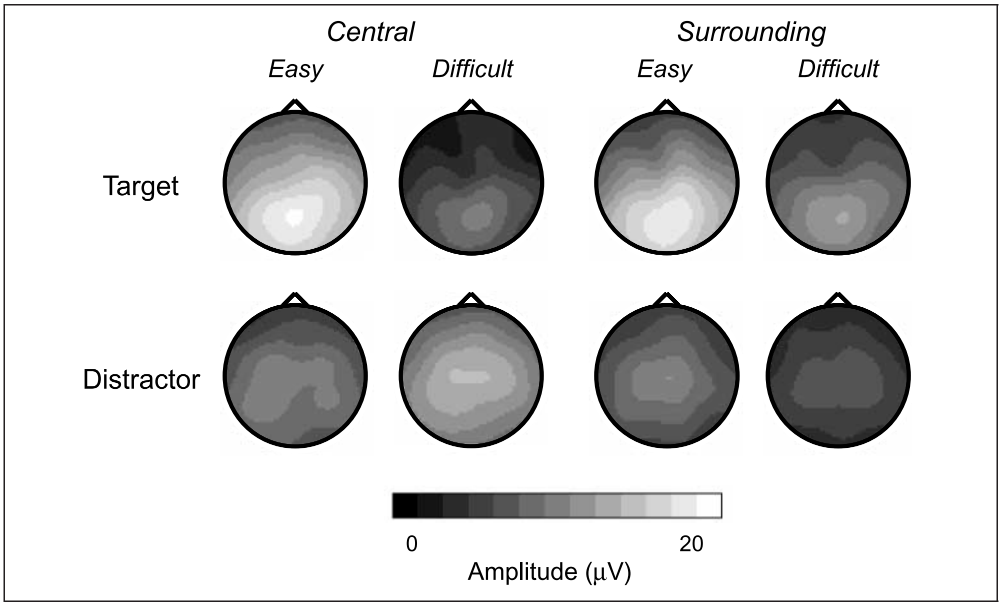

Figure 3. Topographic maps taken at the P3 peak latency from the target and the distractor in each task condition.

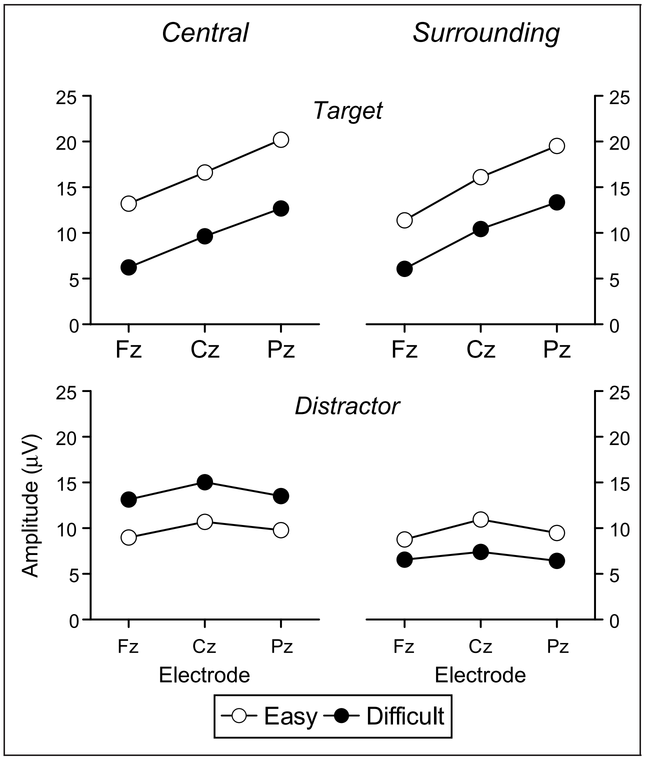

Figure 4. Mean P3 peak amplitude from the target and the distractor in each task condition at the midline electrode site.

difference was greater in the difficult task (target: 487 msec vs. distractor: 376 msec, $p < .001$).

DISCUSSION

The primary objective of this study was to investigate the effect of distractor location on the P3a response in the three-stimulus oddball paradigm in order to elucidate the cognitive mechanism of attentional capture modulation. Previous studies have reported that attentional capture for distractor stimuli is enhanced by increasing difficulty of discrimination between standard and target stimuli in the three-stimulus oddball paradigm, which was reflected by an increase in the P3a response (Sawaki & Katayama, 2006b, 2007; Combs & Polich, 2006; Hagen et al., 2006; Demiralp et al., 2001; Comerchero & Polich, 1998, 1999; Katayama & Polich, 1998). However, it had not yet been resolved how top–down processes are associated with this attentional capture modulation. In the central condition of the current study, the distractor was presented in the central location as with previous studies, whereas in the surrounding condition, it was presented in a surrounding location. If attentional capture is modulated by top–down controlled attentional focus, the P3a response would be enhanced for distractor stimuli in the central location but reduced in the surrounding location when there is an increase in the difficulty of discriminating between standard and target stimuli. In contrast, if attentional capture is modulated by a top–down attentional setting to deviation or by cognitive load, the P3a response would be enhanced with an increase in the discrimination difficulty, regardless of distractor location.

In all task conditions, distractors elicited a P3a response with a central distribution, and targets elicited a P3b response with a parietal distribution. When it was difficult to discriminate target stimuli from standard stimuli, the reaction time for the target increased, the hit rate for the target decreased, and the P3b elicited by the target had a smaller amplitude and longer latency than when target discrimination was easy. These outcomes are highly consistent with many reports using the oddball paradigm where the difficulty of discrimination was manipulated (e.g., Combs & Polich, 2006; Katayama & Polich, 1998; Verleger, 1997; Polich, 1986). Taken together, behavioral and electrophysiological results confirmed that the difficulty of discrimination could be successfully manipulated by varying the physical size of a target central circle (Sawaki & Katayama, 2007).

P3a and Location Effect

For the central conditions, P3a varied with changes in the difficulty of discrimination between standard and target stimuli; its amplitude was significantly larger in the difficult task than in the easy task. These results were

Table 2. Summary of the Four-factor ANOVA (2 Condition types [C] × 2 Discrimination difficulties [D] × 2 Rare stimulus types [R] × 3 electrodes [E]) Performed on the P3 Peak Amplitude

Source (df)	*F*	*p*	*ε*
Condition type [C] (1, 11)	6.9	.03	–
Discrimination difficulty [D] (1, 11)	8.3	.02	–
Rare stimulus type [R] (1, 11)	–	–	–
Electrode [E] (2, 22)	18.2	.001	.71
C × D (1, 11)	6.8	.03	–
C × R (1, 11)	5.5	.04	–
C × E (2, 22)	–	–	–
D × R (1, 11)	12.3	.005	–
D × E (2, 22)	–	–	–
R × E (2, 22)	25.1	.001	.72
C × D × R (1, 11)	25.2	.001	–
C × D × E (2, 22)	–	–	–
C × R × E (2, 22)	–	–	–
D × R × E (2, 22)	–	–	–
C × D × R × E (2, 22)	–	–	–

consistent with previous studies, which reported that the P3a response for distractors is enlarged with an increasing difficulty of discrimination between standard and target (Sawaki & Katayama, 2006b, 2007; Combs & Polich, 2006; Hagen et al., 2006; Polich, 2003; Polich & Comerchero, 2003; Demiralp et al., 2001; Comerchero & Polich, 1998, 1999; Katayama & Polich, 1998). Therefore, it was confirmed that the modulation of attentional capture could be successfully replicated in the central conditions.

For the surrounding conditions, although P3a varied with changes in the difficulty of discrimination between standard and target stimuli, the pattern of variation of the P3a response was different from that for central conditions. In contrast to central conditions, the P3a amplitude for distractors was significantly smaller in the difficult task than in the easy task. Thus, the present study found that the P3a response was enhanced in the difficult task of the central condition, whereas it was reduced in the difficult task of the surrounding condition (Figure 4). These findings suggest that attentional capture for distractors was enhanced in the central location but was reduced in the surrounding location with an increase in the difficulty of discrimination between central standard and target stimuli.

For both the central and surrounding conditions, the distractor stimuli were the same for the easy and difficult tasks, and thus, the bottom–up signal of the distractor in the difficult task was the same as the easy task. Therefore, the modulation of attentional capture must have been induced by top–down processes. The present study found that discrimination difficulty has opposite effects on the P3a response between central and surrounding locations, which does not support possible accounts that the attentional capture is enhanced by a top–down attentional setting toward deviation or by the high degree of cognitive load. On the contrary, it is highly consistent with the attentional focus account. That is, in the difficult task, spatial attention is sharply focused on the central location due to high perceptual load, which increases deviant processing within this focus and facilitates deviant evaluation. Consequently, the stimulus deviance of distractor stimuli within this focus is increased, and thus, the attentional capture for distractors is enhanced at the central location. In contrast, because such focused spatial attention decreases deviant processing outside this focus, attentional capture for distractors is reduced in the surrounding location.

The possibilities of other interpretations should be further discussed. First, there could be a difference in the general task difficulty between central and surrounding conditions. If the degree of task difficulty is different between conditions, current data may be explained by the difference in the general task difficulty. However, there was no significant difference in either behavioral performance or target P3b responses between central and surrounding conditions. Therefore, this possibility can be ruled out. Second, there could be a general difference in attentional function between foveal and parafoveal location. Handy and Khoe (2005) reported that the effect of spatial attention in early visuocortical processing, which is often reported in the parafoveal location, is not observed in the foveal location. However, they also demonstrated that there are no such influences on higher-order processes as reflected by the P3 response. In addition, the present study focused on the pattern of difficulty effect on the P3a response in the central and surrounding conditions, rather than on a direct comparison between the central and surrounding conditions. Therefore, the current data could not be explained by the general difference in the attentional functions of foveal and parafoveal location. Third is the influence of eye blinks. Small eye blinks, which may not be rejected by automatic noise detection, could distort the ERP results. However, the activity of eye blinks is mainly reflected on the frontal electrode sites (i.e., Fpz, Fp1, Fp2, or Fz), whereas P3a was dominantly distributed on the central electrode site (i.e., Cz) in the present study (Figures 3 and 4). This fact rules out the possibility that the current ERP results are associated with eye blink activities rather than attentional capture processing. In sum, the different patterns of difficulty effect in the P3a response between central and surrounding conditions appear to be related to whether distractors fall in or outside the attentional focus.

Attentional Capture Modulation and Perceptual Load Theory

The current finding, that discrimination difficulty modulates attentional capture by regulating attentional focus, is associated with and is further supported by the perceptual load theory (Lavie, 1995, 2005; Lavie et al., 2004; Lavie & Tsal, 1994). The perceptual load theory proposes that the perception of task-irrelevant information is dynamically modified by the level of perceptual load of task-relevant information processing. This theory has been supported by electrophysiological studies that examined the effect of perceptual load on early visuocortical processing as measured by early visual ERP components such as P1 and N1 (Handy, Soltani, & Mangun, 2001; Handy & Mangun, 2000). These studies reported that the magnitude of neural response in the extrastriate visual cortex is modulated correspondingly with the perceptual load of task-relevant processing. In accordance with these perceptual load studies, the following explanation can be given for the current data: The difficult task of the three-stimulus oddball paradigm has a high perceptual load of task-relevant information, and thus, spatial attention is focused on the central location, which induces an increase in perception of distractor stimuli in the central location but a decrease in the surrounding location, as compared with the low perceptual load situation (i.e., easy task). This difference in the degree of perception of distractor stimuli influences the attentional capture for distractors such that attentional capture is enhanced in the central location, whereas it is reduced in the surrounding location.

Importantly, in most previous studies regarding perceptual load theory, the degree of stimulus deviance of distractors was relatively low because they were presented in each trial and their stimulus attributes were similar to those for task-relevant stimuli. The present study revealed that perceptual load affects distractor processing even when the distractor has a stimulus deviance. The modulation of stimulus perception by perceptual load influences the attentional capture process.

Temporal and Spatial Attentional Capture

When stimuli are deviated in a temporal context, they often produce temporal attentional capture. In the typical three-stimulus oddball paradigm, each stimulus is sequentially presented in the same central location, and the distractor is deviated in the standard stimulus sequence and produces the temporal attentional capture. The present study demonstrated that top–down spatial attention involves the modulation of temporal attentional capture such that temporal attentional capture for distractors is modulated corresponding to the top–down controlled attentional focus. This finding indicates that the temporal and spatial factors are closely interrelated in regard to attentional capture modulation, which could significantly contribute to a better understanding of the cognitive mechanisms involved in deviant processing.

In addition, the present study revealed several similarities and differences between temporal and spatial attentional capture. In the visual search paradigm, it has been proposed that the spatial attentional capture is decreased by increased attentional focus (Theeuwes, 1991b, 2004; Theeuwes & Burger, 1998; Yantis & Jonides, 1990) and it is increased by a top–down attentional setting toward deviation (Lamy & Egeth, 2003; Folk & Remington, 1998, 1999; Bacon & Egeth, 1994; Folk et al., 1992, 1994) or a high degree of cognitive load (Lavie & de Fockert, 2005). The present study clarified that the temporal attentional capture is modulated by top–down controlled attentional focus. Therefore, it becomes clear that both types of attentional capture could be modulated by attentional focus under top–down attentional control. Furthermore, there is an interesting difference between spatial and temporal attentional capture modulation: When the degree of attentional focus is increased, spatial attentional capture is decreased, whereas temporal attentional capture is enhanced. This difference can be understood based on the relationship between positions of the distractor stimulus and the top–down attentional focus. In the spatial attentional capture situations, several stimuli including distractors are simultaneously presented on the display and their locations are varied in each trial, and thus, distractors often fall outside the small attentional focus. In contrast, in the typical situation for temporal attentional capture, each standard, target, and distractor stimulus is discretely presented at the same location (i.e., the center of a display). Therefore, distractors inevitably fall inside the small attentional focus and induce strong attentional capture.

Deviant processing underlies a broad range of human behavior, and several disorders may be associated with a dysfunction in such processing. For instance, children and adults with Attention Deficit Hyperactivity Disorder often show high distractibility and atypical neural responses in deviant processing (e.g., Sawaki & Katayama, 2006a; Gumenyuk et al., 2005; Nigg & Casey, 2005). Therefore, the investigation of deviant processing is important for understanding function and dysfunction in human cognition.

Conclusion

In summary, the present study found that attentional capture for distractors was altered as a function of the difficulty of discriminating between standard and target stimuli, and the difficulty of discrimination had different effects in the brain according to the location of distractor presentation. This finding suggests that the stimulus context, which is defined by the relationship between target and standard stimuli, plays an important role in determining top–down controlled attentional focus, and this focus correspondingly modulates deviant processing. Therefore, it is reasonable to conclude that the modulation of attentional capture for distractors results from top–down controlled attentional focus, which facilitates the processing of stimuli within the attentional focus.

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Note

1. Another component related to attentional capture is N2pc (Luck & Hillyard, 1994a, 1994b). This component reflects the shifting of spatial attention onto the object location that requires the suppression of the surrounding information, and it has been investigated under the spatial search situations. N2pc and P3a reflect different aspects of attentional capture. Specifically, N2pc is related to a spatial attentional shift, whereas P3a is related to an attentional allocation.

REFERENCES

Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics, 55,* 485–496.

Combs, L. A., & Polich, J. (2006). P3a from auditory white noise stimuli. *Clinical Neurophysiology, 117,* 1106–1112.

Comerchero, M. D., & Polich, J. (1998). P3a, perceptual distinctiveness, and stimulus modality. *Cognitive Brain Research, 7,* 41–48.

Comerchero, M. D., & Polich, J. (1999). P3a and P3b from typical auditory and visual stimuli. *Clinical Neurophysiology, 110,* 24–30.

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience, 3,* 201–215.

Courchesne, E., Hillyard, S. A., & Courchesne, R. Y. (1977). P3 waves to the discrimination of targets in homogeneous and heterogeneous stimulus sequences. *Psychophysiology, 14,* 590–597.

Courchesne, E., Hillyard, S. A., & Galambos, R. (1975). Stimulus novelty, task relevance and the visual evoked potential in man. *Electroencephalography and Clinical Neurophysiology, 39,* 131–143.

Daffner, K. R., Mesulam, M. M., Scinto, L. F., Cohen, L. G., Kennedy, B. P., West, W. C., et al. (1998). Regulation of attention to novel stimuli by frontal lobes: An event-related potential study. *NeuroReport, 30,* 787–791.

Daffner, K. R., Scinto, L. F., Calvo, V., Faust, R., Mesulam, M. M., West, W. C., et al. (2000). The influence of stimulus deviance on electrophysiologic and behavioral responses to novel events. *Journal of Cognitive Neuroscience, 12,* 393–406.

Dalton, P., & Lavie, N. (2006). Temporal attentional capture: Effects of irrelevant singletons on rapid serial visual search. *Psychonomic Bulletin & Review, 13,* 881–885.

Debener, S., Makeig, S., Delorme, A., & Engel, A. K. (2005). What is novel in the novelty oddball paradigm? Functional significance of the novelty P3 event-related potential as revealed by independent component analysis. *Cognitive Brain Research, 22,* 309–321.

Demiralp, T., Ademoglu, A., Comerchero, M., & Polich, J. (2001). Wavelet analysis of P3a and P3b. *Brain Topography, 13,* 251–267.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18,* 193–222.

Dien, J., Spencer, K. M., & Donchin, E. (2004). Parsing the late positive complex: Mental chronometry and the ERP components that inhabit the neighborhood of the P300. *Psychophysiology, 41,* 665–678.

Donchin, E. (1981). Surprise! … Surprise? *Psychophysiology, 18,* 493–513.

Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences, 11,* 357–374.

Duncan-Johnson, C. C., & Donchin, E. (1977). On quantifying surprise: The variation of event-related potentials with subjective probability. *Psychophysiology, 14,* 456–467.

Egeth, H. E., & Yantis, S. (1997). Visual attention: Control, representation, and time course. *Annual Review of Psychology, 48,* 269–297.

Eriksen, C. W., & Hoffman, J. E. (1972). Temporal and spatial characteristics of selective encoding from visual displays. *Perception & Psychophysics, 12,* 201–204.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40,* 225–240.

Escera, C., Alho, K., Winkler, I., & Näätänen, R. (1998). Neural mechanisms of involuntary attention to acoustic novelty and change. *Journal of Cognitive Neuroscience, 10,* 590–604.

Folk, C. L., & Remington, R. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 847–858.

Folk, C. L., & Remington, R. (1999). Can new objects override attentional control settings? *Perception & Psychophysics, 61,* 727–739.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 1030–1044.

Folk, C. L., Remington, R. W., & Wright, J. H. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset, and color. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 317–329.

Friedman, D., Cycowicz, Y. M., & Gaeta, H. (2001). The novelty P3: An event-related brain potential (ERP) sign of the brain's evaluation of novelty. *Neuroscience and Biobehavioral Reviews, 25,* 355–373.

Giesbrecht, B., Woldorff, M. G., Song, A. W., & Mangun, G. R. (2003). Neural mechanisms of top–down control during spatial and feature attention. *Neuroimage, 19,* 496–512.

Goldstein, A., Spencer, K. M., & Donchin, E. (2002). The influence of stimulus deviance and novelty on the P300 and novelty P3. *Psychophysiology, 39,* 781–790.

Grillon, C., Courchesne, E., Ameli, R., Elmasian, R., & Braff, D. (1990). Effects of rare non-target stimuli on brain electrophysiological activity and performance. *International Journal of Psychophysiology, 9,* 257–267.

Gumenyuk, V., Korzyukov, O., Escera, C., Hämäläinen, M., Huotilainen, M., Häyrinen, T., et al. (2005). Electrophysiological evidence of enhanced distractibility in ADHD children. *Neuroscience Letters, 374,* 212–217.

Hagen, G. F., Gatherwright, J. R., Lopez, B. A., & Polich, J. (2006). P3a from visual stimuli: Task difficulty effects. *International Journal of Psychophysiology, 59,* 8–14.

Handy, T. C., & Khoe, W. (2005). Attention and sensory gain control: A peripheral visual process? *Journal of Cognitive Neuroscience, 17,* 1936–1949.

Handy, T. C., & Mangun, G. R. (2000). Attention and spatial selection: Electrophysiological evidence for modulation by perceptual load. *Perception & Psychophysics, 62,* 175–186.

Handy, T. C., Soltani, M., & Mangun, G. R. (2001). Perceptual load and visuocortical processing: Event-related potentials reveal sensory-level selection. *Psychological Science, 12,* 213–218.

Hickey, C., McDonald, J. J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *Journal of Cognitive Neuroscience, 18,* 604–613.

Hopfinger, J. B., Buonocore, M. H., & Mangun, G. R. (2000). The neural mechanisms of top–down attentional control. *Nature Neuroscience, 3,* 284–291.

Kastner, S., & Ungerleider, L. G. (2000). Mechanisms of visual attention in the human cortex. *Annual Review of Neuroscience, 23,* 315–341.

Katayama, J., & Polich, J. (1996a). P300 from one-, two-, and three-stimulus auditory paradigms. *International Journal of Psychophysiology, 23,* 33–40.

Katayama, J., & Polich, J. (1996b). P300, probability, and the three-tone paradigm. *Electroencephalography and Clinical Neurophysiology, 100,* 555–562.

Katayama, J., & Polich, J. (1998). Stimulus context determines P3a and P3b. *Psychophysiology, 35,* 23–33.

Katayama, J., & Polich, J. (1999). Auditory and visual P300 topography from a 3 stimulus paradigm. *Clinical Neurophysiology, 110,* 463–468.

Knight, R. T. (1984). Decreased response to novel stimuli after prefrontal lesions in man. *Electroencephalography and Clinical Neurophysiology, 59,* 9–20.

Knight, R. T. (1997). Distributed cortical network for visual attention. *Journal of Cognitive Neuroscience, 9,* 75–91.

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology, 38,* 557–577.

Lamy, D., & Egeth, H. E. (2003). Attentional capture in singleton-detection and feature-search modes. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 1003–1020.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 451–468.

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences, 9,* 75–82.

Lavie, N., & de Fockert, J. (2005). The role of working memory in attentional capture. *Psychonomic Bulletin & Review, 12,* 669–674.

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General, 133,* 339–354.

Lavie, N., & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Perception & Psychophysics, 56,* 183–197.

Luck, S. J., & Hillyard, S. A. (1994a). Electrophysiological correlates of feature analysis during visual search. *Psychophysiology, 31,* 291–308.

Luck, S. J., & Hillyard, S. A. (1994b). Spatial filtering during visual search: Evidence from human electrophysiology. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1000–1014.

Maki, W. S., & Mebane, M. W. (2006). Attentional capture triggers an attentional blink. *Psychonomic Bulletin & Review, 13,* 125–131.

Mangun, G. R. (1995). Neural mechanisms of visual selective attention. *Psychophysiology, 32,* 4–18.

Mangun, G. R., & Hillyard, S. A. (1988). Spatial gradients of visual attention: Behavioral and electrophysiological evidence. *Electroencephalography and Clinical Neurophysiology, 70,* 417–428.

Mangun, G. R., & Hillyard, S. A. (1991). Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual–spatial priming. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 1057–1074.

Müller, N. G., Bartelt, O. A., Donner, T. H., Villringer, A., & Brandt, S. A. (2003). A physiological correlate of the ‘‘Zoom Lens’’ of visual attention. *Journal of Neuroscience, 23,* 3561–3565.

Nigg, J. T., & Casey, B. J. (2005). An integrative theory of attention-deficit/hyperactivity disorder based on the cognitive and affective neuroscience. *Development and Psychopathology, 17,* 785–806.

Pfefferbaum, A., Ford, J. M., Roth, W. T., & Kopell, B. S. (1980). Age-related changes in auditory event-related potentials. *Electroencephalography and Clinical Neurophysiology, 49,* 266–276.

Picton, T. W. (1992). The P300 wave of the human event-related potential. *Journal of Clinical Neurophysiology, 9,* 456–479.

Polich, J. (1986). Attention, probability, and task demands as determinants of P300 latency from auditory stimuli. *Electroencephalography and Clinical Neurophysiology, 63,* 251–259.

Polich, J. (2003). Overview of P3a and P3b. In J. Polich (Ed.), *Detection of change: Event-related potential and fMRI findings* (pp. 83–98). Boston: Kluwer Academic Press.

Polich, J., & Comerchero, M. D. (2003). P3a from visual stimuli: Typicality, task, and topography. *Brain Topography, 15,* 141–152.

Polich, J., & Criado, J. R. (2006). Neuropsychology and neuropharmacology of P3a and P3b. *International Journal of Psychophysiology, 60,* 172–185.

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

Rushby, J. A., Barry, R. J., & Doherty, R. J. (2005). Separation of the components of the late positive complex in an ERP dishabituation paradigm. *Clinical Neurophysiology, 116,* 2363–2380.

Sawaki, R., & Katayama, J. (2006a). Severity of AD/HD symptoms and efficiency of attentional resource allocation. *Neuroscience Letters, 407,* 86–90.

Sawaki, R., & Katayama, J. (2006b). Stimulus context determines whether non-target stimuli are processed as task-relevant or distractor information. *Clinical Neurophysiology, 117,* 2532–2539.

Sawaki, R., & Katayama, J. (2007). Difficulty of discrimination modulates attentional capture for deviant information. *Psychophysiology, 44,* 374–382.

Sawaki, R., & Katayama, J. (2008). Distractor P3 is associated with attentional capture by stimulus deviance. *Clinical Neurophysiology, 119,* 1300–1309.

Shih, S. I., & Reeves, A. (2007). Attentional capture in rapid serial visual presentation. *Spatial Vision, 20,* 301–315.

Shulman, G. L., Wilson, J., & Sheehy, J. B. (1985). Spatial determinants of the distribution of attention. *Perception & Psychophysics, 37,* 59–65.

Simons, R. F., Graham, F. K., Miles, M. A., & Chen, X. (2001). On the relationship of P3a and the Novelty-P3. *Biological Psychology, 56,* 207–218.

Sokolov, E. N. (1963). *Perception and the conditioned reflex*. New York: Macmillan.

Spencer, K. M., Dien, J., & Donchin, E. (1999). A componential analysis of the ERP elicited by novel events using a dense electrode array. *Psychophysiology, 36,* 409–414.

Spencer, K. M., Dien, J., & Donchin, E. (2001). Spatiotemporal analysis of the late ERP responses to deviant stimuli. *Psychophysiology, 38,* 343–358.

Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography and Clinical Neurophysiology, 38,* 387–401.

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-potential correlates of stimulus uncertainty. *Science, 150,* 1187–1188.

Theeuwes, J. (1991a). Cross-dimensional perceptual selectivity. *Perception & Psychophysics, 50,* 184–193.

Theeuwes, J. (1991b). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. *Perception & Psychophysics, 49,* 83–90.

Theeuwes, J. (1994). Stimulus-driven capture and attentional set: Selective search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 799–806.

Theeuwes, J. (2004). Top–down search strategies cannot override attentional capture. *Psychonomic Bulletin & Review, 11,* 65–70.

Theeuwes, J., & Burger, R. (1998). Attentional control during visual search: The effect of irrelevant singletons. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1342–1353.

Verleger, R. (1997). On the utility of P3 latency as an index of mental chronometry. *Psychophysiology, 34,* 131–156.

Yamaguchi, S., & Knight, R. T. (1991). P300 generation by novel somatosensory stimuli. *Electroencephalography and Clinical Neurophysiology, 78,* 50–55.

Yantis, S., & Egeth, H. E. (1999). On the distinction between visual salience and stimulus-driven attentional capture. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 661–676.

Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 121–134.