

# Tracking the Location of Visuospatial Attention in a Contingent Capture Paradigm

Émilie Leblanc, David J. Prime, and Pierre Jolicoeur

## Abstract

■ Currently, there is considerable controversy regarding the degree to which top-down control can affect attentional capture by salient events. According to the contingent capture hypothesis, attentional capture by a salient stimulus is contingent on a match between the properties of the stimulus and top-down attentional control settings. In contrast, bottom-up saliency accounts argue that the initial capture of attention is determined solely by the relative salience of the stimulus, and the effect of top-down attentional control is limited to effects on the duration of attentional engagement on the capturing stimulus. In the present study, we tested these competing accounts by utilizing the N2pc event-related potential component to track the locus of attention during an attentional capture task. The results were completely consistent with the contingent capture hypothesis:

An N2pc wave was elicited only by distractors that possessed the target-defining attribute. In a second experiment, we expanded upon this finding by exploring the effect of target-distractor similarity on the duration that attention dwells at the distractor location. In this experiment, only distractors possessing the target-defining attribute (color) captured visuospatial attention to their location and the N2pc increased in duration and in magnitude when the capture distractor also shared a second target attribute (category membership). Finally, in three additional control experiments, we replicated the finding of an N2pc generated by distractors, only if they shared the target-defining attribute. Thus, our results demonstrate that attentional control settings influence both which stimuli attract attention and to what extent they are processed. ■

## INTRODUCTION

Due to the limited capacity of our cognitive systems, as human beings we are often unable to process simultaneously all of the information present in a visual scene. Fortunately, attentional mechanisms allow us to isolate and preferentially process a subset of objects or a region of the visual field suspected of containing relevant information. Attention can be guided in either a voluntary or an involuntary fashion. Voluntary shifts of attention are usually driven by the goals of the individual, whereas involuntary shifts occur in response to the characteristics of the stimuli, the most salient stimuli attracting attention exogenously.

Although there is general agreement that a sufficiently intense and salient stimulus can capture attention, there is a controversy regarding the degree to which the observer's goals and search strategies can affect attentional capture. According to the contingent attentional capture hypothesis (Folk, Remington, & Johnston, 1992), a distractor elicits an involuntary shift of attention to the location it occupies if it matches top-down attentional control settings, that is to say, if it shares a characteristic that is relevant for attentional selection in the task at hand. Hence, if an observer's task is to respond to a red

target, the presentation of a concurrent red distractor will often impair performance, but the presentation of a blue or yellow distractor will not (Leblanc & Jolicoeur, 2005; Serences et al., 2005; Lamy, Leber, & Egeth, 2004; Folk, Leber, & Egeth, 2002; Folk & Remington, 1998). Such contingent capture effects have been observed for color, shape, movement, and sudden onset (Bacon & Egeth, 1994; Folk, Remington, & Wright, 1994).

In contrast, Theeuwes (1991, 1992, 1994, 1996) argues that attentional capture depends solely on the sensory salience of stimuli, and that the item generating the strongest bottom-up signal within the visual display will attract attention regardless of the observer's goals. Evidence for this purely bottom-up account of attentional capture is based primarily on results from the "additional singleton" paradigm. In this paradigm, Theeuwes et al. have demonstrated that, when the task requires searching for a singleton target (e.g., an item with a unique shape), the presence of a distractor singleton in a task-irrelevant dimension (e.g., color) produces a significant response time cost for responses to the target. In order to account for apparently contingent capture effects from other paradigms, Theeuwes, Atchley, and Kramer (2000) have proposed that attention is initially captured by all salient stimuli, but then rapidly disengages from stimuli that do not match the task-relevant features. Thus, when the interval between

distractor and target is sufficiently long, no effect of the nonmatching distractor will be observed on the behavioral response to the target. Theeuwes et al. (2000) provided support for this proposal by examining the effect of distractor singletons across several distractor–target intervals. They found that significant attention capture effects were only observed for targets that onset less than 150 msec after the onset of the distractor. This suggests that attention was initially captured by the distractor singleton but was able to disengage within 150 msec. However, the observed capture effect could be due to the observers adopting a singleton search mode, in which they searched for items that differ from the homogeneous distractors. In paradigms similar to the ones used by Theeuwes et al., when participants are forced to adopt a feature search mode, monitoring for the presence of a specific feature that is relevant to the task at hand, no attentional effects arise from the presence of salient distractors that do not match the target feature even if they differ from the other distractors in some other way (Lamy, Tsal, & Egeth, 2003; Bacon & Egeth, 1994). Moreover, a distractor that matches the top–down attentional control settings does not have to be a singleton or create a pop-out effect within the visual search array to capture attention (Leblanc & Jolicoeur, 2005; Lamy et al., 2004).

According to Folk et al., contingent capture effects on behavioral performance are mediated by a shift of visuospatial attention to the location of the effective distractors that match the observer’s attentional control settings. If this location does not match that of the actual target, a lengthening of response time and/or a decrease in accuracy can be observed. However, a number of nonspatial explanations of the interference observed in capture studies have been proposed. For example, filtering costs associated with the presence of additional items in the visual display, the distractors, might be responsible for at least part of the behavioral impairments observed in attentional capture tasks (Folk & Remington, 1998; Remington, Johnston, & Yantis, 1992), and these costs might be greater for distractors resembling the target. The presence of a distractor possessing the target-defining attribute might also cause delayed allocation of attention to the target because of the greater difficulty of identifying the target location. In trials containing a distractor matching the top–down control settings, two items possessing the target-defining feature are present: the distractor and the target. Therefore, the observer must gather more information about each location where the target-defining feature is present (the target location and the distractor location), before deciding which location holds the target and deploying his attention accordingly (Remington, Folk, & McLean, 2001). There is also a possibility of the distractor being processed as if it were a target, leading to a lengthening of response times and to intrusions of the identity of the distractor in response selection

(Ghorashi, Zuvic, Visser, & Di Lollo, 2003). Several behavioral studies have addressed these possibilities and yielded results consistent with the visuospatial interpretation of contingent capture. For example, Folk and Remington (1998) and Folk et al. (1992) have found an interaction between the effective distractor and target locations, responses being facilitated when the distractor preceded the target in the same location, and impaired when the target followed the distractor in a different location. Similarly, compatibility effects of the identity of the effective distractor on target processing have been observed, such as might be expected if attention was focused on the distractor (Ansorge & Heumann, 2004; Remington et al., 2001; Theeuwes & Burger, 1998; Theeuwes, 1996). Finally, the time course of the contingent capture effect seems to be consistent with rapid shifts of attention to and from the distractor location (Leblanc & Jolicoeur, 2005; Remington et al., 2001). However, overt responses depend on a wide range of processes and it is difficult to identify the stages of processing at which differences in behavioral performance arise.

Recently, the visuospatial attentional shift interpretation of capture has received support from studies that have utilized functional magnetic resonance imaging (fMRI) to examine brain activity during attentional capture tasks. These studies have revealed that brain areas associated with the control of visuospatial attention are active during attentional capture tasks. In one such study, de Fockert, Rees, Frith, and Lavie (2004) utilized a visual search paradigm in which participants were required to search for a singleton target defined by a unique shape. When a color singleton distractor was present, increased activity was observed in the superior parietal cortex, bilaterally, and in the left lateral precentral gyrus of the frontal lobe, compared to when only nonsingleton distractors were present. Additionally, in a study in which participants had to identify a colored target presented within a central rapid serial visual presentation (RSVP) stream while target- or nontarget-colored distractors could appear in the periphery, Serences et al. (2005) found greater fMRI activation to target-colored distractors than to nontarget-colored distractors in contralateral regions of the extrastriate visual cortex responding to the location of the distractor. Target-colored distractors also generated larger fMRI activations than nontarget-colored distractors in the intraparietal sulcus (IPS), frontal eye field (FEF), anterior supplementary motor area (pre-SMA), ventro-frontal cortex (VFC), and right temporo-parietal junction (TPJ). The areas identified by the studies of Serences et al. and de Fockert et al. (2004) have all been linked to a network controlling visuospatial attention (Corbetta & Shulman, 2002), hence, these results are consistent with a visuospatial account of attentional capture. Although the modulation of activation observed in the extrastriate visual cortex by Serences et al. suggests that attention

was engaged at the location of the target-colored distractors, the poor temporal resolution of fMRI makes it impossible to determine the latency and duration of this effect. Importantly, it is likely that fMRI would be insensitive to the very brief attentional engagement predicted by Theeuwes et al.'s (2000) account of contingent capture.

Event-related potentials (ERPs) provide an alternative technique to investigate brain activity. ERPs allow the continuous observation of the processing of stimuli with fine temporal resolution, even in the absence of overt behavioral responses (Luck, 2005). Hence, in the case of attentional capture, ERPs permit a more direct way to monitor the processing of irrelevant distractors, without having to rely on inferences made from observed modulations of the response to the subsequent target and, unlike fMRI, allow the time course of this processing to be determined. For instance, Arnott, Pratt, Shore, and Alain (2001) showed that irrelevant cues possessing the target-defining feature (color or abrupt onset) elicited a larger occipital N1 component than cues that did not match the top-down attentional control settings. This result suggests that the cognitive set adopted by the observer modulated how the cues were processed in early visual areas, but did not allow the study of the spatial dynamics of contingent capture.

The N2pc is an ERP component often utilized as an index of the locus of visual attention. It is measured as a greater negativity over posterior electrode sites contralateral, relative to ipsilateral, to an attended stimulus, present approximately 170 to 280 msec poststimulus onset (Luck & Hillyard, 1994). The N2pc is thought to reflect the attentional selection of a visual stimulus following a shift to a peripheral location because brain activity generating the N2pc is specifically contingent on the location of the stimulus, showing a contralateral distribution, and seems to originate from parietal and occipito-temporal areas, involved in the implementation of attentional selection (Hopf et al., 2000). In addition, a larger N2pc is generated by a target on which a complex discrimination task must be performed, requiring further processing of the target after it has been selected on the basis of the target-defining feature, than by a target simply to be detected according to the mere presence of the target-defining feature (Luck, Girelli, McDermott, & Ford, 1997; Luck & Hillyard, 1994). A larger N2pc is also observed when a target surrounded by more distractors (Luck et al., 1997) or by distractors that are less easily differentiated from the target (Luck & Hillyard, 1994), all situations that require a greater contribution of focal attention. Moreover, the N2pc seems to reflect the locus of attention following shifts of attention predicted by serial models of visual search (Woodman & Luck, 2003). It has also been suggested that the N2pc reflects the top-down selection of a target according to the presence of task-relevant properties (Eimer, 1996).

It has recently been demonstrated that distractors that automatically capture attention elicit an N2pc (Hickey, McDonald, & Theeuwes, 2006). In that study, a visual search task was used in which the target was defined as a shape singleton (a circle among diamonds or a diamond among circles) and a distractor, always a color singleton (a red item among green items or a green item among red items), could be present in the search array. Behavioral capture was observed when an irrelevant color singleton distractor was present, and an N2pc to such color distractors was found. Hickey et al.'s (2006) study, therefore, demonstrated that attentional capture by a salient item does involve allocation of visuospatial attention to the location of the salient distractor, but did not allow studying the allocation of visuospatial attention during contingent attentional capture because both targets and distractors were singletons, thus allowing subjects to adopt a singleton search mode rather than a feature search mode (Bacon & Egeth, 1994).

The primary aim of the present study was to test the contingent capture (Folk et al., 1992) and the brief attentional dwell time (Theeuwes et al., 2000) accounts of capture by tracking the location of visuospatial attention in a capture paradigm using distractors that did not differ in terms of bottom-up salience. We utilized the N2pc component of the ERP to track the spatial locus of attention following the presentation of distractors that did or did not match top-down attentional control settings established in the context of a task requiring a feature search mode (Leblanc & Jolicoeur, 2005). In this paradigm, participants searched for a target-colored digit embedded in an RSVP stream of heterogeneously colored digits. Capture was induced by presenting two irrelevant, peripheral pound signs (“#”) along with the digit preceding the target digit in the RSVP stream. One of the peripheral distractors was gray, and the other was presented in the target color or in a nontarget color. Leblanc and Jolicoeur (2005) and Folk et al. (2002) found attentional capture, indexed by a drop in accuracy of reports of the identity of the target digit, when a target-colored distractor, but not a nontarget-colored distractor, preceded the presentation of the target. Moreover, identical behavioral performance was observed whether a nontarget-colored distractor, only gray distractors, or no distractor was presented prior to the target (Folk et al., 2002). If this contingent capture effect is due to top-down attentional control settings affecting the ability of bottom-up signals to capture visuospatial attention, we should see an N2pc in response to the presentation of a target-colored distractor—indicating that the locus of spatial attention, initially at fixation, would have moved to the location of the target-colored distractor—but not to the presentation of a nontarget-colored distractor. In contrast, if the contingent capture effect is due to a difference in the duration that attention dwells at the distractor location on target-colored and nontarget-colored distractor trials, an N2pc should be

observed in response to all distractors. However, the duration of the N2pc should be longer on target-colored than on nontarget-colored distractor trials. A third possibility is that the contingent capture interference is due to nonspatial mechanisms, in this case, no N2pc would be observed in either distractor condition.

The secondary aim of the present study was to determine whether the capture effect could be modulated by the processing of the peripheral distractor. Recently, Ghorashi et al. (2003) have provided evidence that the time taken to process distractors is an important contributor to the effect of contingent capture on reaction time. In order to explore this issue, we designed a second experiment with an additional category manipulation: The peripheral distractor either shared or did not share the target color and/or category. If top-down attentional control settings influence how stimuli are processed, it is possible that attentional engagement at the location of distractor stimuli may be enhanced for distractors that are similar to the target. Consequently, the magnitude or the duration of the N2pc elicited by distractors that match the target category may be enhanced relative to that elicited by distractors that do not match the target category.

Three additional control experiments were conducted. Experiment 3 replicated the results of Experiment 1 while reducing the temporal predictiveness of the distractor display. In Experiment 4, we replaced the RSVP stream by a search array consisting of three colored digits aligned vertically, in order to eliminate ERP responses to the sequence of rapidly changing items at fixation. Finally, in Experiment 5, we equated the number of times each color could be presented in the periphery, to control for differences in the relative frequency of presentation of the various colors appearing at the two peripheral locations. An N2pc only to the target-colored distractor was found in each experiment, which provides strong support for visuospatial contingent capture.

## GENERAL METHODS

In all five experiments, the subjects viewed a computer monitor from a distance of 57 cm, and a chin rest was used to stabilize the head. The luminance of all stimuli was 12.8 cd/m<sup>2</sup>. Responses were made on a standard computer keyboard. Subjects were instructed to maintain fixation on the centrally presented stimuli and to blink between trials. Trials were self-paced and subjects initiated each trial by pressing the spacebar. All subjects were naive volunteers and were paid Can\$20 for participation in a single 2-hr session. All subjects reported normal or corrected-to-normal vision. The study was approved by the local ethics review board at the Université de Montréal.

The electroencephalogram (EEG) was recorded from the left and right mastoids and 64 standard 10–10 scalp sites with active Ag/AgCl electrodes (Biosemi Active Two

system) mounted on an elastic cap. Eye position was monitored by both the horizontal and vertical electrooculogram (EOG). EEG and EOG channels were low-pass filtered at 67 Hz and digitized at 256 Hz. After acquisition, the EEG channels were referenced to the average of the left and right mastoids and high-pass filtered at 0.01 Hz (half power cutoff). Trials containing blinks, eye movements, and EEG artifacts were removed prior to ERP averaging by applying automated artifact detection routines. Subjects whose average eye position deviated more than  $\sim 0.2^\circ$  (3.2  $\mu\text{V}$ ) from the center (according to the procedure described by Luck, 2005) or who had less than 65% of the trials remaining after the trial rejection procedure were excluded from further analyses.

ERP averages were calculated from EEG epochs time-locked to the presentation of the distractors. Separate ERPs were calculated for each distractor condition and visual field (left or right) of the colored distractor. In Experiments 1, 2, and 3, participants observed an RSVP stream composed of items that changed every 117 msec. Consequently, the ERP curves showed a steady-state-like modulation that corresponded to the presentation rate of items in the RSVP stream. In order to isolate the N2pc wave from this ongoing activity, N2pc difference waves for each distractor condition were computed for the electrode pairs O1/O2, PO3/PO4, and PO7/PO8. ERP waveforms from electrodes ipsilateral to the colored distractor were subtracted from those from contralateral electrodes and the resulting difference waves for each visual field were averaged to produce the N2pc waves. The N2pc waveforms were pooled across the three electrode pairs, low-pass filtered at 25 Hz, and baseline corrected by subtracting the mean voltage during the 200-msec prestimulus period. The N2pc amplitude was quantified by measuring the mean amplitude of the pooled N2pc wave for each subject and each distractor condition in a measurement window that approximately corresponded to the time interval between the point in time that the N2pc reached half of its maximum amplitude during onset and when the N2pc again reached half amplitude during its offset.

## EXPERIMENT 1

### Methods

#### *Stimuli and Procedure*

The task was to identify a digit of a specified color within an RSVP stream of colored digits. The RSVP stream was presented in the center of a black screen. Each of the digits within the stream were  $1.3^\circ$  of visual angle high and colored either red, blue, green, ochre, or gray. The four colors and gray were equiluminant. One of the four colors was designated as the target color for each subject, with the target color counterbalanced across subjects.

A schematic representation of the stimulus sequence is depicted in Figure 1A. Each trial began with the

presentation of a fixation point that served as response accuracy feedback for the previous trial. A “+” indicated that the response on the previous trial was correct and a “-” indicated that the previous response was incorrect. After an interval of 200 msec following the initiation of the trial by the participant (press of the spacebar), the fixation point was replaced by the RSVP stream. The stream consisted of a series of 16 to 22 digits. Each digit in the stream was presented for 117 msec without any interstimulus interval between digits. The color of each nontarget digit in the stream was selected at random from the three nontarget colors and gray, with the restriction that no two consecutive digits could be presented in the same color. The identity of each digit in the stream was also randomly selected from the digits 2 through 9, and again, the same digit could not be presented twice in a row. The serial position of the

target digit in stream was randomly selected from positions 8 through 11. One serial position before the target digit, a pair of distractors was presented, one to each side of the RSVP stream. The choice of the distractor–target lag was guided by Leblanc and Jolicoeur (2005), who found maximum interference at a stimulus-onset asynchrony of 117 msec. The distractors, 1.3° high “#” symbols, were presented 2° from the central stream for 117 msec simultaneously with the RSVP item prior to the target. Each pair of distractors consisted of one gray “#” symbol and one colored symbol. The location, left versus right, of the colored distractor varied randomly across trials. In the target–color distractor condition, the colored symbol had the same color as the target digit. In the nontarget-colored distractor condition, the colored symbol was selected at random from the nontarget colors on each trial. Distractor condition was selected randomly on each trial with the constraint that each distractor condition occurred on 50% of trials in each block.

At the end of the RSVP stream, subjects were required to report the identity of the target digit using the numeric keypad on the computer keyboard and without moving their eyes. Rapid responding was not required and subjects were instructed to attempt to be as accurate as possible. Subjects were also instructed to ignore the lateral distractors. Each experimental session consisted of 20 practice trials followed by 608 experimental trials, divided in four blocks. Each block consisted of an equal number of trials for each distractor condition and colored distractor side.

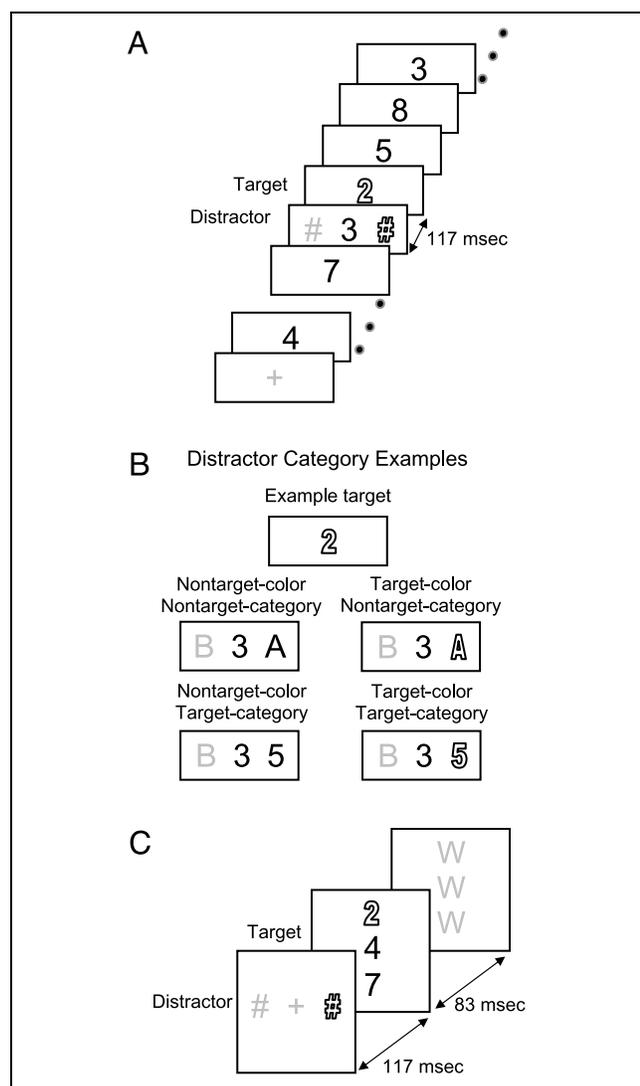
### Subjects

Twenty-one subjects participated in Experiment 1 (7 men, mean age = 23.7 years). Five subjects were excluded from data analysis. One subject was excluded due to an equipment malfunction during recording. Three subjects were excluded because an excessive number of trials were rejected due to artifacts, blinks, and eye movements. Finally, one subject was rejected due to excessive residual horizontal EOG activity after artifact rejection, indicating that the artifact detection procedure was not completely successful in eliminating trials with lateral eye movements. The remaining 16 subjects (4 men) had a mean age of 24.2 years. For these subjects, an average of 87.2% of the trials was included in the ERP analysis.

## Results and Discussion

### Behavioral Results

Mean accuracy of target identification is shown in Table 1A. As expected, mean accuracy was higher in the nontarget-color than in the target-color distractor condition, replicating the attentional capture by the target-colored distractor that had been observed by Leblanc



**Figure 1.** Illustration of the sequence of events in Experiments 1 (A), 2 (B), and 4 (C). Outlined characters represent the target color, black characters were nontarget colors, and gray characters were gray.

**Table 1.** Mean Accuracy in Target Identification by Distractor Condition

<i>Distractor Condition</i>	<i>Mean Accuracy % (SD)</i>		
	<i>Nontarget-color</i>	<i>Target-color</i>	
<i>(A) Experiment 1</i>			
	74.5 (14.5)	64.9 (16.7)	
<i>(B) Experiment 2</i>			
Nontarget-category	76.7 (12.0)	70.6 (10.6)	
Target-category	75.0 (12.8)	68.5 (11.3)	
<i>(C) Experiment 3</i>			
Lag 1	78.2 (17.6)	69.1 (14.9)	
Lag 3	75.4 (17.0)	72.4 (15.8)	
Lag 5	73.7 (17.9)	73.7 (20.1)	
Lag 7	74.1 (19.0)	72.9 (20.4)	
	<i>Absent</i>	<i>Nontarget-color</i>	<i>Target-color</i>
<i>(D) Experiment 4</i>	93.0 (6.4)	93.5 (7.1)	89.4 (9.9)
<i>(E) Experiment 5</i>	88.9 (9.9)	89.5 (9.2)	84.6 (11.5)

and Jolicoeur (2005) and Folk et al. (2002) in a similar paradigm. A repeated measures analysis of variance (ANOVA), with distractor condition as a within-subjects factor, confirmed that this difference in accuracy was reliable [ $F(1, 15) = 17.21, p < .001, MSE = 43.21$ ].

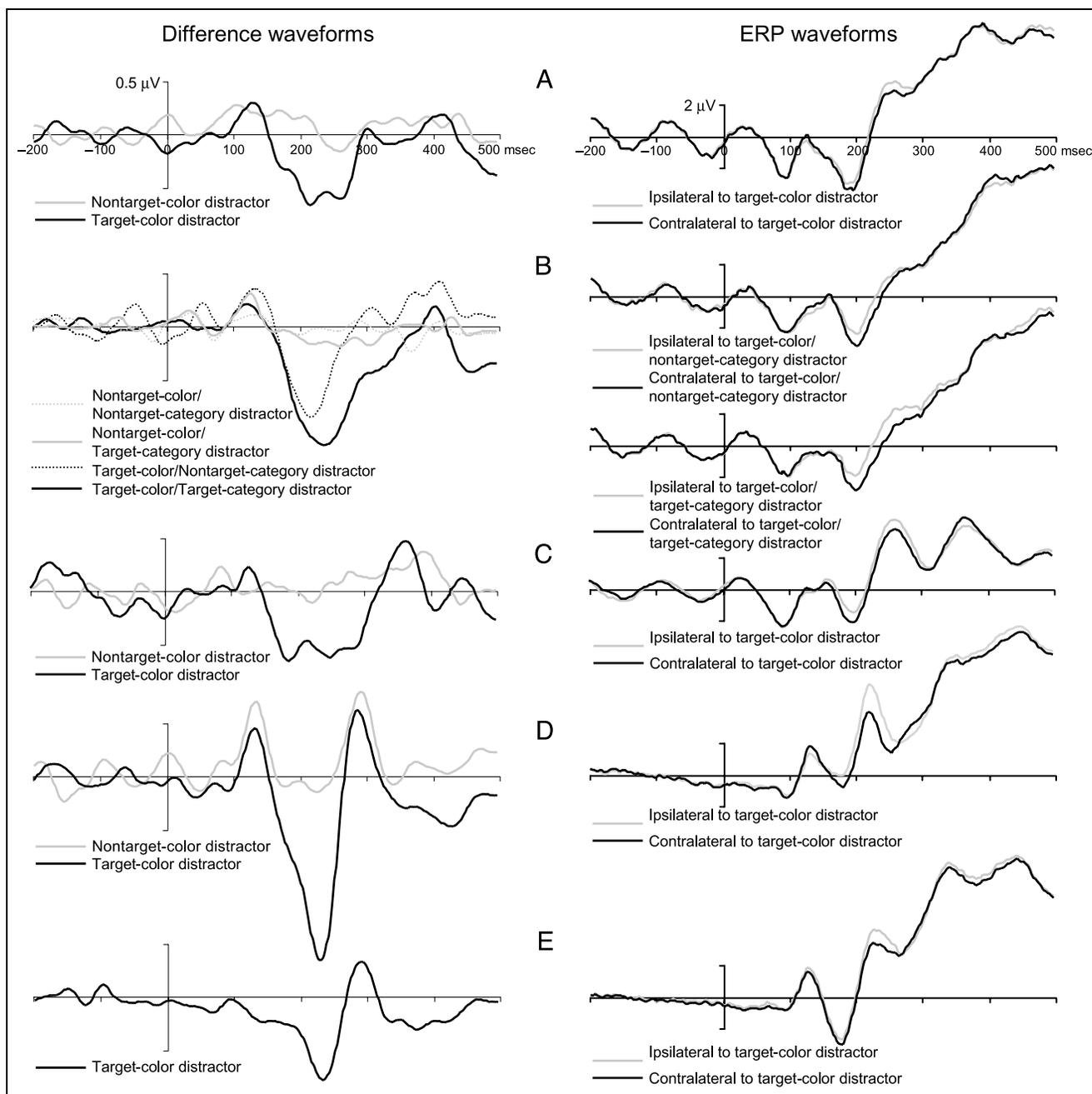
### *Electrophysiological Results*

Contralateral–ipsilateral difference waveforms for each distractor condition are shown on the left side of Figure 2A. As predicted by the contingent capture hypothesis,  $t$  tests versus zero revealed that a significant N2pc was generated in the target-color distractor condition [ $t(15) = -2.54, p < .025, SEM = 0.213$ ], but not in the nontarget-color distractor condition [ $t(15) = 0.14, p > .89, SEM = 0.096$ ], in a 185- to 280-msec time window postdistractor onset. Furthermore, the difference in mean amplitude between the two conditions was significant, as revealed by an ANOVA with distractor condition as a within-subjects factor [ $F(1, 15) = 6.47, p < .025, MSE = 0.3821$ ]. The ERP waveforms recorded at electrodes ipsilateral and contralateral to the target-colored distractor, showing the N2pc effect together with the overlapping activity elicited by the RSVP stream, are presented on the right side of Figure 2A. The ERP waveforms clearly show that the contralateral–ipsilateral difference wave arises from a relative amplitude difference and not from a change in the latency or morphology of the ERP waves. The scalp topography of the difference wave generated in the target-color distractor condition is shown in Figure 3A. The present scalp distribution is very

similar to that of N2pc distributions observed in previous studies that used visual displays comparable to ours (e.g., Brisson & Jolicoeur, 2007; Robitaille & Jolicoeur, 2006a, 2006b), supporting the interpretation of this effect as a shift of visuospatial attention.

Visual inspection of the subtraction curves also revealed a contralateral positivity in the time range of the P1 component. Using the same criteria as that used to define the N2pc measurement window, we analyzed the mean amplitude of the positivity in a time window of 105- to 145-msec postdistractor onset. This analysis revealed that the positivity was significant in the nontarget-color distractor condition [ $t(15) = 3.91, p < .001, SEM = 0.059$ ], but not in the target-color distractor condition [ $t(15) = 1.53, p > .14, SEM = 0.156$ ]. However, the difference in mean amplitude between the two conditions was not significant [ $F(1, 15) = 0.003, p > .95, MSE = 0.1715$ ]. We explore the origin of this positive deflection in Experiments 4 and 5.

The N2pc results are consistent with visuospatial accounts of contingent attentional capture. The fact that an N2pc was observed following the presentation of an attention-capturing target-colored distractor indicates that visuospatial attention was deployed to the position of this distractor. Furthermore, these results provide support for the contingent capture hypothesis of Folk et al. (1992) and against the brief attentional dwell time account of Theeuwes et al. (2000). In direct contradiction to the prediction derived from the brief attentional dwell time account, no N2pc wave was observed following nontarget-colored distractors. This latter result was



**Figure 2.** ERP subtraction waveforms for each distractor condition (left) and raw ERP waveforms ipsilateral and contralateral to target-colored distractors (right) in Experiments 1 (A), 2 (B), 3 (C), 4 (D), and 5 (E).

obtained despite the fact that the nontarget colors were equally salient as the target color. Indeed, across subjects, they were exactly the same colors. However, an N2pc was found only when the colored distractor matched the top-down control setting needed to select the target.

## EXPERIMENT 2

In the previous experiment, the distractor was probably easy to discard as a potential target because it was always a “#” symbol, whereas the participants were searching for a digit. Therefore, it is likely that, despite the ability

of target-colored distractors to capture attention, subjects could most likely avoid prolonged attention engagement and elaborate processing of the distractor. In Experiment 2, we introduced a category manipulation in order to influence the extent and duration of distractor processing. If, in addition to influencing what stimuli capture attention, top-down attentional control settings influence how stimuli are processed, it is possible that attentional engagement at the location of distractor stimuli may be enhanced for distractors that are similar to the target. Consequently, the magnitude or the duration of the N2pc elicited by distractors that match

the target category may be enhanced relative to that elicited by distractors that do not match the target category.

## Methods

### Stimuli and Procedure

The stimuli and procedure used in Experiment 2 were the same as in Experiment 1 with the following exceptions. The task was either to identify a color-defined target digit within an RSVP stream of colored digits or to identify a color-defined target letter within a stream of letters. Target category was counterbalanced across subjects. Digit streams consisted of the digits 2 through 9 and letter streams consisted of the capital letters A through H. The bilateral distractor pairs consisted of one gray nontarget-category item, digit or letter, and a contralateral colored digit or letter. As in Experiment 1, the colored distractor matched the target color on 50% of trials. In addition, the character matched the target category, digit versus letter, on half of the trials. This gave rise to four distractor conditions, depicted in Figure 1B: target-category/target-color, target-category/nontarget-color, nontarget-category/target-color, and nontarget-category/nontarget-color. Each experimental session consisted of 20 practice trials followed by 1024 experimental trials, divided into eight blocks. Each block

consisted of an equal number of trials for each distractor condition and colored distractor side.

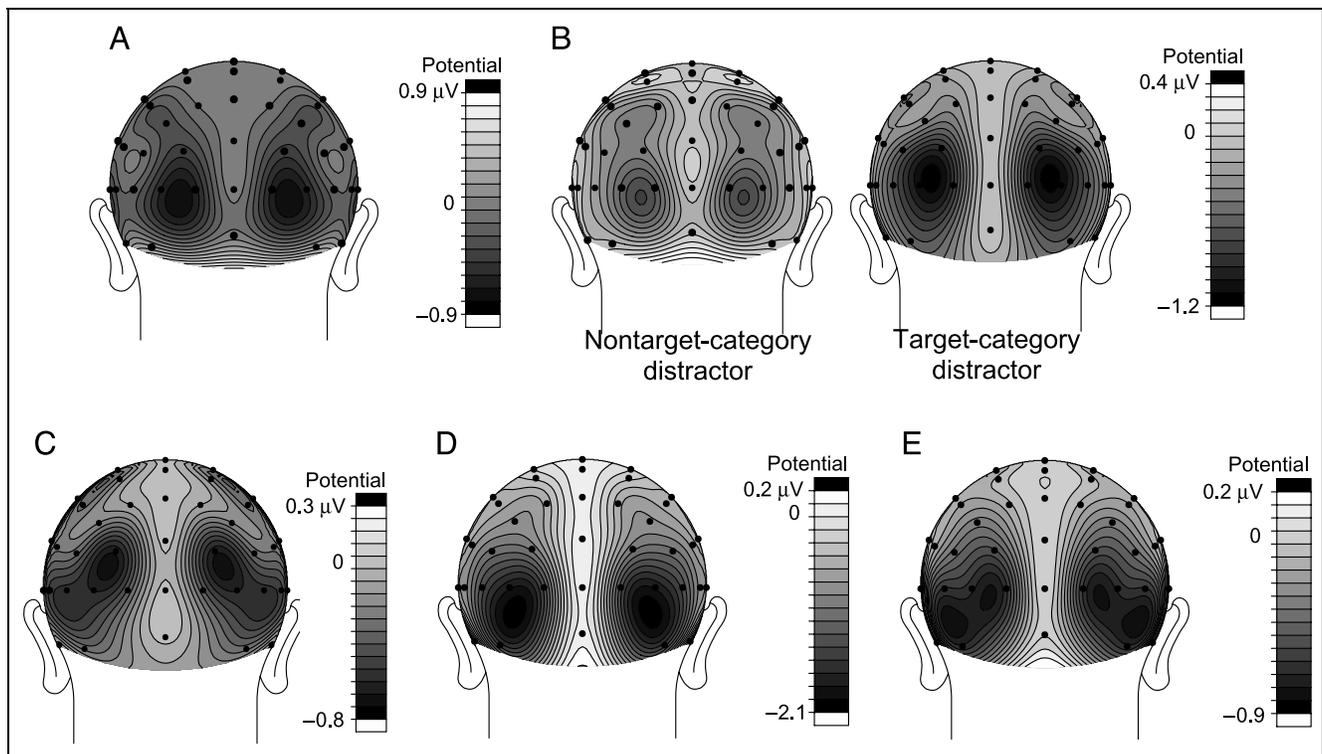
### Subjects

Twenty-one subjects participated in Experiment 2 (6 men, mean age = 21.1 years). Five subjects were excluded from data analysis. Four subjects were excluded because an excessive number of trials were rejected due to EEG or EOG artifacts and one due to poor behavioral performance (0.08% correct in one condition). The remaining 16 subjects (5 men) had a mean age of 21.3 years. An average of 88.2% of the trials was included in the ERP analysis for these 16 subjects.

## Results and Discussion

### Behavioral Results

Mean percentages of correct target identifications (Table 1B) were entered into a repeated measures ANOVA with distractor color condition and distractor category condition as within-subjects factors. Again, a target-colored distractor produced attentional capture [nontarget-colored distractor: 75.9%, target-colored distractor: 69.6%,  $F(1, 15) = 7.89$ ,  $p < .015$ ,  $MSE = 80.82$ ] and there was also a small main effect of target-category [nontarget-category distractor: 73.7%, target-category distractor: 71.8%,



**Figure 3.** Topographical mapping of the N2pc in Experiments 1 (A), 2 (B), 3 (C), 4 (D), and 5 (E). Maps were generated by computing the contralateral minus ipsilateral difference wave for each electrode pair and the mean amplitude in the measurement window used when analyzing N2pc effects was calculated for each N2pc wave. The obtained values were mirrored across the midline, and the values for the midline electrodes were set to zero. The spherical splines interpolation technique was then used to estimate the topographic voltage distribution.

$F(1, 15) = 5.47, p < .035, MSE = 10.47$ ]. The interaction was not significant,  $p > .79$ .

### Electrophysiological Results

The ERP and N2pc subtraction curves are depicted in Figure 2B. Topographic maps of the N2pc effect are shown in Figure 3B. The N2pc was computed in a measurement window of 185- to 285-msec postdistractor onset. Only the two target-color distractor conditions generated significant N2pc [target-color/nontarget-category:  $t(15) = -2.27, p < .04, SEM = 0.226$ , target-color/target-category:  $t(15) = -3.44, p < .004, SEM = 0.267$ ], whereas the mean amplitude did not significantly differ from zero in the two nontarget-color distractor conditions [nontarget-color/nontarget-category:  $t(15) = -0.46, p > .65, SEM = 0.082$ , nontarget-color/target-category:  $t(15) = -1.13, p > .27, SEM = 0.124$ ]. A repeated measures ANOVA with distractor color and distractor category conditions as within-subjects factors revealed that the main effects of both distractor variables were significant, indicating that the N2pc to a target-color distractor was larger than that to a nontarget-color distractor [ $F(1, 15) = 12.26, p < .0035, MSE = 0.5138$ ], and that the same was true for a target-category distractor relative to a nontarget-category distractor [ $F(1, 15) = 5.53, p < .035, MSE = 0.1875$ ]. Although the interaction was only marginally significant [ $F(1, 15) = 3.75, p < .075, MSE = 0.09783$ ], pairwise comparisons showed that target-category distractors produced a larger N2pc only in the target-color distractor condition [ $F(1, 15) = 7.44, p < .016, MSE = 0.1774$ ], and not in the nontarget-color distractor condition [ $F(1, 15) = 0.79, p < .38, MSE = 0.1080$ ].

In addition, the ERP curves seemed to show that the target-color/target-category distractor condition produced a longer-lasting N2pc than the target-color/nontarget-category distractor condition. In order to verify if this effect was significant, the offset latency of the N2pc in each condition was measured by taking the moment in time when the offset of the subtraction curve reached 0  $\mu V$ . Analyses using the jackknife procedure (Ulrich & Miller, 2001) confirmed that the N2pc observed in the target-color/target-category distractor condition had a longer duration than that observed in the target-color/nontarget-category distractor condition [ $F(1, 15) = 6.08, p < .03$ ].

The finding of a significant N2pc in only the two target-color distractor conditions indicates that the contingent attentional capture of visuospatial attention only occurs when distractor items possess the target-defining property. That is to say, if participants were looking for a red digit among colored digits, the relevant stimulus property was the color (red), and not the category (digit), which was shared with nontarget items in the RSVP stream. Therefore, only red items in the periphery were able to generate involuntary shifts of visuospatial

attention to the location they occupied. However, the fact that the N2pc to a target-colored distractor was larger and lasted longer when the distractor also shared the target category than when it did not suggests that, once attention had been captured to the distractor location, it was harder to disengage and shift back to the central RSVP stream when the distractor shared nontarget-defining features with the target. These results suggest that the observer's goals and strategies not only affect which stimuli will capture visuospatial attention but also the extent and duration of visuospatial attentional processing.

As in Experiment 1, the subtraction waveforms showed some evidence of a positive component contralateral to the colored distractor in the P1 time range. However, mean amplitude in a 110- to 155-msec postdistractor onset time window was only significantly different from zero in the target-color/nontarget-category distractor condition [ $t(15) = 2.46, p < .03, SEM = 0.117$ ], and marginally significantly different from zero in the nontarget-color/target-category distractor condition [ $t(15) = 1.87, p < .09, SEM = 0.096$ ]. The other two distractor conditions did not produce contralateral positivities that approached significance, and ANOVAs considering distractor color and category conditions as within-subjects factors did not reveal any significant main effects or interactions, all  $ps > .20$ .

### EXPERIMENT 3

In Experiments 1 and 2, the peripheral distractors always preceded the target by 117 msec. Hence, they conveyed information about when the target would be occurring. It is therefore possible that subjects used the distractor display as an alerting cue, making it task-relevant. However, even if the subjects did use the temporal information provided by the peripheral distractors, we argue that it would not explain either the behavioral pattern of contingent capture, or the N2pc observed following target-colored distractors only. First, the alerting value of the distractor display is identical across distractor conditions so it would not yield any differential effects, behavioral or electrophysiological, between conditions. Second, alerting by a visual cue has been found to be homogeneous across the visual field (Fernandez-Duque & Posner, 1997), so a shift of visuospatial attention related to alerting would not be expected. However, to rule out this possible account of our results definitively, Experiment 3 was designed to minimize the temporally predictive nature of the distractor display by using four distractor-target lags, ranging from 117 to 817 msec, and increasing the variability between the start of the RSVP stream and the presentation of the target. Thus, the onset of the distractors provided no specific information concerning the time at which the target would appear.

Another potential problem with Experiments 1 and 2 was that the distractor display was not always perfectly

balanced in terms of stimulus color. Target-colored distractors were always unique in the distractor display. By contrast, nontarget-colored distractors could share the color of the central digit in approximately 25% of the trials because both colors were selected independently at random. On these trials, the gray item may have attracted attention due to its status as a color singleton. Consequently, any N2pc elicited by nontarget-colored distractors would be attenuated due to a reverse effect on one quarter of the trials. On this account, the N2pc in the nontarget-colored distractor condition should have been smaller than for target-colored distractors, but not eliminated. However, it is possible that a small N2pc elicited by nontarget-colored distractors may have gone undetected in the previous two experiments. To rule out this account, in the present experiment, the color of the central stream digit in the distractor display was chosen randomly with the additional restriction that it could not be gray or the same color as the colored distractor on that trial.

## Methods

### *Stimuli and Procedure*

The stimuli and procedure used in Experiment 3 were the same as in Experiment 1, with the following exceptions. The RSVP stream was composed of 15 to 26 colored digits. As in Experiment 1, the color of each nontarget digit in the stream was selected at random from the three nontarget colors and gray, with the restriction that no two consecutive digits could be presented in the same color. Furthermore, the color of the digit presented in the distractor frame could not be gray, or the color of the colored distractor for that trial. This manipulation ensured that on each trial, both distractors were unique in color. The target position in the stream was randomly selected from the serial positions 7 to 21. The target was always followed by at least two digits. The time of the presentation of the peripheral distractors relative to that of the target was also varied. They could be presented along with the frame preceding the target (distractor–target lag 1), or three, five, or seven frames prior to the target (distractor–target lags 3, 5, and 7). Each experimental session consisted of 20 practice trials followed by 640 experimental trials, divided into five blocks. Each block consisted of an equal number of trials for each distractor condition and colored distractor side.

### *Subjects*

Twelve subjects participated in Experiment 3 (4 men, mean age = 21.3 years). One subject was excluded from data analysis due to an excessive number of rejected trials and poor behavioral performance. The remaining 11 subjects (4 men) had a mean age of 21.4 years. An

average of 92.7% of the trials was included in the behavioral and ERP analysis for these subjects.

## Results and Discussion

### *Behavioral Results*

Mean percentages of correct target identifications were entered into a repeated measures ANOVA with distractor color condition and distractor–target lag as within-subjects factors. The contingent capture effect on accuracy was again observed (Table 1C), the mean accuracy was higher in the nontarget-color than in the target-color distractor condition [ $F(1, 10) = 7.50, p < .03, MSE = 32.5$ ]. The main effect of lag did not approach significance ( $F < 1$ ). However, a significant interaction was obtained between these factors [ $F(1, 10) = 4.41, p < .02, MSE = 20.3$ ]. Consistent with Leblanc and Jolicoeur (2005), the effect of distractor color decreased with increasing distractor–target lag; pairwise comparisons showed that the effect of distractor color was only significant at the shortest distractor–target lag [ $F(1, 10) = 18.04, p < .01, MSE = 25.2$ ].

### *Electrophysiological Results*

The ERP and N2pc subtraction curves are shown in Figure 2C. A topographic map of the N2pc effects is shown in Figure 3C. Analysis of the N2pc in a 170- to 300-msec latency window replicated the results of the previous two experiments. Analysis of mean amplitude revealed that a significant N2pc was generated in the target-color distractor condition [ $t(10) = -2.63, p < .03, SEM = 0.204$ ], but not in the nontarget-color distractor condition [ $t(10) = 0.49, p > .63, SEM = 0.120$ ]. Furthermore, the difference in mean amplitude between the two conditions was significant [ $F(1, 10) = 6.82, p < .03, MSE = 0.286$ ]. Experiment 3 therefore replicates the findings of Experiments 1 and 2 with a perfectly balanced distractor display and in a context where the distractors did not predict the time of target presentation, thus providing further support for the contingent capture hypothesis of Folk et al. (1992), and for visuo-spatial accounts of contingent capture.

As in the previous two experiments, the subtraction waveforms showed some evidence of a positive component contralateral to the colored distractor prior to the N2pc. However, analysis of the mean amplitude versus zero in a 114- to 136-msec latency window did not reveal a significant difference for either the target-color distractor condition [ $t(10) = 1.03, p > .30, SEM = 0.181$ ], or the nontarget-color distractor condition [ $t(10) = 0.01, p > .98, SEM = 0.131$ ]. In addition, a second positivity was observed following the N2pc. Analysis of the mean amplitude in a 332- to 382-msec latency window again failed to reveal a significant effect for either the target-color distractor condition [ $t(10) = 1.77,$

$p > .10$ ,  $SEM = 0.201$ ], or the nontarget-color distractor condition [ $t(10) = 1.60$ ,  $p > .13$ ,  $SEM = 0.156$ ].

## EXPERIMENT 4

Although the lateralized positive components found in the previous experiments do not seem to be reliably significant, we did observe them in three experiments, with different subjects and slightly different distractor conditions. In Experiments 4 and 5, we attempted to determine what experimental factors are responsible for this effect. In Experiment 1 through 3, the RSVP stream elicited a steady-state-like modulation that corresponded to the presentation rate of items in the stream. The observed steady-state oscillation exhibited positive and negative peaks at latencies corresponding to those of the contralateral positivity and the early portion of the N2pc. Therefore, these effects could have arisen from an enhancement of the steady-state activity contralateral to the distractor. Such an effect could possibly arise from a rapid shift of visuospatial attention to the location of the colored distractor that resulted in an amplification of the contralateral positive peak preceding the N2pc. In Experiment 4, we modified the design to eliminate the RSVP stream. If the positivity observed in Experiments 1, 2, and 3 does indeed reflect an enhancement of steady-state activity, it should not be present in Experiment 4.

## Methods

### *Stimuli and Procedure*

A schematic representation of the stimulus sequence used in Experiment 4 is depicted in Figure 1C. The stimuli and procedure used in Experiment 4 were the same as in the previous experiments, with the following exceptions. The RSVP stream was replaced by the simultaneous presentation of three colored digits presented on the vertical midline in the center of the display. Subjects were required to report the identity of a digit with the specified target color within this display. Target color was counterbalanced across subjects and the color of nontarget digits was selected at random from the three nontarget colors. The target display was presented for 83 msec and the vertical position of the target digit was selected at random on each trial. The target display was immediately replaced by a mask display consisting of three gray “W” characters, presented for 117 msec at the locations where the three digits had appeared. On two thirds of trials, a bilateral pair of distractors was presented prior to the target display. As in Experiment 1, the distractors were “#” signs, one gray and the other colored. The distractor display was presented for 117 msec and there was no interstimulus interval between the distractor and target displays. The gray fixation cross remained in the center of the display at the time of presentation of the distractors. On half of the distractor-

present trials, the colored distractor matched the target color (target-color condition), and on the remaining half it did not (nontarget-color condition). Each experimental session consisted of 20 practice trials followed by 1008 experimental trials, divided into seven blocks. Each block consisted of an equal number of trials for each distractor condition and colored distractor side.

### *Subjects*

Twenty-six subjects participated in Experiment 4 (6 men, mean age = 21.4 years). Eight subjects were excluded from data analysis. Seven subjects were rejected because of an excessive number of EEG or EOG artifacts and one subject was rejected due to excessive residual horizontal EOG activity after artifact rejection. The remaining 18 subjects (4 men) had a mean age of 21.4 years. On average, 84.6% of the trials were included in the ERP analysis for these subjects.

## Results and Discussion

### *Behavioral Results*

Mean percentage of correct target identifications are shown in Table 1D. The typical contingent capture effect was observed once again, as the subjects performed significantly worse in the target-color distractor condition than in the nontarget-color distractor or in the distractor-absent conditions [ $F(2, 34) = 8.97$ ,  $p < .001$ ,  $MSE = 10.10$ ].

### *Electrophysiological Results*

The ERP and N2pc subtraction curves are depicted in Figure 2D. A topographic map of the N2pc effect is shown in Figure 3D. As in Experiments 1 and 3, a significant N2pc was generated in the target-color distractor condition [ $t(17) = -5.53$ ,  $p < .001$ ,  $SEM = 0.250$ ], but not in the nontarget-color distractor condition [ $t(17) = -0.70$ ,  $p > .49$ ,  $SEM = 0.122$ ], in a 195- to 250-msec time window postdistractor onset. Furthermore, the difference in mean amplitude between the two conditions was significant [ $F(1, 17) = 25.11$ ,  $p < .001$ ,  $MSE = 0.6025$ ]. We thus replicated, once again, the electrophysiological effect associated with contingent attentional capture showing that the presentation of a target-colored distractor elicits a shift of visuospatial attention to the location it occupies, which is not the case for an equally salient nontarget-colored distractor. The main goal of this experiment was to see if removing the RSVP stream would eliminate the lateralized positivity observed in the first two experiments of the present study. On the contrary, Experiment 4 produced significant positivities in a 115- to 150-msec postdistractor onset time window in both the target-color and nontarget-color distractor conditions [ $t(17) = 2.80$ ,

$p < .015$ ,  $SEM = 0.124$  and  $t(17) = 4.17$ ,  $p < .001$ ,  $SEM = 0.138$ , respectively]. The difference in mean amplitude between the two distractor conditions in this time window was not significant [ $F(1, 17) = 2.35$ ,  $p > .14$ ,  $MSE = 0.1946$ ].

In addition, a second positive deflection could be seen in the subtraction waveforms in Experiment 4. This later, lateralized positivity was significantly different from zero in both target-color and nontarget-color distractor conditions [ $t(17) = 2.87$ ,  $p < .015$ ,  $SEM = 0.165$  and  $t(17) = 3.68$ ,  $p < .002$ ,  $SEM = 0.180$ , respectively], but was not significantly different between the two distractor conditions [ $F(1, 17) = 0.82$ ,  $p > .37$ ,  $MSE = 0.4046$ ].

In Experiment 4, the distractor display, consisting of one gray and one colored distractor, was always presented together with a central gray fixation cross. Therefore, one might argue that the display was not perfectly balanced at the perceptual level, the colored distractor being the only uniquely colored item in the display. However, given the similar results obtained in Experiments 1, 2, and 3 (Experiments 1 and 2 exhibiting the same kind of imbalance, taken care of in Experiment 3), it is very unlikely that this would have affected the pattern of behavioral or electrophysiological results.

## EXPERIMENT 5

Taken together, the results of Experiments 1, 2, 3, and 4 demonstrate that the contralateral positivity observed in the P1 time range is not associated with a particular distractor condition or with the attentional control settings required to perform the task. Consequently, it is unlikely that this effect is related to either attention orienting or to the observed pattern of behavioral performance. In all four experiments, there were always one gray and one colored distractor. Moreover, the colored distractor was presented in the target color more often (in half the trials) than in any of the three nontarget colors (present in one sixth of the trials each). Therefore, the positive component observed here could be linked to a contextual imbalance in the experimental design, regarding the relative frequency of presentation of each color and gray in the periphery, even though each distractor display was balanced on the sensory level, every color and gray being equiluminant. In Experiment 5, the two peripheral distractors were always colored, and each color was used equally often. If the observed lateralized positivity was due to an imbalance in the distractor display in terms of frequency of the colors presented, it should not be observed in Experiment 5.

## Methods

### *Stimuli and Procedure*

The stimuli and procedure used in Experiment 5 were the same as in Experiment 4 with the following excep-

tions. The distractor display always consisted of two colored distractors. In the target-color condition (half of the distractor-present trials), one distractor matched the target color and the other was in a color selected from the three nontarget colors, and in the nontarget-color condition (the remaining half of the distractor-present trials), both distractor colors were selected from the three nontarget colors, with the constraint that they were never the same color. Each of the four colors was attributed to a peripheral distractor equally often. Each experimental session consisted of 20 practice trials followed by 864 experimental trials, divided into six blocks. Each block consisted of an equal number of trials for each distractor condition and colored distractor side.

### *Subjects*

Thirty-four subjects took part in Experiment 5 (12 men, mean age = 21.2 years). Ten subjects were excluded from data analysis. Four subjects were rejected because of an excessive number of EEG or EOG artifacts and six subjects were rejected due to excessive residual horizontal EOG activity after artifact rejection. The remaining 24 subjects (10 men) had a mean age of 21.4 years. On average, 85.0% of the trials were included in the ERP analysis for these subjects.

## Results and Discussion

### *Behavioral Results*

Experiment 5 replicated the contingent capture effect observed in Experiment 4, mean accuracy (Table 1E) in the target-color distractor condition that was lower than in both the nontarget-color distractor and the distractor-absent conditions [ $F(2, 46) = 18.40$ ,  $p < .0001$ ,  $MSE = 9.13$ ].

### *Electrophysiological Results*

The ERP and N2pc subtraction curves for the target-colored distractors are depicted in Figure 2E. A topographic map of the N2pc effect is shown in Figure 3E. A subtraction curve was computed only for the target-color distractor condition, because in the nontarget-color distractor condition, colors were assigned randomly to each distractor, therefore, computing a subtraction curve in this condition would not be informative. Once again, the N2pc results suggested that contingent attentional capture is associated with a shift of visuospatial attention to the location of the distractor. Using a time window of 205- to 255-msec postdistractor onset, we found a significant N2pc in the target-color distractor condition [ $t(23) = -4.57$ ,  $p < .001$ ,  $SEM = 0.136$ ].

The lateralized positivity observed in the first three experiments of the present study was completely absent in Experiment 5. In the 115- to 150-msec postdistractor

onset time window, which was used to calculate this positivity in Experiment 4, the subtraction waveform of Experiment 5 was found to be significantly more negative than zero [ $t(23) = -2.09, p < .05, SEM = 0.082$ ]. The absence of such a lateralized positivity in a paradigm where the peripheral stimuli were not only balanced on the sensory level, but also on the contextual level, with each color presented equally often in the periphery, suggests that the positivity is more likely to be due to perceptual rather than attentional effects. The later positivity seen in Experiment 4 was apparent in the subtraction curve from Experiment 5 as well, but did not reach significance [ $t(23) = 1.59, p < .13, SEM = 0.176$ ].

## GENERAL DISCUSSION

The primary objective of the present study was to test the competing accounts of contingent capture effects proposed by Theeuwes et al. (2000) and Folk et al. (1994). To achieve this goal, we utilized the N2pc component of the visual ERP to track the allocation of visuospatial attention after the presentation of peripheral distractors that either shared or did not share the target-defining selection feature. In all five of the current experiments, the target was a color-defined item embedded in an RSVP stream or spatial search array of heterogeneously colored items. Target items were preceded by distractor displays composed of two equiluminant items presented in the periphery of the visual field. Thus, our distractor displays consisted of stimuli that were balanced at the sensory level, and the only differences between items in the left and right visual fields were defined according to the attentional goals of the observer. Between-subjects counterbalancing ensured that any small residual differences in bottom-up salience across the colors could not have produced the observed behavioral and electrophysiological results.

The results of all five experiments were consistent and unequivocal. Target-colored distractors elicited significant N2pc waves, indicating that visuospatial attention had been drawn to their location. In contrast, nontarget-colored distractors did not generate N2pc waves, suggesting that participants were able to ignore them and remain focused on the central search array. These electrophysiological findings parallel the behavioral effects. Target identification accuracy was better when targets were preceded by nontarget-colored distractors than when they were preceded by target-colored distractors. Furthermore, in Experiments 4 and 5, accuracy was no worse in the nontarget-color distractor conditions than in a distractor-absent condition, in which there were no distractors at all, replicating the finding of Folk et al. (2002). Taken together, these results provide strong evidence against the brief attentional dwell time account of capture proposed by Theeuwes et al. (2000). In contrast, the current results are completely consistent with contingent capture hypothesis of Folk et al.

A secondary objective of the current study was to study the effect of target–distractor similarity on distractor processing. Recently, Ghorashi et al. (2003) demonstrated that irrelevant distractors that possessed the target-defining attributes slowed target identification reaction time when presented prior to the target within the focus of attention. This result indicates that the time required to shift attention toward and away from attention-capturing distractors is not the only source of processing interference underlying contingent capture and that the time taken to process the distractor also plays a role. In order to account for their results, Ghorashi et al. proposed a two-stage model to explain contingent capture, the *contingent processing hypothesis*, arguing that the visuospatial interpretation was not sufficient to account for the temporal deficit in the response to a target preceded by an attention-capturing distractor. In their view, items are first submitted to an input-filtering stage that determines if they match the observer's attentional settings. If it is found that they do, they move on to a capacity-limited processing stage in which stimuli are processed serially. Hence, if a distractor sharing the target feature is presented before the target, it will gain access to this second processing stage, preventing or delaying the processing of the target itself and causing longer response times and/or lower accuracy (e.g., if masked).

We investigated the effect of distractor processing in Experiment 2 by manipulating the extent to which targets and distractors shared features. In addition to our standard color manipulation, we added a category manipulation. A distractor could share the target color, the target category, both attributes, or neither attribute. According to Ghorashi et al.'s (2003) model, a distractor is processed as though it were a target if it matches the observer's attentional control setting. Given this, one would expect that distractors that are similar to the target and allow for similar processing will receive more extensive processing than dissimilar distractors that can be quickly discounted. Therefore, we hypothesized that a distractor sharing both the target color and category would result in a larger or longer-lasting capture effect. In accordance with this prediction, we found that both distractor color and distractor category affected response accuracy, with accuracy rates being the lowest when the distractor shared both attributes with the target. In addition, an N2pc was generated only by target-colored distractors, showing that only distractors that shared the target-defining selection feature—and not just any target feature—triggered an involuntary shift of attention to their location. Furthermore, when the distractor shared the target category in addition to the target color, the N2pc was larger and offset later than when it shared only the target color. This effect suggests that once attention has been attracted to the distractor location, if the distractor shared the category attribute with the target, it was more likely to be

processed further, thus prolonging the engagement visuospatial attention at this location. When the distractor did not share the target category, however, attention could be disengaged more easily from the distractor location and returned to the central search array more quickly. Therefore, the current results indicate that distractor processing can play a part in contingent capture, as suggested by Ghorashi et al., and that distractor processing extends the duration of the allocation of visuospatial attention to the location of the distractor.

Taken together, the current results and those of Hickey et al.'s (2006) provide strong evidence that contingent capture and capture by highly salient task-irrelevant singletons share similar underlying mechanisms, even though they occur under different attentional conditions. Hickey et al.'s study provided convincing evidence that highly salient singleton color distractors trigger shifts of attention to their location when observers are searching for a less salient singleton shape target (thus adopting a singleton search mode) by showing that such distractors generated an N2pc component. In the present study, we show that the same mechanism seems to come into play when attention is captured in a contingent manner by a distractor that is not particularly salient on the sensory level (at least not more salient than other distractors that do not capture attention), but that is unique in that it corresponds to the observer's attentional set (requiring feature search mode).

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Reprint requests should be sent to Émilie Leblanc, Département de psychologie, Université de Montréal, C.P. 6128 Succursale Centre-ville, Montreal, Quebec, Canada, H3C 3J7, or via e-mail: emilie.leblanc-langlois@umontreal.ca.

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