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Contingent capture of visual-spatial attention depends on capacity-limited central mechanisms: Evidence from human electrophysiology and the psychological refractory period

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ABSTRACT

It has recently been demonstrated that a lateralized distractor that matches the individual's top-down control settings elicits an N2pc wave, an electrophysiological index of the focus of visual-spatial attention, indicating that contingent capture has a visual-spatial locus. Here, we investigated whether contingent capture required capacity-limited central resources by incorporating a contingent capture task as the second task of a psychological refractory period (PRP) dual-task paradigm. The N2pc was used to monitor where observers were attending while they performed concurrent central processing known to cause the PRP effect. The N2pc elicited by the lateralized distractor that matched the top-down control settings was attenuated in high concurrent central load conditions, indicating that although involuntary, the deployment of visual-spatial attention occurring during contingent capture depends on capacity-limited central resources.

1. Introduction

At any given moment, our visual world offers us a large amount of information, far more than what can be processed at one time by our capacity-limited cognitive system. It is therefore crucial to identify and isolate efficiently a subset of objects or a region of the visual field suspected of containing relevant information, so that this information can benefit from preferential processing, and ultimately guide our actions. This selection is accomplished by attentional mechanisms that can act at early or late stages of processing, depending on the stimuli and task at hand (see Luck et al., 2000).

One type of attention that has been studied extensively is often referred to as visual-spatial attention. Numerous studies have demonstrated that performance is improved when stimuli appear at an attended location (Posner, 1980; Jonides, 1981; Müller and Rabbitt, 1989). It is also postulated that visual-spatial attention must be deployed on individual items in a search array in order to identify a pre-defined target amongst multiple distractors, at least when the distractors and target share similar features (Duncan and Humphreys, 1989; Treisman and Gelade, 1980; Woodman and Luck, 2003). It is well known that visual-spatial attention can be deployed voluntarily to specific locations (and/or items) in the visual field, according to the individual's goals, or can be captured by a sufficiently intense and salient stimulus, independently of the individual's volition. An item can also capture attention if it matches the individual's top-down attentional control settings, that is to say, if it shares a characteristic that is relevant for attentional selection, even if the item itself is task-irrelevant. For example, 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 (Folk et al., 2002; Folk and Remington, 1998; Lamy et al., 2004; Leblanc and Jolicœur, 2005; Serences et al., 2005). Such contingent capture effects have been observed for colour, shape, movement, and sudden onset (Bacon and Egeth, 1994; Folk et al., 1994). Recent electrophysiological studies have demonstrated that distractors that share the relevant attentional selection characteristic generate an N2pc (N2 *posterior contralateral*) component (Leblanc et al., 2008), as do both salient task-irrelevant singletons (Hickey et al., 2006; although this effect can be overridden in the presence of a specific task set, if the singleton is very different from the target, see Luck and Hillyard, 1994), and voluntarily attended items (Eimer, 1996; Luck and Hillyard, 1994; Luck et al., 1997;

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Woodman and Luck, 2003). The N2pc is a lateralized event-related potential (ERP) component that typically occurs about 180–280 ms after the onset of a visual display and is maximal at posterior electrode sites contralateral to an attended item. Because the N2pc likely indexes covert visual-spatial attention (for a review, see Woodman and Luck, 2003), the Hickey et al. (2006) and Leblanc et al. (2008) studies convincingly demonstrated that capture by highly salient task-irrelevant singletons and contingent capture share at least some underlying visual-spatial attention mechanisms that are similar to voluntary visual-spatial attention mechanisms. In addition, several earlier studies using spatial cuing paradigms combined with the ERP technique strongly suggest that stimuli that appear in the focus of attention benefit from enhanced early sensory-perceptual processing (indexed by the P1 and/or N1 components), independently of whether visual-spatial attention is deployed voluntarily or captured involuntarily by a salient peripheral onset cue (Hopfinger and Mangun, 1998, 2001; Mangun, 1995; Mangun and Hillyard, 1991).

Another type of attention that has been extensively studied, often referred to as central attention, involves our limits in performing concurrent multiple tasks. The psychological refractory period (PRP) paradigm has been used extensively to study multitasking attentional limitations. In the PRP paradigm, two distinct targets, T_1 and T_2, are presented sequentially, and a speeded response is required for each target. The processing overlap between $Task_1$ and $Task_2$ is usually manipulated by varying the temporal interval between the onset of the two targets (i.e., the T_1–T_2 stimulus onset asynchrony, or SOA). Even with very simple stimuli and associated tasks, the PRP paradigm yields robust interference effects, reflected mostly by an increase in mean response time to the second target (RT_2) as SOA is reduced (i.e., as task overlap is increased). Virtually all models of dual-task interference claim that interference in the PRP paradigm occurs at a relatively late, central locus of processing, such as response selection and decision-making (e.g., Pashler, 1994; Tombu and Jolicœur, 2003).

Based on behavioural evidence, some researchers claimed that visual-spatial attention and central attention are independent (e.g., Johnston et al., 1995; Pashler, 1991). However, in recent electrophysiological studies, Brisson and Jolicœur (2007a,b,c) measured the N2pc elicited by a lateralized visual target (defined by colour) under different task overlap conditions using audio–visual cross-modal PRP paradigms, and observed a smaller N2pc in high concurrent central load conditions, that is to say, with shorter T_1–T_2 SOAs or a more difficult task associated with T_1. The N2pc was quantified following the subtraction of the ipsilateral waveforms from the contralateral waveforms, eliminating all overlapping activity that was not lateralized with respect to the side of T_2 (i.e., $Task_1$ stimulus, preparation, and response activity, as well as T_2 display onset, and $Task_2$ preparation, and response activity). Therefore, the N2pc attenuation in these studies could not have been caused by overlapping $Task_1$ activity obscuring the N2pc.[1] Brisson and Jolicœur (2007a) have also demonstrated that the N2pc attenuation could not have been caused by a PRP-induced failure of colour perception, nor by cross-modal spatial capture by the tone (McDonald and Ward, 2000). Therefore, the N2pc attenuation in high concurrent central load conditions observed in Brisson and Jolicœur (2007a,b,c) provided strong evidence that concurrent central processing of a tone interferes with the voluntary deployment of visual-spatial attention, and therefore that at least the voluntary deployment of visual-spatial attention requires central resources.

[1] For further discussion and empirical evidence validating this theoretical assumption, see Brisson and Jolicœur (2007a,b).

The goal of the present study was to determine whether the contingent involuntary deployment of visual-spatial attention, occurring in response to a task-irrelevant distractor sharing the relevant attentional selection characteristic, also requires capacity-limited central resources. To accomplish this goal, the contingent capture task used in Leblanc et al. (2008; Experiment 4) was incorporated as the second task of an audio–visual PRP paradigm, and the N2pc elicited by the lateralized distractor that matched the observers' top-down attentional control settings was measured in different concurrent central load conditions, manipulated with SOA. In this particular contingent capture task, only two peripheral distractors are presented, in the left and right visual fields. One distractor is grey, and the other is coloured. In half the trials, the coloured distractor shares the target-defining attribute, that is to say, its colour. This symmetrical configuration allows the measurement of the N2pc in a balanced display on the sensory level. Moreover, because there are only two distractors and that each of them is uniquely coloured, it ensures that the effect of the target-coloured distractor is due to the contingency between the distractor's colour and the top-down attentional control settings in favour of the target colour, and not to the singleness of the coloured distractor.

Measuring the N2pc was essential, not only because it provided a direct moment-by-moment index of the locus of visual-spatial attention, but also because behavioural results alone can lead to opposite interpretations. The present study was designed so that contingent capture would be reflected principally by a decline in accurate report of the second visual target when preceded by a target-coloured distractor compared to when it is preceded by a nontarget-coloured distractor. To determine whether the involuntary deployment of attention underlying contingent capture requires central resources, we would need to look at the interaction between the distractor colour condition (target-coloured distractor vs. nontarget-coloured distractor) and the SOA condition. At least two patterns of results could be expected: an underadditive effect of distractor colour with decreasing SOA, or an additive effect. Although it could be tempting to interpret an underadditive effect as evidence that concurrent central processing blocked the deployment of attention to the target-coloured distractor, thus reducing contingent capture, this pattern of results would also be predicted if the involuntary deployment of attention was independent from central resources, had time to be deployed to the distractor location and return to fixation before central processing was freed from the first task. On the other hand, it could be tempting to interpret an additive effect as an indication that contingent capture of visual-spatial attention was not affected by SOA, and therefore that the involuntary deployment of visual-spatial attention, occurring during the contingent capture of attention, does not require central resources. However, an additive effect could also indicate that contingent capture of visual-spatial attention was reduced at the shortest SOA, that is to say, that visual-spatial attention was not drawn, or not to the same extent, to the location of the target-coloured peripheral distractor, but that this effect was counterbalanced by an opposite effect. For example, it has been demonstrated that during the PRP period short-term consolidation of T_2 is delayed (Jolicœur and Dell'Acqua, 1998) and that before it gains access to short-term memory, T_2 representation is susceptible to decay, leading to a decrease in T_2 accuracy as SOA decreases when T_2 is masked in variants of the PRP paradigm (Brisson and Jolicœur, 2007a; Jolicœur, 1999; Jolicœur and Dell'Acqua, 1999; Pashler, 1991). Therefore, if the difficulty of selecting the item to be consolidated in short-term memory (i.e., the target) depends on the number of items that possess the target defining characteristic (i.e., selection of the target would be more difficult when a target-coloured distractor is