Acta Psychologica 135 (2010) 100–102

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/ locate/actpsy

Commentary

The top-down control of visual selection and how it is linked to the N2pc component

Martin Eimer *, Monika Kiss

Department of Psychology, Birkbeck College, University of London, Malet Street, London WC1E 7HX, UK

Is the spatial selection of visual objects fully under the control of top-down factors such as current tasks sets? In his admirably clear and systematic review (Theeuwes, 2010), Jan Theeuwes claims that the selection of visual objects is determined solely by bottom-up mechanisms that are independent of observers' selection intentions, and that top-down control only comes into play at later stages of attentional processing. His argument starts with the assumption that visual information is initially processed in a parallel and feedforward fashion, and that this early stage is entirely stimulus-driven. That much is not contentious — in fact, many models of visual processing and attentional selectivity assume the existence of an early fast feedforward sweep that is essentially non-selective. Theeuwes' central and controversial claim concerns the factors that drive the subsequent attentional selection of visual objects. He argues that this selection is determined by bottom-up salience maps that are computed during the initial parallel visual processing stage. Crucially, this salience-driven attentional object selection cannot be prevented or even modulated by top-down task set. Top-down factors can only influence what happens after an object has been selected; for example, attention can be rapidly disengaged from objects that do not possess currently task-relevant attributes. But intentional factors have no role whatsoever in the attentional selection of visual objects.

It is unusual to define a psychological concept (bottom-up visual selection) by applying a *negative* criterion (the absence of intentional modulation). As a result, there is a surprisingly wide range of cases that appear to meet this criterion. For example, Theeuwes considers phenomena such as intertrial feature priming or memory-driven attentional capture to be instances of bottom-up selection, even though here the selection of visual objects is not determined by their salience. Such an extension of the concept of bottom-up selection beyond situations where attentional selectivity is demonstrably and exclusively driven by visual salience comes at a price: if we no longer have a straightforward empirical criterion on which to base the distinction between bottom-up versus top-down attentional selection, we are likely to find cases that could be categorized either way. Theeuwes argues that intertrial priming phenomena such as the priming-of-popout effect described by Maljkovic & Nakayama (1994) are bottom-up, because they are unrelated to top-down selection intentions. But is this strictly true? Such intertrial priming effects owe their existence to the fact that on preceding trials, observers employed top-down control to select search targets and inhibit distractors. Likewise, memory-driven attention capture effects (Olivers, Meijer & Theeuwes, 2006) arise when observers intentionally decide to maintain specific objects in visual working memory. Are such situations really conceptually different from task-set contingent attentional capture (Folk, Remington & Johnston, 1992), which – according to Theeuwes – represents a prototypical case of top-down controlled attentional selection? In fact, Folk et al. (1992) characterize this type of attentional capture as 'involuntary', because once a top-down control setting is established (usually via task instructions at the start of the experiment), singletons that match this setting attract attention even though they are known to be task-irrelevant and thus unrelated to current selection intentions. In this respect, task-set contingent attentional capture seems remarkably similar to intertrial feature priming and memory-driven capture, and it is by no means obvious why these phenomena should be located on opposite sides of the top-down/bottom-up divide.

Leaving aside this specific conceptual concern, the main question is whether we should accept Theeuwes' general claim that top-down factors play no role in the attentional selection of visual objects. At first sight, this hypothesis seems relatively easy to refute: all that is required is a clear case where the attentional processing of salient visual objects (such as feature singletons) is demonstrably modulated (enhanced, prevented, delayed) by top-down factors such as currently active task sets. However, Theeuwes' claim is more specific. He does not suggest that the entire temporally extended process of attentionally processing visual objects is exclusively driven by bottom-up factors (which would indeed be easy to refute). Instead, he argues that the *initial* stage of selection is unaffected by top-down control. It is not always entirely clear where exactly this initial stage of attentional selectivity is supposed to be located. Sometimes, it seems to be the early rapid feedforward stage of visual processing itself that is characterized as selective but immune to top-down modulation. On other occasions, and more plausibly, Theeuwes argues that it is the output of this early feedforward stage – essentially salience maps – that provides the sole basis for the subsequent selection of visual objects, and that at this initial stage of attentional processing, top-down control has no role.

This emphasis on the 'initial stage' of attentional selection makes it clear that Theeuwes' claim for the primacy of bottom-up factors in attentional object selection is essentially a temporal argument—put simply: bottom-up selection precedes top-down selection. It is therefore no surprise that event-related potential (ERP) markers of attentional object selection play an increasingly prominent role in this

* Corresponding author. Tel.: +44 20 76316358; fax: +44 20 76316312.
E-mail address: m.eimer@bbk.ac.uk (M. Eimer).

0001-6918/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.actpsy.2010.04.010

debate, as ERPs can provide a millisecond-by-millisecond record of perceptual processes and how they are modulated by attention. In particular, the N2pc component has been employed in numerous studies, and on both sides of the top-down/bottom-up debate. The N2pc is an enhanced negativity at posterior electrodes contralateral to the visual field of a candidate target stimulus, is typically triggered at relatively early post-stimulus latencies (200 ms or less), and is thought to reflect the space-based attentional selection of visual objects (Luck & Hillyard, 1994; Eimer, 1996). Given these properties, the N2pc seems to provide an excellent tool to resolve disputes about the roles of bottom-up and top-down factors in the attentional selection of visual objects. Obviously, before this component can be employed to test Theeuwes' claim that the 'initial stage' of object selection is completely determined by bottom-up factors, it is essential to demonstrate that the N2pc is indeed a valid electrophysiological marker of attentional selection processes that take place at this hypothesized 'initial' stage. In his review paper, Theeuwes argues that the N2pc does not meet this requirement. In fact, the N2pc "does not say anything about attentional capture but about the post-selection processing occurring at a particular location" (section 3.2.2, p. 86). In other words, the N2pc does not reflect the initial selection of visual objects, but is instead linked to the attentional processing of visual features that takes place after an object has been selected.

This interpretation of the N2pc component has interesting consequences for the evidential role that N2pc results can play in debates about the impact of top-down versus bottom-up factors in attentional selection. According to Theeuwes, the presence of an N2pc in response to salient but task-irrelevant visual objects (as found by Hickey, McDonald & Theeuwes, 2006) provides irrefutable evidence for salience-driven bottom-up attentional capture. However, the observation that the presence of an N2pc to salient visual objects is completely determined by whether or not these objects match the currently active task set (as found in several of our recent studies: Eimer & Kiss, 2008; Eimer, Kiss, Press & Sauter, 2009; Eimer & Kiss, 2010) cannot be interpreted as evidence for the top-down control of attentional object selection. In cases where a perceptually salient visual stimulus fails to trigger an N2pc, the conclusion is instead that attention has been initially captured, but was rapidly disengaged before the post-selective attentional processing that is responsible for the N2pc has got under way. Essentially the same argument is also used to explain why no N2pc is elicited by salient colour distractors in the additional singleton paradigm when target and distractor features remain constant throughout a block of trials (Hickey & Theeuwes, 2008). In short, the N2pc provides unequivocal evidence for the bottom-up control of attentional object selection when it is triggered by task-irrelevant singletons, but no pattern of N2pc results can ever demonstrate that selection is determined by top-down factors. This is the case because the absence of an N2pc to salient but task-irrelevant objects is perfectly consistent with the possibility that attention was transiently captured but rapidly disengaged prior to any focal-attentional processing that would have triggered an N2pc. One does not have to be a strong believer in top-down control to be dismayed by this apparent bias in the evidential support that N2pc results can provide for the two different sides of the bottom-up/top-down debate. In fact, Theeuwes himself expresses similar sentiments about the idea of two independent search modes (feature versus singleton search; see Bacon & Egeth, 1994), which appears to him to be irredeemably biased towards top-down control, "because each time one observes attentional capture, the claim is that people choose to be captured" (section 3.3.3, p. 90). His conclusion is that the concept of search modes may not be very useful after all. One is tempted to raise an analogous objection with respect to the 'rapid attentional disengagement' hypothesis—"each time one presents salient visual singletons and observes no behavioural or ERP evidence for attentional capture, the claim is that there was attentional capture and almost instantaneous disengagement".

According to Theeuwes, N2pc results cannot provide evidence for the top-down control of visual object selection because this component is associated with a later, post-selective stage of attentional processing. Interestingly, this claim is based on the results of a recent ERP study from our lab (Kiss, Van Velzen & Eimer, 2008) where visual search displays with shape singleton targets were preceded by symbolic cues that signaled the side of a subsequent target with 100% validity, or by uninformative cues. Our aim was to determine whether the N2pc is exclusively linked to the attentional selection of visual objects, or whether this component also reflects preparatory shifts of endogenous spatial attention that take place in response to informative cues, prior to the presentation of visual search targets. In Theeuwes' own terminology, these preparatory attention shifts are equivalent to top-down controlled adjustments of the attentional window. Results were clear-cut: ERP components in the cue-target interval and behavioural spatial cueing effects demonstrated that observers made active use of spatially informative cues to direct their attention to the indicated target location. Critically, the N2pc that was elicited in response to visual search displays with shape targets was virtually identical on trials with informative and with uninformative cues. This result is important, because it demonstrates that the N2pc does not reflect preparatory endogenous adjustments of the attentional window that occur prior to the presentation of visual search displays, but instead the rapid attentional selection of visual targets that can only take place once these stimuli are actually physically present. Put differently: the N2pc is linked to the attentional selection of objects at specific locations, but not to the selection of spatial locations per se (see also Woodman, Arita & Luck, 2009, who use different procedures to demonstrate that the N2pc is associated with object-based rather than purely space-based attentional selection).

While the results of Kiss et al. (2008) demonstrate the link between the N2pc and the spatial selection of visual objects, there is nothing in these findings, or in our interpretation of these findings, that would suggest that the N2pc is linked to the focal-attentional processing of visual objects that takes place after their initial attentional selection. There is in fact every reason to assume that the N2pc reflects precisely this initial selection itself, and not the subsequent attentional processing of task-relevant visual features. In another experiment conducted in our lab (Mazza, Turatto, Umiltà & Eimer, 2007), where participants searched for colour singleton targets, the N2pc was measured in blocks where observers had to report the side where this singleton was presented, and in blocks where they had to make a much more difficult shape discrimination. In spite of the fact that in-depth feature processing was required only in the latter case, and a simple location discrimination was sufficient in the former case, N2pc components were virtually identical in both types of blocks, which strongly supports the hypothesis that this component does indeed reflect the initial spatial selection of visual target objects that precedes their subsequent in-depth analysis.

If there is no reason to assume that the N2pc is exclusively (or even primarily) linked to post-selective attentional processing, there is no basis for arguing that the N2pc cannot be used to demonstrate the impact of top-down factors on the initial attentional selection of visual target objects. Taking into account the experimental evidence that connects the N2pc with exactly this process, the fact that physically identical colour singleton cues trigger an N2pc when they share target-defining features, but not when their colour is task-irrelevant (e.g., Eimer & Kiss, 2008; Eimer et al., 2009) does provide strong support for the top-down control of visual selection. Even though the N2pc is a perfectly fine measure of rapid attentional object selection, one could still be tempted to argue that salient but task-irrelevant visual objects invariably capture attention, but that top-down controlled attentional disengagement is virtually instantaneous, thereby eliminating any measurable trace of an N2pc for such objects, and resulting in attentional capture without corresponding N2pc. One plausible response to this line of argument is to question the usefulness of a concept such as 'rapid

capture followed by instantaneous disengagement'. An alternative response – one that we are currently pursuing in our lab with new ERP experiments – is to track the time course of attentional disengagement and how it is affected by currently active task sets.

Acknowledgement

This work was supported by a grant from the Biotechnology and Biological Sciences Research Council (BBSRC), UK.

References

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

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology*, *99*, 225–234.

Eimer, M., & Kiss, M. (2008). Involuntary attentional capture is determined by task set: evidence from event-related brain potentials. *Journal of Cognitive Neuroscience*, *20*, 1423–1433.

Eimer, M., & Kiss, M. (2010). Top-down search strategies determine attentional capture in visual search: Behavioral and electrophysiological evidence. *Attention, Perception & Psychophysics*, *72*, 951–962.

Eimer, M., Kiss, M., Press, C., & Sauter, D. (2009). The roles of feature-specific task set and bottom-up salience in attentional capture: an ERP study. *Journal of Experimental Psychology: Human Perception & Performance*, *35*, 1316–1328.

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.

Hickey, C., & Theeuwes, J. (2008). ERP correlates of inter-trial effects in visual search. *Journal of Vision*, *8*, 6 (Abstract).

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

Kiss, M., Van Velzen, J., & Eimer, M. (2008). The N2pc component and its links to attention shifts and spatially selective visual processing. *Psychophysiology*, *45*, 240–249.

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

Maljkovic, V., & Nakayama, K. (1994). Priming of pop-out: I. Role of features. *Memory & Cognition*, *22*, 657–672.

Mazza, V., Turatto, M., Umiltà, C., & Eimer, M. (2007). Attentional selection and identification of visual objects are reflected by distinct electrophysiological responses. *Experimental Brain Research*, *181*, 531–536.

Olivers, C. N. L., Meijer, F., & Theeuwes, J. (2006). Feature-based memory-driven attentional capture: visual working memory content affects visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 1243–1265.

Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. *Acta Psychologica*, *135*, 77–99 (this issue).

Woodman, G. F., Arita, J. T., & Luck, S. J. (2009). A cuing study of the N2pc component: An index of attentional deployment to objects rather than spatial locations. *Brain Research*, *1297*, 101–111.