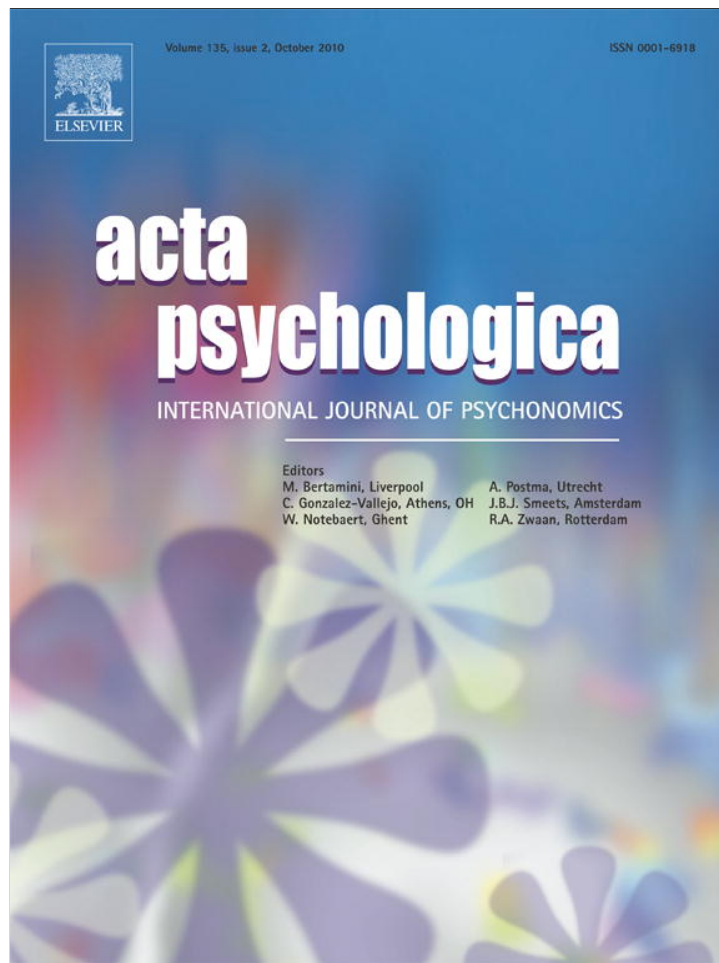


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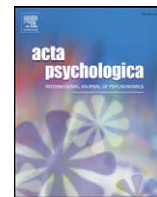
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Commentary

## Priming in visual search: A spanner in the works for Theeuwes's bottom-up attention sweeps?

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In his target paper, [Theeuwes \(2010\)](#) argues that when attention is spread across the visual field, the first sweep of information thorough the brain is completely stimulus driven. While I am sympathetic to many of the arguments in the paper, it seems clear that in some cases the argument hinges on how particular concepts are defined, namely, when can a psychological or perceptual process be considered “bottom-up”.

The core of Theeuwes's argument is that “[...] attention will shift in an exogenous fashion to the location with the highest local feature contrast, or salience” (p. 80) and that “[...] when attention is spread across the display, the calculation of a local feature difference occurs in a bottom-up fashion, which is not penetrable in a top-down volitional way” (p. 80) ([Theeuwes, 2010](#), p. 80). My argument here is that there are notable exceptions to this, which are not dealt with sufficiently well in the review.

I will consider the case of priming in visual search tasks (see e.g. [Kristjánsson & Campana, 2010](#), for review). Evidence from studies of priming in visual search shows that even very basic attentional processes, such as feature search, where the target differs from the distractor set on a single feature, are modulated by what occurs on a previous trial. While such priming seems not to be in any sense under conscious control, it can hardly be considered “stimulus driven”. [Theeuwes \(2010\)](#) argues nevertheless that priming is a bottom-up process, and priming plays, as we shall see, an important role in many of the arguments Theeuwes makes.

Another reason why priming may present problems for Theeuwes's account, one which may, in fact, prove harder to deal with, is that such priming has been shown to be affected by motivational factors, such as reward ([Hickey & Theeuwes, 2007](#); [Kristjánsson, Sigurjónsdóttir & Driver, in press](#); [Shen & Chun, 2009](#)) and attentional cueing ([Fecteau, 2007](#)). This would seem to suggest that priming is not as stimulus driven as Theeuwes's account seems to require. Since Theeuwes conceives of a priming as a bottom-up mechanism, this evidence for the role of motivational factors cries out for a satisfactory explanation within the account.

This comment has three main purposes. Firstly, to argue that priming of visual search suggests that feature search is indeed affected by non-stimulus driven factors, secondly that the conception of priming in the target paper is in need of clarification, and thirdly that findings of motivational effects upon priming causes problems for the account of attention in the target article ([Theeuwes, 2010](#)).

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### 1. Basic findings on priming

Probably the first systematic analyses of priming in visual search were performed by [Treisman \(1992\)](#) and [Maljkovic and Nakayama \(1994\)](#). The findings of Maljkovic and Nakayama are most relevant in this context. Maljkovic and Nakayama found that during search for a singleton target diamond of odd color relative to two distractor diamonds, search was faster if the target color from the last trial was repeated. These priming effects upon search times then accumulated the more often in a row the same target color was repeated.

This result was quite surprising in light of foregoing theorizing about visual attention, since pop-out was assumed in many theories to be entirely stimulus driven (e.g., [Treisman & Gelade, 1980](#); [Julesz, 1984](#)) and should subsequently not be affected by such repetition biases, since the target should simply pop out very clearly from its background, “no matter what”. This seems to present problems for Theeuwes's current account ([Theeuwes, 2010](#)), as well, since some key characteristics of these earlier accounts are retained in his current one.

Importantly, [Maljkovic and Nakayama \(1994\)](#) also showed that priming between trials for features such as color, spatial frequency, and spatial position was due to an implicit short-term memory mechanism, and not to the observers expectancies. The between trial priming effects were unchanged even though observers were 100% certain that the color on the next trial would change.

Priming in visual search has usually been interpreted as reflecting perceptual facilitation for the primed target (see e.g. [Kristjánsson & Campana, 2010](#)). At which level of perceptual processing these priming effects occur is important. While some have argued that priming affects response selection ([Huang, Holcombe & Pashler, 2004](#)) others have shown that perceptual sensitivity measured with  $d'$  is increased with priming while decision measures ( $c$ ) are not ([Sigurdardóttir, Kristjánsson & Driver, 2008](#)). [Kristjánsson and Campana \(2010\)](#) argued, in a recent review, that priming in visual search reflects modulations of processing at multiple levels of the perceptual hierarchy (see also [Kristjánsson, Ingvarsdóttir & Teitsdóttir, 2008](#)).

### 2. Priming and attentional capture

A purely bottom-up account of early attention predicts that there should be strong interference from task irrelevant distractors in feature search, if they have sufficient feature contrast against the other search

items, and also that these effects should not be modulated by any external task characteristics which do not affect the feature contrast of the irrelevant stimulus. In a number of cases Theeuwes argues that results which do not, on the surface, seem consistent with his bottom-up account can be explained with priming.

In Pinto, Olivers and Theeuwes (2005) the observers underwent trial blocks, where the shape of targets and singleton distractors was constant throughout a block. This was compared with blocks where the shape of the targets and singleton distractors randomly changed from trial to trial. The costs associated with the presence of a color singleton distractor were larger in this mixed condition, which is seemingly problematic for a bottom-up account of attentional capture, since the feature contrast alone should determine the degree of attentional capture.

But when Pinto et al. compared the singleton distractor effect on trials where the target identity switched from the preceding trial versus when it remained unchanged in the variable condition with the effect in the constant condition they found that "...this increased distractor singleton effect was entirely traced to intertrial priming, since the increased costs occurred only on trials in which the target and the distractor singleton swapped identity [...] or [...] the target alone changed identity" (Theeuwes, 2010, p. 82). Fine. But if this is to serve as support for the bottom-up nature of attentional capture, priming must be bottom-up. Theeuwes is clear on this, arguing that in this case the "...selection is driven by relatively automatic bottom-up priming effects (p. 82)."

Another case in point are results showing that cueing the observers about the properties of an upcoming target only leads to modulations of feature search when the actual target is used as a cue (Theeuwes, Reimann & Mortier, 2006), which is likely to reflect priming, as Theeuwes correctly argues. Also Theeuwes and Van der Burg (2007) found that symbolic cues did not affect perceptual sensitivity in a singleton search task, but cueing with the actual target speeded selection and improved sensitivity. This was attributed to priming, since cueing effects were only seen when the cue-stimulus was repeated on the search trial that followed.

Finally, Theeuwes argues that the "contingent-capture" findings of Folk, Remington and Johnston (1992), perhaps the most prominent alternative to Theeuwes's bottom-up account of attentional capture, reflect "bottom-up priming" instead of modulation of attentional capture by the observers goals (Belopolsky, Schreij & Theeuwes, 2010). In fact this argument is reminiscent of the one of Kristjánsson, Wang and Nakayama (2002) who argued that a large portion of effects attributed to top-down guidance in visual search tasks in fact reflect priming.

From the above it is clear that priming plays an important role in some key arguments in the paper. Theeuwes (2010) argues that priming is: "...bottom-up, because these [priming] effects cannot be counteracted by volitional top-down control" (p. 78). There is indeed good evidence that priming is implicit, but can the priming effects be part of the first sweep of attention which is completely stimulus driven, according to the account provided in the paper?

Theeuwes's account can be contrasted with an account of priming effects from Wolfe, Butcher, Lee and Hyle (2003) who argued that priming is an example of implicit top-down guidance, noting: "Because [priming] relies on what the observer has learned about the prior trials and does not rely solely on the state of the stimulus, we consider it to be a form of implicit top-down guidance." (p. 483). A third way of looking at this can be found in Kristjánsson et al., 2002 who argued that "top-down activation may [...] be [...] thought of as an elevated activation state for a given feature, determined by the display items on the preceding few trials" (p. 50). What this highlights is that there is no consensus on how priming in visual search tasks is to be defined. Theeuwes claims that priming is bottom-up while the latter two accounts are concerned with the role priming plays in determining top-down attentional set.

These differences in opinion as to what the nature of priming is are at the heart of the matter here. It is clear that in many cases what priming exactly involves is vital for the arguments made. Even though a process is automatic, it does not necessarily follow that it is entirely stimulus driven, or "bottom-up". Here perhaps lies the weakest point of Theeuwes's argument, especially when we read that "selection is driven by relatively automatic bottom-up priming mechanisms" (p. 82), which is not particularly clear. The question remains then, to what extent can these effects be considered "bottom-up"?

Theeuwes (2010) notes on page 81 that the "crucial question is whether top-down knowledge can affect the initial selection of stimuli" (p. 81), and goes on to argue that it cannot. For the present purposes the question becomes whether priming can affect this initial selection, and to what degree the priming effects are a bottom-up process. Theeuwes's main reason for postulating that priming is bottom-up is that priming is implicit, that it is not under top-down control. But below I will present some examples where motivational factors seemingly affect priming.

### 3. Motivational factors influence priming

Fecteau (2007) found that precuing a singleton target on a consequent search trial led to modulations of the within-trial priming pattern. Her participants searched for a color or shape singleton. A verbal cue at the beginning of each trial indicated which singleton was relevant for that trial. The observers were supposed to report the direction of a gap (left vs. right) on the relevant singleton. Fecteau found that the cue strongly affected the priming pattern, leading her to conclude that "...our goals change what we process automatically" (p. 9) and that "our intentions [...] govern which properties of the previous trial influence performance" (p.7).

More recent evidence has shown that priming is sensitive to reward (Kristjánsson, Sigurjónsdóttir & Driver, 2010; Hickey & Theeuwes, 2008; Shen & Chun, 2009). Kristjánsson et al. found that the amount of monetary reward associated with a particular target color in a feature search task strongly affected the priming of pop-out. This occurred even though the reward schedule was probabilistic, and could even reverse unexpectedly.

The most straightforward explanation for such effects is that what is stimulus-based (or bottom-up) in the display is affected by motivational factors – by definition a top-down process. These motivational factors do not appear to have to be particularly explicit, however – the observers were, for example, unaware of the reward schedules in Kristjánsson et al (2010).

Theeuwes has a comment relevant to this, stating that bottom-up signals can "[...] be acquired through intertrial priming, conditioning, or reward contingencies" (p. 78, footnote). Unfortunately this is too vague, and does not clarify how priming should be considered a bottom-up process, and certainly not what it means when priming is affected by non stimulus-based factors.

### 4. Conclusions

To sum up, one might criticize Theeuwes' account (2010) on the grounds that priming affects performance on feature search tasks – the hallmark of bottom-up effects in attention research. This is not a problem for Theeuwes' account of visual attention if one accepts the proposal that priming is indeed bottom-up. Priming can hardly be considered a top-down effect, and it has rather conclusively been shown not to reflect response facilitation but affect a more basic (or "earlier") process (Sigurdardóttir et al., 2008). But my argument here is that Theeuwes's account comes up short in this regard. The bottom-up nature of priming is not made explicit despite its importance for some key arguments.

It is clear that a precise delineation of priming in visual search as a bottom-up process is required for Theeuwes's account to be

considered complete. Perhaps the most important thing to note is that Theeuwes has not effectively ruled out the most obvious explanation for the original findings on priming. Namely, that the degree to which a target which has a higher feature contrast against its background captures attention is modulated by what has gone before, by the reward level associated with a given feature, or by the observers goals.

Priming is used to explain important findings which on the surface seem to contradict the authors account, which makes a clear delineation of what level of processing priming operates on all the more important. Priming is used to explain away evidence against a "bottom-up" view of early attention, and is somewhat conveniently defined as bottom-up, but there is no consensus in the literature that priming is bottom-up, nor does the target article elucidate why it is.

Finally, in light of the foregoing, one is left wondering whether models of attention where attention is assumed to operate as a race between selection and identification handle these issues better since they avoid the dichotomy of purely bottom-up stages of processing and subsequent stages which are affected by the observers goals in each case. A model such as Bundesen's theory of visual attention (Bundesen, 1990) is aimed at sidestepping the early versus late debate, and in the end this issue revolves around at what point motivational factors enter into the picture — how "early" or how "late" given your preference.

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