Consciousness and Cognition 35 (2015) 30–32

Contents lists available at ScienceDirect

Consciousness and Cognition

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

Commentary

Using continual flash suppression to investigate cognitive aftereffects ☆

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ARTICLE INFO

Article history:
Received 24 April 2015

Keywords:
Cognitive aftereffects
Priming
Continual flash suppression
Habituation
Negative valence
Reading

ABSTRACT

In a naming task with visually presented words, Prioli and Kahan (in press) reported that negatively valenced words were identified more slowly than neutral words in a condition with continual flash suppression (CFS), which involves showing the dominant eye changing Mondrian patterns, delaying awareness for the word shown to the other eye. However, when these same words were shown to both eyes (i.e., no CFS), negatively valenced words were identified more quickly. The authors hypothesized that the negative word deficit with CFS reflects greater habituation (i.e., a cognitive aftereffect) that accrues for negative words before the observer becomes aware of the word. However, aftereffects typically occur in response to a target stimulus that follows an adapting stimulus, rather than in response to a single stimulus that is initially processed without awareness. Thus, it is not immediately obvious that the explanation provided by Prioli and Kahan is adequate. Here I report a simulation using a model that was previously applied to cognitive aftereffects, demonstrating that their account can explain this crossover interaction. These results suggest that CFS may be a useful technique for studying cognitive aftereffects without concern for conscious decision strategies.

For more than a century, vision scientists have used visual aftereffects to study visual processing. For instance, by observing that a white stimulus is perceived as red following adaptation to a green stimulus, vision scientists developed the theory of opponent processing (e.g., Hering, 1878/1964). The neural habituation dynamics that underlie these effects have been observed at the level of single neurons not only within visual areas of the brain, but throughout the cortex (Nelson, Varela, Sen, & Abbott, 1997). It follows that aftereffects should exist for high-level perception and even abstract concepts; the study of 'cognitive aftereffects' may illuminate the nature of representations for many aspects of cognition. However, because the observer is aware of the adapting stimulus, an effect that may appear to be a cognitive aftereffect may instead reflect a bias, demand characteristic, or decision strategy. This is less of a concern for visual aftereffects because "seeing is believing"; a skeptic need only experience the visual aftereffect for herself to conclude that the effect is truly visual rather than the result of a post-perceptual decision processes.

A key property of an aftereffect is that it takes time to emerge; if the adapting stimulus is viewed only briefly, this reduces the aftereffect, and can even produce perception congruent with the adapting stimulus rather than contrasting with it (Long, Toppino, & Mondin, 1992). In my research I have used this property to document cognitive aftereffects (see Huber (2014) for

☆ Commentary on Prioli, S. C., & Kahan, T. A. (in press). Identifying words that emerge into consciousness: Effects of word valence and unconscious previewing. *Consciousness and Cognition*, xx, xxx–xxx.

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http://dx.doi.org/10.1016/j.concog.2015.04.017
1053-8100/

a recent review), observing reversals from positive aftereffects to negative aftereffects as a function of increasing time spent considering the first stimulus (e.g., changing the viewing duration of a prime word prior to a subsequent target word). Nevertheless, it could be argued that a negative aftereffect following a long-duration prime reflects strategic discounting or a bias shift to counteract the "true" positive aftereffect that is seen following a brief prime (Burt, Kipps, & Matthews, 2014; Jacoby & Whitehouse, 1989; Ratcliff & McKoon, 2001; Whittlesea & Williams, 2000). The continual flash suppression (CFS) results reported by Prioli and Kahan (in press) suggest that CFS may be a technique for differentiating between these theoretical alternatives because, with CFS, an adapting stimulus can be presented for a duration sufficient to produce a negative aftereffect and yet the observer is completely unaware that anything has been presented (Tsuchiya & Koch, 2005); in the absence of awareness, a negative aftereffect cannot be explained as strategic correction.

In Prioli and Kahan's (in press) study, observers pressed a button as soon as they could identify a visually presented word. The visual contrast of the word gradually increased over time and reaction time was the measure of interest. In the CFS condition, the word was shown only to the non-dominant eye, and it took observers approximately 1600 ms to identify the word. In the binocular condition, the word was shown to both eyes, and it took observers approximately 700 ms to identify the word. Thus, it appears that presenting changing Mondrian patterns to the dominant eye in the CFS condition delayed awareness of the word by nearly a second. Remarkably, they reported a crossover interaction between word valence and binocular/CFS viewing in which negatively valenced words (e.g., 'loser') were identified more quickly than neutral words with binocular viewing but more slowly than neutral words with CFS viewing.

Prioli and Kahan (in press) hypothesized that the advantage for negative words with binocular viewing reflects the well-supported assumption that negatively valenced words automatically grab attention. They further supposed that the deficit with CFS reflects greater habituation for negative words (i.e., a cognitive aftereffect) owing to the previous allocation of attention without awareness during CFS. However, aftereffects typically occur in response to a target stimulus that follows an adapting stimulus, rather than in response to a single stimulus that transitions from processing without awareness to processing with awareness. Thus, it is not immediately obvious that their account is adequate. To examine this situation in greater detail, I simulated their paradigm with a neural habituation model (Huber & O'Reilly, 2003) previously used to explain word priming (Huber, 2008), face priming (Rieth & Huber, 2010), semantic satiation (Tian & Huber, 2010), recognition priming (Huber, Clark, Curran, & Winkielman, 2008), change detection (Davelaar, Tian, Weidemann, & Huber, 2011), and of greatest relevance to the current simulation, the priming of speeded valence ratings made in response to highly affective pictures (Irwin, Huber, & Winkielman, 2010). The parameters of the model were set to the default values for visually presented words, which were determined from Experiment 1 of Huber (2008); these same default values have been used to produce accurate quantitative accounts of word reading as measured both by behavioral choices (Huber, Clark et al., 2008) and electrophysiology (Huber, Tian, Curran, O'Reilly, & Woroch, 2008; Tian & Huber, 2013).

Neutral words were processed in the same manner as in previous applications of the model, using only default parameters. Negative words also used default parameters, but with stronger visual input owing to greater attentional capture (the model includes three layers of representation, with visual input driving a visual response, which in turn drives an orthographic response, which in turn drives a semantic response). Negative words initially had the same visual input as neutral words, but as the semantic response rose above zero, visual input was increased by an amount equal to the magnitude of the semantic response multiplied by an attentional capture parameter set to 10. For instance, if the visual contrast of the word was 50%, the magnitude of visual input to the model was initially .5 for all words, but whereas this value remained constant for neutral words, it gradually rose for negative words as the semantic response resulted in attentional capture. In this manner, the model was able to "see" the negatively valenced words more quickly at low visual contrast. Response latencies were predicted by accumulating semantic activation values over time until a threshold value of 50, reflecting the evidence necessary for accurate identification (e.g., Ratcliff, 1978).

As described above, the model predicts an advantage for negative words with binocular viewing. To capture the effect of CFS, the accumulation of semantic activation for behavioral responses was delayed until the observer became aware that a word was presented. In other words, prior to conscious detection of the word, there is a semantic response to the word, but that response is ignored because the perceptual source is unknown. The simulation in Fig. 1 used the exact timing and visual contrasts used by Prioli and Kahan (in press) to investigate different delays in the time to detect the word (i.e., different delays in the start of the semantic activation accumulation process). Up until 300 ms, there was no effect of delaying word detection. This is because with low initial visual contrast, the model predicts that semantic activation does not rise above zero for the first 300 ms. Delays less than 300 ms correspond to binocular viewing, which allows rapid detection of the word, providing a quantitatively accurate account of the observed data by predicting 700 ms reaction times and by predicting a 50 ms advantage for negatively valenced words. However, if CFS delays word detection beyond 600 ms, a very different pattern emerges. With a large delay, the representation of the word is habituated prior to the onset of the accumulation process. Once accumulation begins, a negatively valenced word is at a disadvantage because, despite receiving greater visual input, the representation for that word is more habituated and less responsive to any visual input. If the delay is 900 ms, the model provides a quantitatively accurate account of the observed CFS data by predicting 1600 ms reaction times and by predicting that negative words will take 100 ms longer to identify.

In summary, by adding an attentional capture factor and by assuming that CFS delays the start of evidence accumulation, this simulation provides a fairly accurate quantitative account of Prioli and Kahan's (in press) data. Not only does this provide further support for this particular neural habituation model, but it suggests that CFS may be a useful tool for investigating cognitive aftereffects. If CFS delays the start of evidence accumulation, it is as if two different stimuli are presented

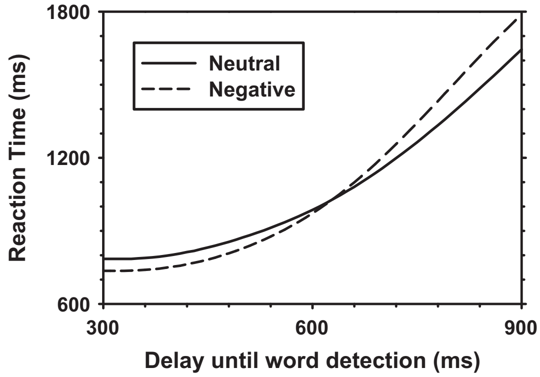

Fig. 1. Simulation of the continual flash suppression (CFS) results reported by Prioli and Kahan (in press), using the neural habituation model of Huber and O'Reilly (2003). The *y*-axis shows the reaction time to accumulate a threshold amount of semantic activation in response to a visually presented word of increasing visual contrast. The visual input for negatively valenced words was assumed to rise above the level for neutral words owing to attentional capture (see text for details). As compared to binocular viewing, the effect of CFS was modeled by assuming that conscious detection of the word was delayed by an amount shown on the *x*-axis, which delayed the accumulation of semantic activation toward a behavioral response.

(the second one a repetition of the first), with the first stimulus (e.g., the word prior to awareness) serving to produce habituation that negatively affects processing of the second stimulus (e.g., the same word after awareness). In this manner, CFS can be used to produce cognitive aftereffects that will provide deeper insight into a broad range of cognitive phenomena without concern for decision biases and other forms of strategic responding based on conscious awareness for the adapting stimulus.

Acknowledgment

This work was supported by the National Science Foundation BCS-1431147.

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