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Neural evidence that inhibition is linked to the affective devaluation of distractors that match the contents of working memory

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ABSTRACT

Stimuli appearing as visual distractors subsequently receive more negative affective evaluations than novel items or prior targets of attention. Leading accounts question whether this distractor devaluation effect occurs through evaluative codes that become associated with distractors as a mere artefact of attention-task instructions, or through affective consequences of attentional inhibition when applied to prevent distractor interference. Here we test opposing predictions arising from the evaluative-coding and devaluation-by-inhibition hypotheses using an electrophysiological marker of attentional inhibition in a task that requires participants to avoid interference from abstract-shape distractors presented while maintaining a uniquely-colored stimulus in memory. Consistent with prior research, distractors that matched the colour of the stimulus being held in memory elicited a Pd component of the event-related potential waveform, indicating that their processing was being actively suppressed. Subsequent affective evaluations revealed that memory-matching distractors also received more negative ratings than non-matching distractors or previously-unseen shapes. Moreover, Pd magnitude was greater on trials in which the memory-matching distractors were later rated negatively than on trials preceding positive ratings. These results support the devaluation-by-inhibition hypothesis and strongly suggest that fluctuations in stimulus inhibition are closely associated with subsequent affective evaluations. In contrast, none of the evaluative-coding based predictions were confirmed.

1. Introduction

Stimuli appearing as visual distractors subsequently receive more negative affective evaluations than novel items or prior targets of attention (Raymond et al., 2003). Such distractor devaluation effects have been found across a wide range of attention tasks requiring stimulus discrimination based on features, categories, spatial location, or temporal position (e.g., Fenske et al., 2004; Goolsby et al., 2009b; Kihara et al., 2011; Martiny-Huenger et al., 2014; Raymond et al., 2005), and have been obtained with a variety of stimuli including simple abstract patterns and shapes (e.g., Raymond et al., 2003), alphabetic and logographic characters (e.g., Martiny-Huenger et al., 2014; Veling et al., 2007), common objects (e.g., Griffiths and Mitchell, 2008), corporate brands (e.g., Duff and Faber, 2011), and human faces (e.g., Raymond et al., 2005). The distractor devaluation effects in these studies have been observed as changes in a number of different subjective emotional judgments, including stimulus valence, likeability, favorability, beauty, cheerfulness, dreariness, pleasantness, and trustworthiness.

1.1. The devaluation-by-inhibition hypothesis

The distractor devaluation effect has been taken as evidence that attentional inhibition, presumably applied to prevent distractor interference, has negative affective consequences for associated stimuli (see Fenske and Raymond (2006), Gollwitzer et al. (2014), Raymond (2009) for reviews). Support for this devaluation-by-inhibition hypothesis has come from both cognitive-behavioural and neuroimaging studies. The cognitive-behavioural studies (e.g., Fenske et al., 2005, 2004; Raymond et al., 2005) utilized experimental conditions that are considered to vary in the level of inhibition required for successful task completion. In subsequent evaluations, the stimuli in conditions thought to involve greater inhibition consistently received more negative ratings than those in conditions thought to involve less inhibition. The results of Raymond et al. (2005) and Martiny-Huenger et al. (2014), for example, both supported a key prediction arising from the devaluation-by-inhibition hypothesis; namely, because distractors located close to a target of selective attention have greater interference potential and are therefore subjected to greater levels of inhibition than items further away (Cutzu and Tsotsos, 2003; Hopf et al., 2006; Mounts, 2000), they

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should also subsequently receive more negative stimulus ratings than distant distractors.

Other findings from a line of studies involving Go/No-go and Stop-Signal tasks (Fenske et al., 2005; see Gollwitzer et al. (2014) for review; Kiss et al., 2008; Wessel and O'Doherty, 2014) suggest that motor-response inhibition also has deleterious consequences for associated stimuli. This raises the possibility that stimulus devaluation results from neurocognitive inhibition regardless of the specific processing level (i.e., sensory/perceptual, response/action, memory/cognition, etc.) at which it is applied. Converging support for this more general version of the devaluation-by-inhibition hypothesis comes from experimental paradigms designed to explore the inhibition of stimulus memories (e.g., Think/No-think, Directed Forgetting), which have likewise provided results suggesting that stimuli whose memories have been inhibited become affectively devalued (De Vito and Fenske, 2017; Vivas et al., 2016, cf. Janczyk and Wühr, 2012). Taken together, the cognitive-behavioural results obtained following a variety of manipulations of attention-, response-, and memory-related inhibition broadly support the hypothesis that cognitive processes of inhibition have negative affective consequences for associated stimuli.

The devaluation-by-inhibition hypothesis has also received support from the results of neuroimaging investigations into the affective consequences of selective attention (Kiss et al., 2007) and response inhibition (Doallo et al., 2012; Kiss et al., 2008) in tasks using visual stimuli. Kiss et al.'s (2007) electroencephalography (EEG)-based approach, for example, involved an assessment of the N2pc component of the event-related potential (ERP) waveform during periods in which participants ignored a distractor while searching for a stimulus with a pre-specified target feature. They found that differences in the emergence of the N2pc component—widely considered to provide an index of the efficiency with which attention was selectively allocated to a target stimulus in the presence of visual distractors (e.g., Eimer, 1996; Luck and Hillyard, 1994)—were linked to the magnitude of distractor devaluation. The N2pc component on trials containing distractors that subsequently received the most negative ratings emerged significantly earlier than the N2pc on trials containing distractors that subsequently received more positive ratings. To the extent that trial-by-trial variations in N2pc onset reflect the efficiency of attentional selection aided by distractor inhibition (Luck and Hillyard, 1994), these results are consistent with the notion that the level of attentional inhibition applied to a distracting stimulus is linked to the magnitude of its subsequent affective devaluation. Nevertheless, inhibition is not the only factor that has been proposed as an explanation for the distractor devaluation effect.

1.2. The evaluative coding hypothesis

A leading alternative to the devaluation-by-inhibition account of distractor devaluation is Dittrich and Klauer's (2012) proposal, based on Eder and Rothermund's (2008) evaluative coding principle, that prior distractors are only rated more negatively than prior targets because of evaluative codes that become associated with targets and distractors solely through attention-task instructions. According to this perspective, merely instructing participants to seek, attend to, select, respond to or otherwise accept some items (targets), and to ignore, avoid, or otherwise reject other items (distractors) is sufficient to impact subsequent ratings because of prior associations linking stimulus approach to positive items and stimulus avoidance to negative items (Chen and Bargh, 1999). Consistent with this view, Dittrich and Klauer observed that stimulus ratings in two experiments were critically affected by manipulations of the attention-task instructions that altered the evaluative meaning of targets and distractors. Indeed, differences in stimulus ratings in their studies were primarily linked to instruction-driven connotations about which items were irrelevant and to-be-rejected or relevant and to-be-accepted, rather than the actual attentional status of a given item as a prior target or prior distractor as would have been predicted by the devaluation-by-inhibition hypothesis.

In reconciling Kiss et al.'s (2007) electrophysiological findings regarding a link between the N2pc component and distractor devaluation with their evaluative-coding hypothesis, Dittrich and Klauer (2012) argue that fluctuations in the efficiency of selective attention, as reflected by N2pc latency, may impact how well targets and distractors can be perceptually discriminated and therefore how likely each could be clearly coded as something to-be-accepted or to-be-rejected. Thus, the evaluative-coding account posits that the effects of selective attention on subsequent stimulus ratings has nothing to do with distractor inhibition and everything to do with the strength of the association between each item and the evaluative codes that become attached during the selection process. The strength of conclusions about the specific link between distractor inhibition and affective devaluation that can be drawn from Kiss et al.'s (2007) results has also been affected by the emergence of findings that question the specific link between the N2pc and distractor suppression. Indeed, there is growing consensus that the N2pc component, while often emerging under conditions involving distractor inhibition, is not itself an index of inhibition but more directly related to enhanced processing of target information (e.g., Mazza et al., 2009). Fortunately, other advances in cognitive-electrophysiology include the identification of a marker that more directly reflects distractor inhibition during selective attention (e.g., Hickey et al., 2009). This is known as the Pd component—a positive-voltage deflection in the ERP waveform appearing 150–300 ms post-stimulus over regions of visual cortex contralateral to the location of a visual distractor—and is now widely thought to indicate the termination of attention to distracting stimuli and the active suppression of their perceptual processing (see Sawaki and Luck (2014) for review). The benefit of having this more direct neural index of distractor inhibition is that it enables a more direct test of the devaluation-by-inhibition hypothesis. We report the results of this test here, which we conducted using a paradigm that was selected for its ability to simultaneously provide an assessment of competing predictions arising from the evaluative-coding and devaluation-by-inhibition hypotheses.

1.3. Tests of competing predictions

The experimental procedure used in our study is a modified version of that developed by Sawaki and Luck (2011) to investigate the potential involvement of attentional inhibition in protecting the contents of visual working memory from the interfering effects of salient distractors. The main task requires participants to first select one of two visual stimuli and then maintain it in working memory throughout a retention interval. This would allow them to accurately choose this memorized item from a subsequent test display that includes the original plus a rotated version of it. The ability to correctly remember the item on these memory trials is complicated by the appearance of a pair of task-irrelevant distractors during the retention interval—one on each side of fixation. Moreover, the potential for interference is increased by always having one of the distractors be the same colour as the memorized item. While such memory-matching stimuli have been shown to initially capture attention (e.g., Soto et al., 2005), Sawaki and Luck found that their perceptual processing is ultimately actively suppressed, as evidenced by a Pd contralateral to the memory-matching distractor. This finding suggests that the level of suppression required to prevent the memory-matching distractor from interfering with the active contents of working memory was greater than that required to prevent interference from the non memory-matching distractor.

We adapted Sawaki and Luck's (2011) main experimental task to incorporate affective evaluations of stimuli that had previously appeared as either a memory-matching distractor or non-matching distractor during a memory-retention interval. Beyond providing an experimental context for assessing possible links between fluctuations in an electro-cortical index of distractor inhibition and subsequent