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## REWARD HISTORY MODULATES PERCEPTUAL LOAD EFFECTS

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### ABSTRACT

The reward history of a stimulus can yield strong attentional selection biases. Indeed, attentional capture can be triggered by previously rewarded items which are neither salient nor relevant for the ongoing task, even when selection is clearly counter-productive to actually obtain the reward outcome. Therefore, value-driven attentional capture (VDAC) has been argued to be an automatic attention mechanism. Our study aimed at putting the VDAC automaticity directly to the test. For this purpose, the Load Theory offers a comprehensive framework where distraction is observed under low but not high perceptual load condition. Nevertheless, if VDAC is indeed automatic, distraction by reward-stimuli should be observed on both perceptual load conditions. We used a feature vs. conjunction discrimination of a go/no-go cue to manipulate perceptual load. As expected, our results revealed that perceptual load decreased interference produced by low-reward distractor. However, this effect was not significant for high-reward distractor, giving support to VDAC automaticity. We discussed our results in light of the Load Theory literature and we strongly encourage to consider reward history along with perceptual load in determining attentional capture.

### KEYWORDS

Selective Attention; Distraction; Reward; Perceptual Load; Automaticity

## INTRODUCTION

In face of a continuous stream of sensory inputs that exceed our limited information processing resources, selective attention allows the selection of some information for further processing while rejecting others (Desimone & Duncan, 1995; Hickey et al., 2009). Most of the time, we can intentionally pick out relevant information to achieve our current goal, a process referred to as top-down or “goal-driven” selection. However, we also sometimes experience that some stimuli (mainly physically salient stimuli in the environment, e.g., a sudden bright flash) capture our attention against our will, despite being completely irrelevant to the ongoing task (i.e., distractors), a process referred to as bottom-up or “stimulus-driven” selection. Goal- and stimulus-driven selection are not mutually exclusive and, during the last decades, researchers invested a great amount of work in studying the interplay between these attentional processes (for reviews see: Corbetta & Shulman, 2002; Ruz & Lupiáñez, 2002; Theeuwes, 2010). However, it has been recently pointed out that a host of selection biases may not be explained in the framework of this theoretical dichotomy (Awh et al., 2012). Notably, attention could also be drawn toward stimuli that are neither relevant for the task at hand nor physically salient but that have been previously paired with a reward outcome (for reviews see: Anderson, 2015; Bourgeois et al., 2016; Failing & Theeuwes, 2018). In this case, attentional capture would be solely triggered by the distractor value, due to its *reward history* (Awh et al., 2012), an effect referred to as value-driven attentional capture (VDAC).

Evidence that reward history can constitute a separate class of priority signal in attentional selection, above and beyond top-down and bottom-up processes, comes from various experimental designs (e.g., Anderson et al., 2011; Anderson & Halpern, 2017; Bourgeois et al., 2015; Bucker & Theeuwes, 2016, 2017a, 2017b; Failing et al., 2015; Le Pelley et al., 2015; Munneke et al., 2015, 2016; Pearson et al., 2015; Roper et al., 2014). Typically, those studies involve a visual search task of a target singleton (e.g., a diamond) among irrelevant

shapes (e.g., circles). As a classic manipulation, one of the irrelevant shapes can appear in a color that constitutes the *signal* of the potential reward that could be obtained in the current trial (e.g., Failing et al., 2015; Failing & Theeuwes, 2017; Le Pelley et al., 2015; Pearson et al., 2015). However, the distractor should not be considered as relevant because reward is only obtained in case of fast (i.e., below a given threshold) and correct response to the target, or when the first saccade is initiated toward the target (Failing et al., 2015; Pearson et al., 2015). Otherwise, reward is not obtained. In this way, a strategy wherein distractor selection occurs voluntarily would be always clearly *counterproductive* to obtain the reward (Le Pelley et al., 2015). Indeed, such strategy would delay the observer's response time, or the first saccade would be initiated toward the distractor and not toward the target, leading to reward omission. Nevertheless, the presence of this irrelevant reward-signaling stimulus typically increases reaction times and error rates, or triggers oculomotor capture. Therefore, in this context, any reward distractor processing is aimed to result from (overt and/or covert) attentional capture. Some studies (Failing et al., 2015; Pearson et al., 2015) have reported that oculomotor capture by the reward distractor occurred especially for saccades with short latencies (i.e., triggered involuntarily). Furthermore, those effects have been observed even if the reward distractor was displayed among other colored shapes and thus appeared as a non-salient distractor (e.g., Failing & Theeuwes, 2017). Finally, the VDAC increased with the magnitude of the reward associated with the distractor, high-reward distractors leading to stronger capture than low-reward distractors (Failing & Theeuwes, 2017; Le Pelley et al., 2015). There are therefore compelling evidence for a direct influence of reward history in the guidance of attention.

Considering that VDAC is observed when reward stimuli are irrelevant, non-salient and when their selection is undoubtedly detrimental to the goal of obtaining an immediate reward, VDAC has been argued to reflect an irrepressible, automatic attentional mechanism (Anderson et al., 2011; Failing et al., 2015; Failing & Theeuwes, 2014; Hickey et al., 2010; Le Pelley et

al., 2015; Munneke et al., 2015, 2016). However, it has been proposed that the extent to which irrelevant distractors are processed does not depend only on the participants' expectancies or intentions to ignore them, but also on the processing demands of the current task. Notably, the Load Theory (Lavie, 1995, 2005, 2010; Lavie & Tsal, 1994) posits that one of the factors determining whether an irrelevant distractor will be successfully ignored or counterproductively processed is the level of perceptual load involved in the current task (Lavie, 2005, 2010; Murphy et al., 2016). Situations of low perceptual load (e.g., tasks involving small search set or simple perceptual discriminations) would leave spare capacities that would inevitably "spill-over" to the processing of distractors. Conversely, when the task imposes a high perceptual load (e.g., involves large search set sizes or complex perceptual discriminations), it could exhaust available perceptual resources in processing the relevant stimuli, thus preventing the processing of irrelevant information. Even if the Load Theory has been criticized on several grounds (e.g., Eltiti et al., 2005; Tsal & Benoni, 2010), a wealth of evidence suggests that perceptual load is a major determinant of selective attention (see Murphy et al., 2016 for a review). Reduced distractor processing under high perceptual load condition has been reported in various kind of laboratory paradigms (for reviews see: Lavie, 2005, 2010; Murphy et al., 2016) as well as in ecological studies (Marciano & Yeshurun, 2012, 2015; Murphy & Greene, 2017). Besides, perceptual load has been frequently manipulated to test whether a specific processing is automatic, the premise of these studies being that when attention is exhausted in high-load conditions, any interference by the distractor is an indication of automatic processing (see Benoni, 2018 for a discussion on automaticity within the framework of the Load Theory).

Several studies have revealed that the perceptual load of the task at hand could influence differentially the processing of neutral, emotionally positive or negative (mostly expressive faces) to be-ignored stimuli (e.g., Gupta & Srinivasan, 2015; Pessoa et al., 2002; Silvert et al.,

2007; Srinivasan & Gupta, 2010). However, to our knowledge, only one previous study has specifically addressed the question of whether *attentional capture* by *reward*-distractors could occur independently of the current task load (Experiment 3 in Gupta et al., 2016). In this study, participants first performed a betting game in order to associate neutral faces with gain or loss outcomes (the association phase). Then, participants ran an unrewarded letter search task (the test phase). On each trial, target (X or N) and non-target letters were arranged around an imaginary circle with one of the faces of the association phase displayed at its center. Perceptual load was manipulated by varying the heterogeneity of the non-target letters (Os exclusively in the low load condition; H, K, W, M, Z in the high load condition). As expected, both gain- and loss-faces produced a strong distraction effect (i.e., RTs were longer on distractor faces present-trials rather than absent-trials) in the low load condition. But remarkably, whereas no significant distraction effect was observed for loss-faces distractors in the high load condition, it remained significant for gain-faces distractors. Gupta et al. (2016) therefore concluded that distractors associated with gain (i.e., reward) can capture attention even when the processing of relevant stimuli consumes all available resources. However, the distractor faces were presented at the center of the screen where the observer's attention was already deployed at the beginning of a trial. Consequently, the results do not speak to the guidance of attention by reward distractors: as acknowledged by the authors, the greater distraction effect observed for reward- vs. loss-distractors under high-perceptual load could rather reflect a more difficult attentional disengagement from reward-faces centrally displayed.

Our aim was therefore to investigate more thoroughly the impact of the perceptual load of the task at hand on the distractive effect of reward distractors. Perceptual load was manipulated by varying the processing requirement of a go/no-go cue centrally presented (for similar load manipulation see: Chen & Cave, 2016; Lavie, 1995). In comparison with related studies (e.g., Gupta et al., 2016; Gupta & Srinivasan, 2015), such a manipulation of perceptual

load has the advantage to involve strictly identical displays across conditions and therefore to discard any influence of distractor relative salience between low and high load (Murphy et al., 2016). The go (or no-go) cue was defined by a simple feature (e.g., any black cue) in the low-load condition and by a feature conjunction (e.g., a black circle cue) in the high-load condition. On “go” trials, the participants had to determine the identity of a black target letter (i.e., H or S), while ignoring a more peripheral colored distractor letter (also a H or a S) whose color (red or green) signaled either high- or low-reward outcomes in case of fast and accurate response to the target (Bucker & Theeuwes, 2016; Failing et al., 2015; Le Pelley et al., 2015; Munneke et al., 2015, 2016; Pearson et al., 2015). Importantly, as recommended by some authors (Gaspelin et al., 2014; Lachter et al., 2004; Theeuwes & Burger, 1998), attentional capture by the distractor was measured by the size of the compatibility effect, that is, by the benefit in target identification performance when the distractor letter was compatible (i.e., identical) versus incompatible (i.e., different) with the target identity. The rationale here is that if attention is captured by the distractor, its identity should influence RTs to identify the target with RTs in the compatible condition should be consistently faster than RTs in the incompatible condition. Behavioral evidence of attentional capture is an important debate in our field (e.g., Folk, 2013) but compatibility effect might be considered as the most reliable measure (for comparisons between different measures and attentional capture paradigms see Becker, 2007).

Since both high- and low-reward distractors are visually salient (colored), they should both capture attention in the low perceptual load condition. We should therefore observe a significant compatibility effect for both types of distractors in the low load condition. However, if attentional capture by high-reward distractors is indeed automatic (Anderson et al., 2011; Failing et al., 2015; Failing & Theeuwes, 2014; Gupta et al., 2016; Hickey et al., 2010; Le Pelley et al., 2015; Munneke et al., 2015, 2016) we should observe a significant interaction between perceptual load, reward-distractors and compatibility effects. Indeed, in the high-load

condition, the compatibility effect should be significantly more reduced for low- than high-reward distractors.

## **METHOD**

### **Participants**

Thirty-two volunteers<sup>1</sup> (29 females;  $M = 21.9$ ,  $SD = 2.6$ ) from Université Clermont Auvergne participated in the experiment for course credit after giving their written informed consent. All were right-handed, reported normal or corrected-to-normal visual acuity and normal vision color, and were naïve as to the purpose of the experiment.

### **Apparatus**

Participants were tested individually in a quiet room with constant ambient illumination, in front of a 14-inch VGA monitor (1024 × 1280 resolution, 60 Hz) at a distance of approximately 50 cm. The presentation of the stimuli, timing operations and data collection were controlled by E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA, United States).

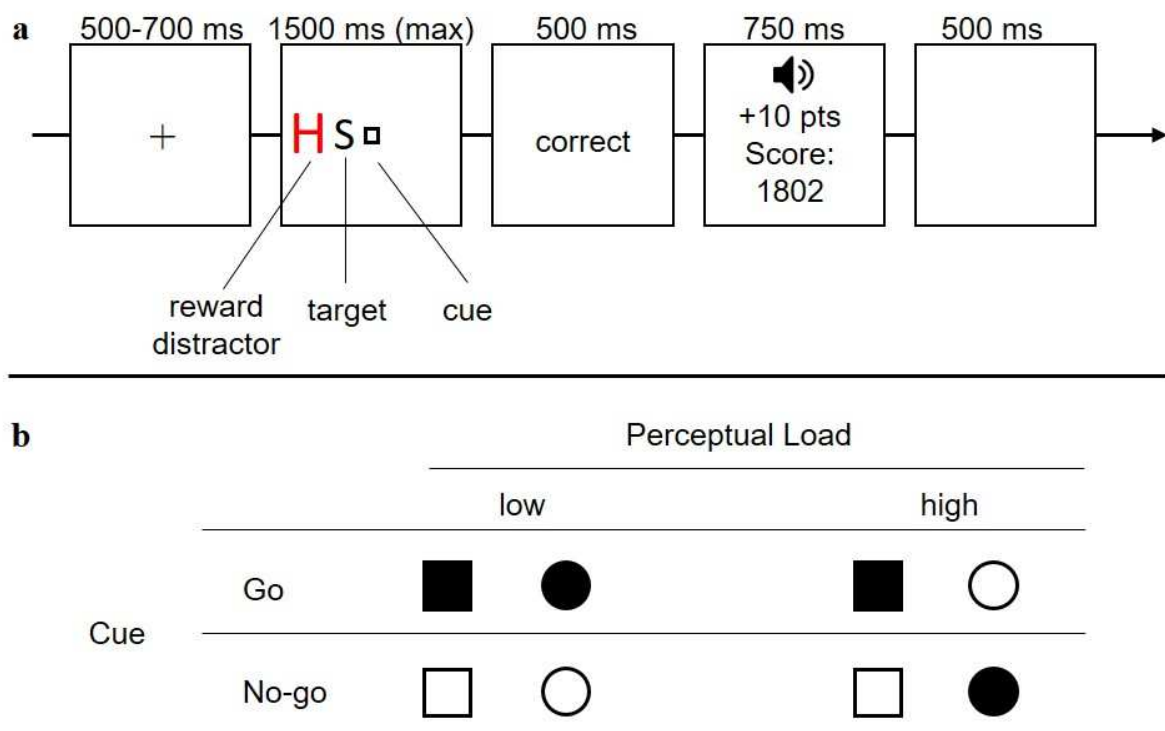
### **Stimuli and procedure**

The experimental setting was similar to the one used by Chen & Cave (2016; Experiment 2). Each trial (Figure 1a) began with a black fixation cross ( $0.57^\circ$  width x  $0.57^\circ$  height, expressed in degrees of visual angle) displayed at the center of a white screen for 500, 600 or 700 ms (randomly determined at run time). Then the search display containing the go/no-go cue ( $0.46^\circ$  x  $0.46^\circ$ ), the target ( $0.57^\circ$  x  $0.8^\circ$ ) and the distractor ( $0.8^\circ$  x  $1^\circ$ ) was presented until

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<sup>1</sup> The sample size was determined in order to be consistent and large enough to replicate the main effects and interactions reported in previous studies (e.g., Gupta et al., 2016). However, our study includes a three-way interaction that has not been previously tested in the literature. Therefore, we increased our sample size to minimize the risk of not observing a three-way interaction associated to a relatively small population effect size.

participant's response or until 1500 ms had elapsed. The go/no-go cue could be either a full (i.e., black) or empty (i.e., white with black border) disc or square (Figure 1b). Target and distractor letters (H or S; uppercase, Calibri font) were horizontally aligned with the cue at the center of the screen and both letters always appeared together on the same side of the cue (with the target immediately next to the cue and the distractor further apart). The cue-target distance was  $1.4^\circ$  (center-to-center) and cue-distractor distance was  $2.8^\circ$ . The target was always displayed in black, the distractors appeared equally often in red (RGB: 255, 0, 0) or green (RGB: 0, 159, 0).



**Figure 1a** Stimuli and time-course of a trial with a color distractor (red H) signaling a high-reward outcome (+10 pts) in case of correct and fast identification of the target (S). **1b** Go/No-go cues were defined by a simple feature (i.e., color) in the low load condition, or by a feature conjunction (i.e., color and shape) in the high-load condition. Features associated with a Go or No-go cues were counterbalanced across the participants.

In the low-load condition, the “go” cues were a black disc or a black square for half of the participants and a white disc or a white square for the other half. In the high-load condition,

the “go” cues were a black disc or a white square for a half of the participants, and a white disc or a black square for the other half. On “go” trials participants were instructed to report the target letter identity (H or S) by pressing “2” or “5” on the numeric keypad (counterbalanced across participants) with their right forefinger and middle finger respectively. On “no-go” trials, they had to press the space bar with their left hand. At the beginning of the experiment, the participants were explicitly informed of the association between the color of the distractors and the reward magnitude. For half of the participants, red distractors acted as *high-reward* distractors that signaled the possibility to win 10 points, green distractors acted as *low-reward* distractors signaling the possibility to win 1 point. For the other half, the color/reward association was reversed. A reward was obtained on “go” and “no-go” trials for correct responses that were faster than the participant’s latency limit (see below). Errors or correct responses that were slower than the participant’s latency limit were not rewarded, but the participant was nonetheless told how much he/she could have won. Hence, two feedbacks were displayed after the participant’s response (or after the search display time had elapsed). The first feedback concerned the participant’s accuracy and was displayed for 500 ms (“correct”, “error” or “missed when the participant did not respond”). Then, a second feedback, displayed for 750 ms, informed the participant of the number of points he/she had earned (“+10 pts”; “+1 pt”; “+0 pt”) or missed (“+10 pts missed” or “+1 pt missed”). Finally, a blank screen separated two consecutive trials for 500 ms. The participants aimed at maximizing their score to obtain an additional 10€ gift card. For that purpose, they had to obtain at least 2000 points, but the threshold was announced only at the end of the session in order to maintain their motivation constant.

The experiment was split into 8 experimental blocks of 48 trials. Within each block, half of the trials contained a high-reward distractor and the other half, a low-reward distractor. Two-thirds of trials were “go” trials and the remaining third was “no-go” trials, equally distributed

across high- and low-reward distractors trials. For half of the trials, the distractor was compatible with the target (i.e., same letter) and incompatible (i.e., different letter) for the other half. Targets and distractors appeared equally often on each side of the cue. The order of trials within each block was random.

Half of the participants started with four consecutive blocks of the low perceptual load condition before taking part to four consecutive blocks of the high perceptual load condition, and the order was counterbalanced for the other half of the participants. A small break was given between each block. Each perceptual load condition began with a training block of 48 trials. The third quartile of correct responses latencies within each training block defined the participant's latency limit for each condition. If the participant's accuracy was below 75%, he/she had to repeat the training phase. The participants were informed of their latency limit and informed that for subsequent trials they would earn a reward only for correct responses that were faster than this limit.

## RESULTS

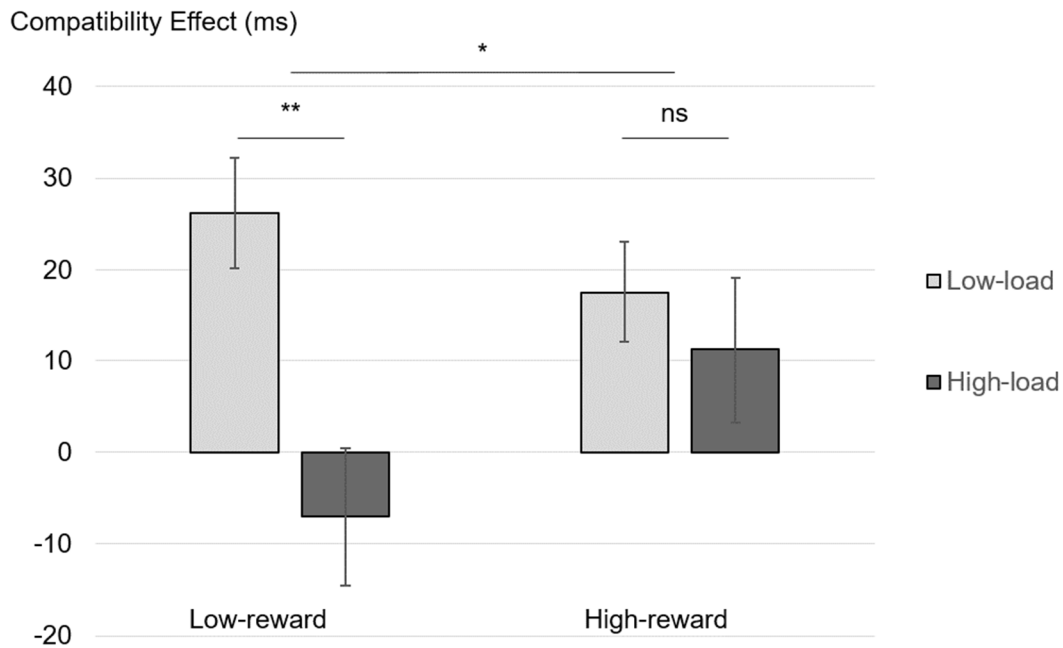
Reaction times (RTs) for correct responses on “go” trials were analyzed. For each participant, RTs plus/minus 2.5 absolute deviations around the median (Leys et al., 2013) were discarded. This resulted in the loss of less than 3% of the data. Two participants were excluded from statistical analysis because of error rates above 40% (on overall trials or on no-go trials).

We performed a 2 x 2 x 2 ANOVA on RTs with Load (low-load; high-load), distractor Compatibility (compatible; incompatible) and Reward distractor (low-reward; high-reward) as within-subject factors<sup>2</sup>. The main effect of Load was significant [ $F(1, 29) = 252.1, p < .001$ ,

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<sup>2</sup> Controlling for color-reward association or bloc order as between-subject factors did not change the pattern of results. Thus those factors have been removed from the current analyze for clarity and simplicity of the reading. This reasoning was applied for RTs and error rates.

$\eta^2_p = .9]$  with faster RTs in the low-load ( $M = 677$  ms;  $SE = 16$ ) than in the high-load condition ( $M = 867$  ms;  $SE = 20$ ), as usually observed. The main effect of Compatibility was significant [ $F(1, 29) = 11.6, p = .002, \eta^2_p = .28$ ] with slower RTs for incompatible ( $M = 778$  ms;  $SE = 17$ ) than compatible distractors ( $M = 766$  ms;  $SE = 17$ ). Importantly, the Load x Compatibility interaction [ $F(1, 29) = 5.1, p = .032, \eta^2_p = .15$ ] revealed successful load manipulation with larger compatibility effect under low- [ $M_{incomp - comp} = 22$  ms;  $SE = 5; t(29) = 4.3, p < .001$ ] than high-load [ $M = 2$  ms;  $SE = 6; t(29) < 1, p = .74$ ]. The main effect of Reward was also statistically significant [ $F(1, 29) = 52, p < .001, \eta^2_p = .64$ ] with slower RTs for low- ( $M = 796$  ms;  $SE = 18$ ) than high-reward distractors ( $M = 748$  ms;  $SE = 16$ ). Moreover the Load x Reward interaction was also significant [ $F(1, 29) = 8.6, p = .007, \eta^2_p = .29$ ] showing a larger difference between reward distractors (low- minus high-reward) under high- ( $M_{diff} = 65$  ms;  $SE = 10$ ) rather than low-load condition ( $M = 31$  ms;  $SE = 7$ ). The interaction between Reward and Compatibility did not reached significance [ $F(1, 29) = 1.2, p = .28$ ] but, as we hypothesized, the interaction between Load, Reward and Compatibility did [ $F(1, 29) = 4.4, p = .046, \eta^2_p = .13$ ]. As shown on Figure 2, the compatibility effect in the low-reward distractor condition significantly decreased [ $F(1,29) = 8.3, p = .007, \eta^2_p = .22$ ] from low- ( $M = 26$  ms;  $SE = 6$ ) to high-load ( $M = -7$  ms;  $SE = 7$ ). However, in the high-reward distractor condition, the compatibility effect observed in low- ( $M = 17$  ms;  $SE = 6$ ) and high-load ( $M = 11$  ms;  $SE = 8$ ) did not differ significantly [ $F(1,29) = .4, p = .54$ ].



**Figure 2** Compatibility Effect (in ms) for low-reward and high-reward distractors under low and high perceptual load. Error bars represent standard errors (SE). \*  $p < .05$ , \*\*  $p < .01$ , ns: non-significant.

We performed a 2 x 2 x 2 ANOVA on error rates with Load (low-load; high-load), distractor Compatibility (compatible; incompatible) and Reward distractor (low-reward; high-reward) as within-subject factors. As classically observed, we found a significant main effect of Load [ $F(1, 29) = 60.5, p < .001, \eta^2_p = .68$ ], the error rate being higher in the high load ( $M = 19.8\%; SE = 2.2$ ) than in the low load condition ( $M = 7.4\%; SE = 1.2$ ). The interaction between Load and Compatibility [ $F(1, 29) = 3, p = .083, \eta^2_p = .1$ ] corresponded to a larger, but non-significant, difference between incompatible and compatible distractor under low- [ $M_{incomp - comp} = 1.5 \%; SE = .8; F(1, 29) = 3.3, p = .08$ ] than high-load [ $M = .8 \%; SE = 1; F(1, 29) = .58, p = .45$ ]. Confirming the effect on incentive motivation obtained for RTs, the main effect of Reward was also significant [ $F(1, 29) = 14.1, p < .001, \eta^2_p = .33$ ] with fewer errors when the high-reward distractor ( $M = 10.8 \%; SE = 1.6$ ) rather than the low-reward distractor ( $M = 16.3\%; SE = 1.8$ ) was present. Finally, the interaction between Load and Reward

also reached significance [ $F(1, 29) = 7, p = .013, \eta^2_p = .19$ ]. The error rates difference between low- and high-reward distractor (Table 1) was significant in the high- [ $M_{diff} = 9.4\%; SE = 2.8; F(1, 29) = 11.5, p = .002, \eta^2_p = .28$ ] but not in the low-load condition [ $M_{diff} = 1.6\%; SE = 1; F(1, 29) = 2.5, p = .13$ ]. None of the other main effects and interactions reached significance [ $F_s(1, 29) < .25, p_s > .62$ ].

**Table 1.** Error rates (%) and standard errors for each condition of Load and Reward distractor.

|                                | Low-reward distractor | High-reward distractor |
|--------------------------------|-----------------------|------------------------|
| Low-load (feature search)      | 8.2 (1.3)             | 6.6 (1.2)              |
| High-load (conjunction search) | 24.5 (2.8)            | 15 (2.4)               |

## DISCUSSION

The present study investigated the influence of the processing demands of the task at hand on the extent to which irrelevant reward stimuli can capture attention. The current results revealed that the low-reward distractor interference (i.e., compatibility effect) observed in the low-load condition was significantly reduced in the high-load condition, replicating well-known effects of load on salient but unrewarded stimuli (e.g., Experiment 2 in Chen & Cave, 2016 for a similar experimental design). In sharp contrast, the distractor interference produced by high-reward stimuli was not statistically different in the two load conditions. Therefore, it seems that attentional capture by high-reward distractors can survive strong tests of attention that involve task conditions of high perceptual load.

As mentioned above, one previous study (Gupta et al., 2016) already suggested that the processing of reward-distractors (and more generally positive valence stimuli) could modulate

the effects of perceptual load. However, this study is not conclusive regarding attentional *capture* by reward-distractors (that is, involuntary allocation of spatial attention) because the distractors were presented at the center of the screen, where the observer's attention was already deployed at the beginning of a trial. As acknowledged by the authors themselves, the paradigm could not differentiate between the effects of reward on capturing attention and those on the latency of holding and captivating attention. In contrast, in the current study, the reward-distractors were always presented peripherally to the central cue that had to be attended at first. Moreover, response compatibility effects, rather than simple reaction times, were taken as an auxiliary measure for attentional capture (Becker, 2007; Theeuwes & Burger, 1998). Compatibility effect is often cited as the most reliable measure for detecting occurrences of attentional capture (e.g., Becker, 2007; Gaspelin et al., 2014; Lachter et al., 2004). We are therefore confident that the present study constitute a more accurate evaluation of attentional capture by reward-distractors under load.

In the framework of the Load Theory (Lavie, 2005, 2010; Murphy et al., 2016) the current results suggest that high-reward distractors have the ability to be processed and interfere with the task at hand even when few, or maybe even no, attentional resources are available for irrelevant processes. As such, the present study provides new arguments in favor of VDAC automaticity: attentional capture by reward stimuli appears to be automatic in the stronger sense of the term, occurring in full independence from top-down factors, such as intentionality, volition, task instructions, but also attention (see Pessoa, 2005). However, as already mentioned, the Load Theory has been criticized (see Murphy et al., 2016, for a review) and alternative interpretations of the results could be put forward. Mainly, it has been proposed that, in many previous studies in which load was manipulated by varying the number of items in the display, perceptual load may have affected interference not by influencing capacity, but rather by diluting the distractor among additional competing items (Tsal & Benoni, 2010) or by

changing the relative saliency of the distractors (Eltiti et al., 2005). Note that these criticisms cannot apply to the task we used here since the display was strictly identical across conditions and load was manipulated through the difficulty in discriminating a (central) go/no-go cue, a manipulation which does not affect the visual saliency of the (peripheral) distractors.

Still, we cannot completely exclude that the processing of high-reward distractors in the high-load condition relied on some residual resources that were not fully consumed by the load manipulation and that a much greater load would have abolished this processing. In fact, this criticism could be formulated against pretty much all the studies involving load manipulations to verify automaticity (Benoni, 2018; but see Maquestiaux et al., 2020 for a recent demonstration that a visual stimulus can indeed be processed automatically in the strongest sense) but it is certainly not at odds with the claim that the processing of reward distractors requires *less* resources than the processing of neutral ones. In that sense, VDAC would be "more automatic" than attentional capture by salient stimuli (Moors & De Houwer, 2006). Therefore, our study encourages Load Theory (Lavie, 2005, 2010; Murphy et al., 2016) and related model (Neokleous et al., 2016) to give greater consideration to reward history in order to provide a better comprehension of distractor processing under a large range of situations and to go beyond bottom-up, salience-based distraction.

Additionally, in this kind of task, the differential degree of distractor processing may also depend on how broadly/narrowly the attention is focused on the cue rather on the availability of the attentional resources (Belopolsky & Theeuwes, 2010; Chen & Cave, 2016; Theeuwes, 2010). More precisely, low (resp. high) perceptual load might rather widen (resp. narrow) the attentional zoom (or attentional window) than consuming more or less perceptual resources. In this framework, in the high-load condition of the current study, low-reward distractors may have failed to capture attention because they stood outside the (narrow) attentional window of the observer. This has been previously observed in similar designs with

unrewarded salient colored distractors (e.g., Theeuwes, 2004). Anyhow, our data indicate that, in contrast, high-reward salient distractors standing outside the attentional window could produce interference by capturing the observer's attention. Interestingly, it has been demonstrated that particularly salient stimuli, such as abrupt onsets, could break through the attentional window (Gaspelin et al., 2012). Therefore, the current results are consistent with the idea that reward associated stimuli are processed at a perceptual level as if they were more perceptually salient than unrewarded ones, or, in other words, that reward may boost their representation above and beyond their physical salience (Anderson & Kim, 2019). They also fit well with previous findings showing that reward-associated stimuli can break through the inhibitory region around attentional focus (Wang et al., 2014).

One potential limitation of the current study is that the longest RTs and highest error rates were observed when no compatibility effects (i.e., no attentional capture) occurred (i.e., in the high load, low reward condition). This could indicate that attentional capture by the distractor may in fact *facilitate* the response to the target (in particular when the target and the distractor are compatible). Also, overall, the presence of high- rather than low-reward distractors was associated with faster target selection and improved accuracy. In prior studies investigating the effects of monetary reward on attention with visual search tasks, the differences between high- and low-reward distractors were classically in the opposite direction (e.g., Le Pelley et al., 2015). The current pattern of results could therefore cast some doubts on whether reward stimuli were actually processed as *distractors*. To reiterate, we reasoned that attending to reward-predictive distractors would, if anything, hinder participants' performance and hence the payoff they achieved. Indeed, the colored letters predicted whether a reward could be obtained, but it was the response to the black target letters that determined whether a reward was actually delivered. Therefore, the best available strategy was logically to try to ignore the reward-predictive distractors, and the data suggest that observers have actually adopted this

strategy. Indeed, if they had deliberately chosen, as a global strategy, to attend to the reward-signaling color, the compatibility effect should have been preserved for the low-reward distractor in the high-load condition too. The current pattern of results could alternatively be explained by the fact that, 1) the target appeared unpredictably on the left or right side of the fixation point (just as in visual search tasks) but (contrary to visual search tasks) the target and the distractor always appeared in immediate proximity, on the same side of the screen, and 2) spatial shift of attention could be triggered earlier in time by high reward stimuli (Kiss et al., 2009) even when irrelevant (Donohue et al., 2016). Thus, the observer's attention might be more rapidly oriented toward the screen side containing the high-reward distractor and the target, leading to faster reaction times. Note also that improved accuracy in reporting the target in the presence of distractors associated with high- rather than low-reward has already been reported (Anderson, 2016). The authors had proposed that high-reward distractors might trigger greater recruitment of goal-directed mechanisms and enhanced incentive motivation to actually perform the task better and obtain the reward outcome. This view also fits a reinforcement learning framework (for a review in connection with psychology see: Sutton & Barto, 2018), with participants maximizing the accumulated reward not only at the trial level, but also at the experiment level. After a few trials, participants may estimate the cost-benefit tradeoff to answer correctly and fast enough to steadily obtain the reward. Indeed, 10 low-reward trials were required to compensate for a single failed high-reward trial (1 vs. 10 points awarded). Under low load, processing all information with limited effort is possible, leading to the observed compatibility effect, low response times and error rates, moderated by the reward level (high vs. low). Under high load, trying to be fast and accurate for every single trial will lead to fatigue, and therefore errors or misses on high-reward trials, thus reducing the cumulative reward. As a consequence, participants could adapt their behavior to maximize the accumulated reward at the experiment level. In this way, when a low-reward distractor captured attention

(low-load) or when no capture occurred (high-load), participants might simply relax their attention, leading to the highest mean response times and error rates. In contrast, automatic attentional capture by high-reward distractor may promote a greater effort investment on those trials, leading to lower response times and error rates. As this strategy would be particularly relevant in situation of high-level fatigue, it could explain why high-reward distractors triggered lower response times and error rates particularly in the high-load condition. According to this strategy, it is possible that the high-reward distractor color was part of the observers' attentional control settings. Indeed, the contingent capture hypothesis (Folk et al., 1992, 1994) claims that involuntary attentional shifts occur only where there is a contingency between the properties of the eliciting event and the properties required for task performance (but for one exception see Folk & Remington, 2015). Therefore, attentional capture by high-reward distractor could have survived perceptual load manipulation because, although irrelevant, they were contingent with task goals (maximizing reward without too much fatigue). This proposal is consistent with the results of a study by Belke et al. (2008), in which the interference produced by semantically related distractors (i.e., matching the observer's attentional set) was not modulated by perceptual load manipulations (but see discussion in Cosman & Vecera, 2009). Further research are now needed to determine more precisely how perceptual load and distractor contingency could interact with reward. Anyhow, this would not call into question the conclusion that the processing of high-reward stimuli persists in conditions in which the processing of low-reward ones is suppressed.

Furthermore, we argue that interactions between reward and load might find strong applied perspectives. For example, the magnitude of attentional bias arising from learned associations between visual stimuli and monetary reward has been linked to psychopathology (addiction, depression, social anxiety; see Anderson, 2015). Distraction is also identified as one of the determinants of car accidents with distractors standing from outside (e.g., advertising

billboards: Belyusar et al., 2016; Chattington et al., 2009; Crundall et al., 2006; Decker et al., 2015) or inside the vehicle (e.g., by irrelevant but driving-related information: Arexis et al., 2017; or by “infotainment” systems: Strayer, 2015). However, those distractors, which can very often be regarded as rewarding, have usually been considered under the scope of bottom-up salience alone (Bakiri et al., 2013; Crundall et al., 2006; Klauer et al., 2006). The Load Theory certainly offers a relevant and fruitful framework when investigating distraction on driving simulator (Marciano & Yeshurun, 2012, 2015; Murphy & Greene, 2017) but distractor's reward history has not been considered yet in those studies.

To conclude, the present study confirms the particular role of reward-related stimuli in attentional selection and the need to integrate reward history effects into attentional models (Awh et al., 2012). Our study and a handful of others suggest that attentional capture by rewarded or positive distractors could occur when few, or maybe even no, attentional resources are available for their processing (see Gupta, 2019 for a review). However, the question of the automaticity of attentional allocation to negative stimuli (which has generated much more studies so far) is still a matter of vigorous debate (see Victeur et al., 2020). Besides, when considering “valued” stimuli altogether, it is still unclear whether it is the motivational saliency (i.e., high vs. low) or the valence (i.e., positive/reward vs. negative/punishment) of a stimulus which is the major determinant of attentional capture (e.g., Gupta et al., 2019). Therefore, one could regret that current attentional models usually focus almost exclusively on either negative/threat-related or positive/rewarded stimuli, or put them together in the same “value-driven” category (Failing & Theeuwes, 2017; Pourtois et al., 2013; Theeuwes, 2018). Thus, future research are certainly needed to contrast more precisely attentional effects produced by various types of “valued” distractors, and integrate them into a comprehensive model of the interactions between motivation, emotion and load in attentional capture.

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