Boosting or choking – How conscious and unconscious reward processing modulate the active maintenance of goal-relevant information

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A B S T R A C T

Two experiments examined similarities and differences in the effects of consciously and unconsciously perceived rewards on the active maintenance of goal-relevant information. Participants could gain high and low monetary rewards for performance on a word span task. The reward value was presented supraliminally (consciously visible) or subliminally at different stages during the task. In Experiment 1, rewards were presented before participants processed the target words. Enhanced performance was found in response to higher rewards, regardless whether they were presented supraliminally or subliminally. In Experiment 2, rewards were presented after participants processed the target words, i.e., during maintenance. Performance increased in response to relatively high rewards when they were presented subliminally, but decreased when they were presented supraliminally. We conclude that both consciously and unconsciously perceived rewards boost resources supporting the maintenance of task-relevant information. Conscious processing of rewards can, however, heavily interfere with an ongoing maintenance process and impair performance.

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1. Introduction

Rewards are effective tools to encourage people to perform better on physical and cognitive tasks. Rewards influence the way we maintain and act on information relevant to attain our goals, and as such are central to successful goal-directed behavior. Interestingly, recent research has revealed that rewards cause people to invest more effort in a task, even when they are not conscious of the rewards (Aarts, Custers, & Marien, 2008; Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trotschel, 2001; Bijleveld, Custers, & Aarts, 2009; Pessiglione et al., 2007). This work suggests that consciously and unconsciously perceived rewards have parallel effects on the boost of resources and improvement of task performance. A question that has received little attention to date is under which circumstances conscious and unconscious rewards might affect performance differently. Conscious rewards are different from unconscious rewards in that only the former are subject to conscious reflection. We argue that this conscious reflection can distract from the task at hand and increase load on the limited capacity of conscious processes (Moors & De Houwer, 2006). This leads to the intriguing hypothesis that effects of consciously and unconsciously perceived rewards may be dissociated under conditions where reflective thoughts hinder ongoing performance.

In the present research, we examine how consciously and unconsciously perceived reward cues affect how people maintain information in memory when reward cues are presented either before or after the information is given. We propose that a conscious valuable reward (e.g., money or an ice-cream to remember a list of groceries) that is presented before one is

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given a series of items to keep in mind (e.g., the list of grocery items) can improve maintenance of the items in memory. However, presenting such conscious rewards during maintenance may interfere with the maintenance process and impair later recall. Moreover, we predict that unconsciously processed rewards lead to better recall irrespective of whether they are presented before or during the process of keeping the information active.

To study this issue, we experimentally tested the effects of conscious and unconscious monetary rewards on performance in an active maintenance task. Active maintenance refers to the process of keeping representations highly accessible in memory after they are no longer externally present or supported. These representations may be goals, action plans, or stimuli. Active maintenance is typically ascribed to working memory (e.g., Baddeley, 1986), a theoretical construct that encompasses the temporary retention and inhibition of selected information in order to perform operations (e.g., Baars & Franklin, 2003; Baddeley, 1986; Jonides et al., 2008). An important characteristic of working memory is that it has limited capacity. Not all the information in the environment can be attended to and maintained at the same time. Furthermore, other meaningful or personally relevant information that enters conscious attention interferes with the maintenance process, causing information that was held active to be lost from working memory (Dolcos & McCarthy, 2006). This is why a reward-driven modulation of working memory maintenance is thought to be highly adaptive (see Miller & Cohen, 2001; Pessoa, 2009).

Consistent with this argument, previous research has provided evidence for a facilitating effect of rewards on active maintenance performance. Most of these studies have exclusively focused on consciously perceived rewards. For instance, Heitz, Schrock, Payne, and Engle (2008) tested the effects of monetary rewards on performance on a reading span task and found that participants performed significantly better when they could earn money than when they could not. Gilbert and Fiez (2004) used functional magnetic resonance imaging (fMRI) to study the effect of monetary rewards on active maintenance performance. They specifically focused on the delay period during which participants had to maintain target words. It was again found that participants performed better when performance was rewarded. Furthermore, during the delay period of rewarded (compared to not rewarded) trials, greater activation was found in the dorsolateral prefrontal cortex (DLPFC), an area that is typically recruited during the active maintenance of information after it is no longer externally present.

Interestingly, recent studies have shown that unconsciously perceived rewards can have the same positive effects on performance as consciously perceived rewards (Pessiglione et al., 2007; Bijleveld, Custers, & Aarts, 2010; Bijleveld et al., 2009). For instance, Bijleveld and colleagues (2009) used a physiological measure – the degree of pupil dilation – to observe the recruitment of resources as a function of consciously and unconsciously detected rewards. Pupil dilation increases with sympathetic activity, and therefore provides a direct measure of the quantity of resources invested in a task. In the experiment, participants could gain rewards of either 1 or 50 euro cents on a digit span task. The reward value was indicated by a coin presented either supraliminally or subliminally (i.e., too quickly to be consciously perceived). It was found that participants showed increased pupil dilation on highly rewarded trials, and this was true regardless whether the rewards were presented supraliminally or subliminally. These results show that consciously and unconsciously perceived rewards alike ignite an immediate boost of resources to support the process of maintaining goal-relevant information.

The studies discussed above point to parallel effects of consciously and unconsciously perceived rewards. This concurs with the view that our thinking and doing starts in the unconscious (e.g., Blackmore, 2003; Frith, 2007; Wegner, 2002; Wilson, 2002), and that conscious processes emerge on top of that. However, to conclude that conscious reflection on a valuable reward does not affect performance beyond its initial resource boost may be pre-mature. Based on research on the potentially harmful effects of conscious reflection processes on the performance of goal-directed behavior (for an overview see Dijksterhuis & Aarts, 2010), we argue that reflection on valuable rewards can be detrimental to performance when it interrupts an ongoing active maintenance process. The reason why this effect has not been observed before is that in previous studies rewards were always presented before participants engaged in the process of maintaining information in memory (e.g., Bijleveld et al., 2009; Gilbert & Fiez, 2004; Heitz et al., 2008). Accordingly, any (potentially interfering) reflective thoughts in reaction to the rewards may have been down-regulated by the time participants received to be remembered information. When one is already engaged in an active maintenance task, however, conscious perception of a high reward distracts attention and disrupts the task, and hence impairs performance. Importantly, such effects may not occur for unconscious rewards. In fact, unconsciously processed rewards boost resources without evoking such conscious reflection process, and therefore should improve active maintenance performance even when presented while one is already engaged in the task.

The idea that particularly high (consciously perceived) rewards can sometimes lead to a decrease in performance is supported by research on the so-called choking under pressure phenomenon (e.g., Beilock, 2007; Mobbs et al., 2009). An explanation for choking under pressure in cognitive tasks is that conscious reflection about a high reward taxes the limited capacity of conscious processes and distracts attention (Beilock, 2007, 2008). Whereas in studies on choking under pressure it is often suggested that the disruptive influence of rewards on performance occurs during execution of the task, here we test whether consciously (but not unconsciously) presented rewards during an active maintenance task decrease performance. Conscious reflection requires attentional resources and disrupts the ongoing process of maintaining target information, with the consequence that the information is forgotten. Of course, once a disruptive conscious thought emerges, it may be inhibited and attention may be quickly re-focused on the maintenance task. However, because the relevant information is no longer externally present at this point, it cannot be fully regained, leading to potentially strong decrements in recall performance. In contrast, when rewards are presented before participants engage in the maintenance process, any conscious thoughts about the perceived valuable reward can be inhibited before the incoming task-relevant information is presented. As a result, performance is not hampered by conscious thought processes, but in fact improved by the resource boost

produced by the reward. Indeed, there is evidence that reward related brain activation elicited by rewards presented during preparation for a task are suppressed upon the execution of cognitive tasks (Gilbert & Fiez, 2004).

Based on the reasoning discussed above, we yield the following two hypotheses. First, relatively high (vs. low) rewards primed either supraliminally or subliminally *before* the maintenance of task-relevant information enhance performance on a maintenance task. Second, relatively high (vs. low) rewards primed *during* the maintenance of task-relevant information enhance performance when presented subliminally, but decrease performance when presented supraliminally. We tested these hypotheses in two experiments using a word span task with monetary rewards. Participants could win either 1 cent or 50 cents by correctly recalling a series of words after a short delay period. Rewards were indicated by 1 cent and 50 cents coins which were presented either supraliminally or subliminally. In Experiment 1, the coins were presented before participants processed the target words (and thus before they engaged in the maintenance process), and in Experiment 2 the rewards were presented after processing of the target words, and hence when participants were already engaged in the active maintenance process.

2. Experiment 1

The goal of Experiment 1 was twofold. Firstly, this experiment tested the hypothesis that supraliminally as well as subliminally primed cues indicating high monetary rewards boost resources. This boost should facilitate performance in an active maintenance task when primed at the beginning of the task. Moreover, this experiment was designed to examine whether conscious perception of meaningful information presented during the maintenance of task-relevant information impairs performance due to interference with the maintenance process. This is particularly relevant to our hypothesis tested in Experiment 2, which suggests that rewards presented supraliminally during the maintenance task would likewise cause interference, independent of their boosting effect on resources.

Research has shown that the conscious presentation of meaningful information during the delay period of an active maintenance task interrupts the maintenance process. The irrelevant information captures conscious attention and processing resources, leading to impaired performance (Dolcos & McCarthy, 2006). Thus, we expected that conscious perception of meaningful (distracting) external information should interfere with maintenance performance. Moreover, we expected that the interference would be independent of the performance facilitating effect produced by a valuable reward. Whereas resources are boosted in response to a high reward, the processing of distracting information should interfere with the maintenance of the relevant information. To test this, we introduced different levels of conscious distracting information (consciously perceived meaningful words vs. meaningless letter strings) during the delay period of the maintenance task. Performance was expected to suffer more from meaningful and hence relatively highly interfering information than from meaningless information (e.g., Forster & Lavie, 2008). To sum up, while high compared to low rewards were expected to enhance performance, high compared to low interference should decrease performance equally for both high and low reward conditions.

3. Methods

3.1. Participants and design

Twenty-six students (19 female) with a mean age of 21.7 years ($SD = 1.7$) were recruited for this experiment. There was no general fee for participation, but payment was entirely dependent on performance (with a theoretical maximum of 15 €). Therefore, only participants were recruited who were interested in earning money. A 2 (reward value: low vs. high) × 2 (reward presentation duration: supraliminal vs. subliminal) × 2 (interference: low vs. high) within-participants design was used.

3.2. Materials

The target words that were used consisted of 305 concrete Dutch one-syllable nouns, of which 280 were used for the experimental phase and 25 for a practice phase. The stimuli presented during the delay phase in the high interference condition consisted of 192 concrete Dutch two-syllable nouns, of which 168 were used for the experimental phase and 24 for the practice phase. The words were obtained from the CELEX lexical database (Baayen, Piepenbrock, & Gulikers, 1995). The stimuli presented in the low interference condition consisted of strings of identical letters. All the letters of the alphabet were used except the letter 'x'.

3.3. Procedure

Participants performed a working memory span task in which they were asked to remember five words over a short time period. Participants were instructed that they would earn money for every correctly recalled series of words, noting that the words could be recalled in an arbitrary order. They were further told that the amount of money to be won would differ per word span and could be either 1 cent or 50 cents, which would be indicated by the brief presentation of an image of the corresponding coin at the beginning of the trial. Participants were not informed about the relative frequency of each amount in

the task. Regarding the presentation of the coin, participants were told that it could at times be very brief, and that they had to pay attention in order to see it. After reading the words, there was a delay period during which participants were consciously presented with information, consisting of either unrelated meaningful words (high interference; e.g., "WATER") or identical meaningless letter strings (low interference; e.g., "FFFFF"). They were instructed to simply look at the screen, until a recall cue appeared, asking them to repeat the words. Participants received feedback about their performance on each trial, informing them whether they had correctly recalled all five words or not, and how much they had earned for the current trial. Before starting the task, participants performed a practice round to see how the task worked. In the practice round, they could not earn money, and would therefore see no coins.

The reward consisted of 1 cent on half the trials and 50 cents on the other half. The coin was presented supraliminally on half the trials and subliminally on the other half. Furthermore, interference during the delay period of the task was low on half the trials and high on the other half. Per condition, there were seven repetitions, which amounted to 56 experimental trials. Five additional trials served as practice trials.

For a graphical overview of a trial, see Fig. 1. A trial started with the presentation of a fixation cross for 1 s. Then followed the presentation of a masked reward prime, a coin presented in the centre of the screen for either 17 ms or 300 ms (for a subliminality test of this procedure, see Bijleveld et al., 2009). The coin was preceded by a pre-mask shown for 1000 ms, and followed by a post-mask with the variable duration of 600 ms minus the duration of the coin display. This priming episode was followed by another fixation cross shown for 1000 ms. Next, the words were presented for 400 ms per word, with an inter-word interval of 200 ms. After the last word, there was a blank screen for 500 ms, followed by presentation of eight (meaningful or meaningless) words, each shown for 800 ms, intermitted by pauses of 500 ms. To ensure that these words could be clearly distinguished from target words, the background colour changed from black to white during the delay period. After the delay, the text "Recall the words now" appeared, upon which participants recalled the words verbally. Participants only earn the primed coin if they would recall all the five words. Thus, a trial was scored as correct when all the five words were verbally reported. At the end of each trial, feedback about the performance and the amount of money obtained was shown for 1000 ms. The inter-trial interval was 1000 ms.

4. Results and discussion

To test performance on the word span task as a function of supraliminally and subliminally primed high and low monetary rewards and distraction, the proportion of correct trials was calculated for each condition. This yielded performance scores that could range from 0 (i.e., no correct trials) to 1 (i.e., 100% correct trials).

A repeated measures ANOVA with the factors reward value (low/high), reward presentation duration (supraliminal/subliminal) and interference (low/high) was performed, with the proportion of correctly recalled word series as the dependent measure. This analysis yielded the predicted main effect of reward value, $F(1, 25) = 8.14$, $p < .01$, as can be seen in Fig. 2. Con-
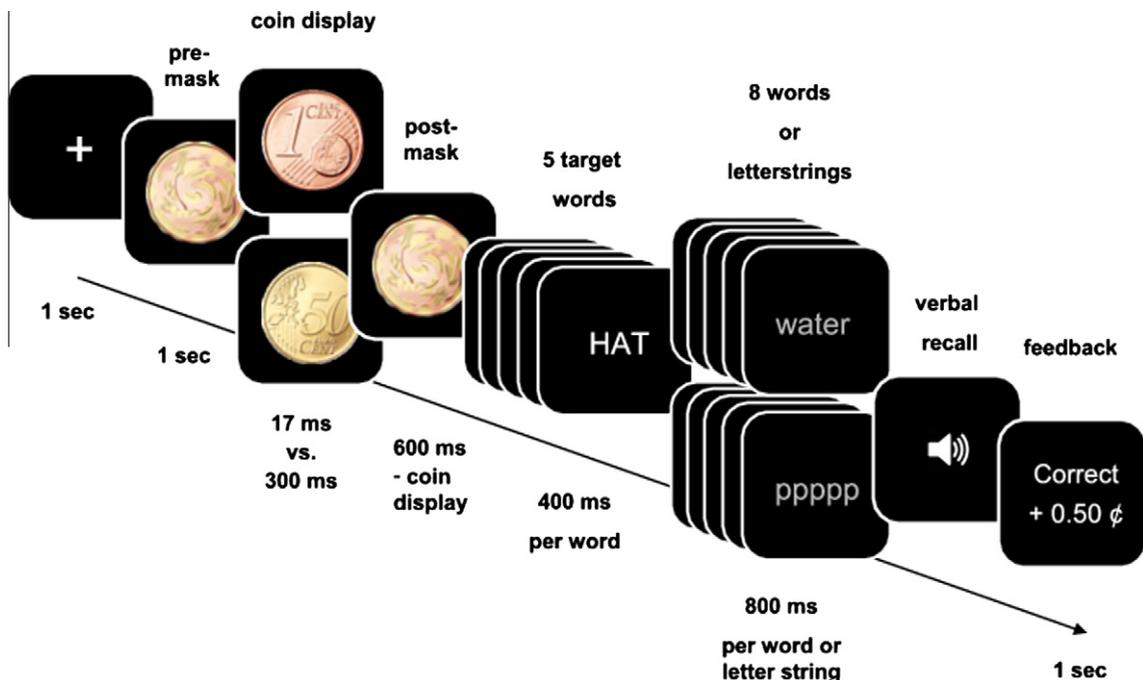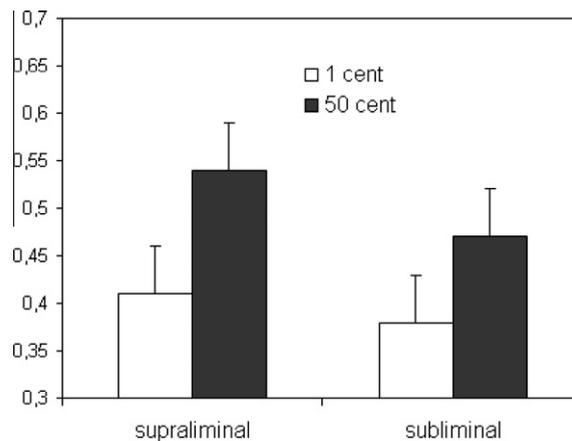

Fig. 1. Overview of a trial.

Fig. 2. Proportion of correct trials as a function of reward value and reward presentation duration. Error bars represent the standard error of the mean.

sistent with our hypothesis, performance was better on highly rewarded trials then on trials with a low reward. Simple effect tests revealed that the effect of reward was significant for the supraliminal, $F(1, 25) = 6.88$, $p = .02$, as well as for the subliminal condition, $F(1, 25) = 4.39$, $p = .05$. These results confirm our main hypothesis that valuable rewards facilitate the maintenance of task-relevant information, regardless whether people are consciously aware of the reward value or not. These results are in line with previous research showing resource boosting effects after processing unconscious rewards (Bijleveld et al., 2009), and extend previous research (Gilbert & Fiez, 2004; Heitz et al., 2008) by showing that unconsciously perceived rewards can improve performance on an active maintenance task.

Furthermore, we found a main effect of interference, $F(1, 25) = 6.07$, $p = .02$; performance was better when interference was low ($M = 0.48$, $SD = 0.24$) compared to when it was high ($M = 0.43$, $SD = 0.25$). As predicted, there was no interaction between reward value and interference, $F < 1$. Thus, rewards affect maintenance performance by a process whereby resources are boosted proportionally to the value of potential rewards, independently of the interference of the active maintenance process as a result of the conscious processing of meaningful (distracting) stimuli.

5. Experiment 2

Experiment 1 demonstrated that both consciously and unconsciously perceived rewards boost the active maintenance of information in memory, and that conscious perception of meaningful information during maintenance interferes with this process and decreases performance. These results open up the possibility that conscious and unconscious rewards can have differential effects on performance when processed during the active maintenance of information. As consciously perceived high (vs. low) rewards are particularly meaningful and likely to be reflected upon, they have the potential to distract from and disrupt the process of keeping information active in memory. Consequently, the target information is likely to be removed from working memory, and as the information is no longer externally present, it may be difficult to recover. This should lead to potentially strong impairment on later recall performance. Conscious reflection is not triggered when rewards are presented unconsciously. Therefore, unconscious perception of a valuable reward during maintenance should still boost resources and lead to improved performance.

To test this, we replicated Experiment 1, with an important modification: the reward was now offered immediately after participants had encoded the target words, that is, at the beginning of the delay maintenance phase. At this stage, rewards should still have the potential to facilitate performance by boosting resources for the active maintenance process (Gilbert & Fiez, 2004). However, conscious reflection on relatively high rewards should heavily interfere with the task (Beilock, 2007; Mobbs et al., 2009), at the expense of the internal maintenance of target information. Thus, performance should be impaired on high reward compared to low reward trials in the supraliminal condition. In contrast, subliminally presented high (vs. low) rewards are expected to enhance active maintenance performance due to their boost of resources.

The presentation of the reward cue after the display of the target words also allowed us to verify our hypothesis that the rewards have an impact on the active maintenance of relevant information, and not only on the initial encoding of the information. Obtaining such a result would be in line with the research discussed above showing that subjects display sustained active maintenance related DLPFC activity during the delay period in a working memory task, and that this activity is heightened when working memory performance is rewarded (Gilbert & Fiez, 2004). Thus, if the presentation of the 50 cents (vs. 1 cent) coin serves as a reward after encoding, then we should find improved performance in the subliminal condition, but impairment in the supraliminal condition due to its interference effect.

6. Methods

6.1. Participants

Thirty-four students (25 female) with a mean age of 21.2 years (SD = 2.3) were recruited for this experiment. There was no minimal fee for participation, payment was again fully dependent on performance (with a theoretical maximum of 15 €).

6.2. Design and procedure

A 2 (reward value: low vs. high) × 2 (reward presentation duration: supraliminal vs. subliminal) × 2 (delay: long vs. short) within-participants design was used.

The procedure resembled the one described in Experiment 1 with a few exceptions. First, and most importantly, reward primes were now presented after presentation of the target words. Specifically, the priming episode (including pre-mask, coin, and post-mask) started 200 ms after the last target word was shown. Furthermore, in this experiment only the low distracting letter strings were shown during the delay period. Finally, on half the trials, the delay period was shortened to 100 ms. This was done to ensure that participants would not generally expect a long delay period and consequently look away from the screen after reading the last word, thereby missing the coin priming event.

7. Results and discussion

To test the effects of supraliminally vs. subliminally presented high and low rewards on the successful maintenance of reward-instrumental information, we again assessed the proportion of correct responses. A repeated measures ANOVA with the factors reward value (low/high), reward presentation duration (supraliminal/subliminal) and delay (long/short) was performed on the proportion of correct responses. This resulted in a marginally significant main effect of reward presentation duration, $F(1, 33)$ = 3.16, p = .09, indicating that performance was slightly better when the rewards were presented subliminally then when they were presented supraliminally. Importantly, this effect was qualified by the predicted interaction of reward value x reward presentation duration, $F(1, 33)$ = 12.65, p = .001. The three-way interaction effect with delay was unreliable, F < 1, showing that delay did not influence the effects of reward value on active maintenance performance under different conditions of reward presentation duration. Means of the reward value x reward presentation duration interaction effect are depicted in Fig. 3.

Simple effects analyses revealed that performance increased in response to high rewards compared to low rewards when presented subliminally, $F(1, 33)$ = 5.28, p = .03, thus replicating the findings of the first experiment. Relevant to the present hypothesis, however, for supraliminally presented rewards the opposite was found, $F(1, 33)$ = 3.29, p = .08. High rewards led to worse performance than low rewards.

The results of Experiment 2 are in line with the predictions that unconsciously perceived high rewards facilitate the maintenance of target words even when the rewards are displayed after the encoding and during the maintenance of the words. This finding indicates that the coins presented after encoding still served as rewards, with the potential to improve performance. It is important to note, however, that the improved performance as a result of the proposed boost of resources was only observed in the subliminal 50 cents coins condition. In the supraliminal condition, the conscious perception of the 50 cents (vs. 1 cent) coins caused impairment of performance, independent of this boost. In fact, it seems that the interference effect of the consciously perceived high (50 cents) reward has a stronger influence on performance than the initial boost of resources of the reward itself. This suggests that, in the context of the present research, conscious reflection on relatively high rewards is particularly harmful when one is engaged in actively maintaining information that is no longer externally present.
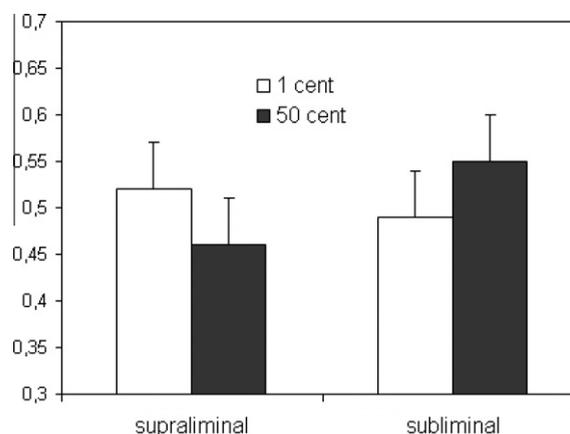

Fig. 3. Proportion of correct trials as a function of reward value and reward presentation duration. Error bars represent the standard error of the mean.

The findings from Experiment 2 also provide more compelling evidence for our interpretation that the reward-dependent increase in performance was due to an improvement of the active maintenance process. In response to Experiment 1, an alternative explanation could have been that differences in performance simply reflected better encoding of task-relevant information on highly rewarded trials. However, the finding that the subliminally primed high reward still led to enhanced task performance even when the rewards are presented after participants had encoded the target words rules out an encoding advantage account.

8. General discussion

Two experiments investigated the effects of consciously and unconsciously perceived rewards on performance in an active maintenance task. In Experiment 1, when rewards were primed before participants read the target stimuli and kept them active in mind, it was found that relatively high rewards did indeed lead to enhanced performance. This was true when the rewards were presented supraliminally as well as when they were presented subliminally. This finding confirmed that people can unconsciously process the value of potential rewards, and that unconsciously processed rewards boost resources and facilitate active cognitive performance in a similar way as conscious rewards do. It was further shown that this process is prone to interference by consciously perceived meaningful information appearing in the environment, but that rewards facilitated maintenance independent of the amount of external interference. These findings concur with previous research demonstrating that consciously attended rewards affect maintenance performance (e.g., Heitz et al., 2008; Veling & Aarts, in press), and that consciously and unconsciously perceived rewards have a similar potential to facilitate effortful tasks by boosting additional resources (e.g., Bijleveld et al., 2009).

In Experiment 2, we obtained an interesting and novel finding when rewards were presented while participants were already engaged in the maintenance task. Specifically, while performance was facilitated by high rewards when primed subliminally, performance decreased when high rewards were primed supraliminally. Thus, consciously perceived rewards are capable of strongly taxing and disrupting ongoing active maintenance processes, independent of their potential to boost resources. Importantly, the taxing effect inherent in a consciously detected reward appears to be particular for valuable (50 cents) rewards, presumably because a reward of 50 cents has more significant consequences in comparison to a reward of 1 cent (which is essentially less meaningful). This is in line with research showing that cognitive interference is particularly strong for meaningful information, which signals a greater importance for the individual (Dolcos & McCarthy, 2006).

It is important to note that our line of reasoning suggests that conscious perception of high rewards causes interference only during the process of actively maintaining information, and not during the preparation stage of the task. One might expect that a high conscious reward would capture attention for a duration long enough that it would nevertheless interfere with subsequent cognitive processes. This is certainly possible, and might apply for outstandingly high rewards with a greater power to capture attention throughout a task, such as they are often used in experiments on choking under pressure (e.g., Mobbs et al., 2009). However, we believe that the experimental setup in Experiment 1 allowed participants to recover from such an attention capturing effect and to (re)direct attention to the task before they the targets words were presented (e.g., Yantis & Jonides, 1984; Franconeri & Simons, 2003).

The present findings may raise questions regarding their underlying mechanisms. A particularly puzzling question concerns the processes underlying the interference effect of conscious reward processing in Experiment 2. What is it that makes the conscious perception of valuable rewards so detrimental to the ongoing maintenance process? One possibility would be that the conscious knowledge of the chance for a high reward goes along with increased emotional experiences that disrupt the ongoing maintenance process (cf. Kunde, 2003; Nieuwenhuis, Ridderinkhof, Blow, Band, & Kok, 2001). It could also trigger conscious thoughts related to success or failure that claim attentional resources and require inhibition to return to the ongoing task. In a sense, then, conscious reflection of valuable rewards produces interference similar to a dual-task setting. Interference may thus result from a single-channel constraint that allows processes to run serially, or from capacity sharing of resources for different tasks (e.g., Pashler & Johnston, 1998). Thus, compared to subliminally presented rewards, which due to unawareness do not put much strain on the limited capacity of conscious processes, consciously processed rewards provide a substantially higher cognitive load. Importantly, whether strong disruption or load on conscious attentional resources explain why high rewards trouble people to keep information active in memory (Beilock, 2007), they only do so when rewards are consciously perceived once people are engaged in an effortful maintenance process.

There is evidence from neuroimaging studies supporting the finding that, while the conscious perception of a high reward in preparation of a cognitively demanding task facilitates performance, it might be detrimental at a later stage. Thus, an explanation at a different level for why conscious rewards can interfere pertains to how our cortical brain structures deal with consciously perceived rewards. In a study by Gilbert and Fiez (2004), it was shown that reward primes presented at the beginning of a maintenance task caused increased activation of the ventral frontal cortex (VFC), an area involved in affective motivational processing. Interestingly, however, during the delay period following the presentation of the words to be remembered, the VFC was deactivated, and this deactivation was more pronounced on consciously rewarded then on not rewarded trials. Similar results were found in the study by Pochon et al. (2002), who concluded that VFC activity might be suppressed during cognitively demanding tasks in order to minimize interference by thoughts and emotional responses evoked by a reward. This interpretation is compatible with our pattern of findings. Conscious processing of the high reward

primes in Experiment 2 may have activated the VFC at a time when deactivation of this area would be profitable, causing interference with the maintenance task.

In the present research, we looked at performance on an active maintenance task because we deemed it likely that reflective thoughts elicited by consciously perceived high rewards would interfere with the task. Based on these findings we cannot conclude, however, that reflection on a high reward during ongoing activity impairs performance always and on all tasks. Also, enhanced performance may not always be a smart reaction upon encountering a reward cue. When performance on a particular task is not instrumental for attaining an incidentally presented reward, investing effort in a task can be a waste of effort. One possibility is that conscious reflection enables a person to take such circumstances into consideration and helps to downregulate one's spontaneous reaction to a reward cue, while such regulatory operation may be less likely to occur when rewards are processed unconsciously. Whereas this adaptive function of conscious reflection processes for reward processing and goal-directed behavior has been proposed before (Baars, 1988; Dijksterhuis & Aarts, 2010), it would be interesting for future research to study whether and how this improves performance in comparison to unconsciously processed rewards.

To conclude, the present experiments show that the value of an expected reward can be processed unconsciously, and the unconscious perception of high rewards can support goal-directed cognitive performance. For the conscious processing of valuable rewards, this facilitative effect is not unconditional but depends on the level of task involvement at the time a reward is detected. When people are involved in a cognitively demanding task, high rewards seize attention, much like other conscious meaningful information, and interfere with the process of keeping information active. Our study, then, indicates that once one is busy with making money, valuable rewards are best taken unconsciously.

Acknowledgment

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