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A new perspective on human reward research: How consciously and unconsciously perceived reward information influences performance

Claire M. Zedelius · Harm Veling · Ruud Custers · Erik Bijleveld · Kimberly S. Chiew · Henk Aarts

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Abstract The question of how human performance can be improved through rewards is a recurrent topic of interest in psychology and neuroscience. Traditional, cognitive approaches to this topic have focused solely on consciously communicated rewards. Recently, a largely neuroscience-inspired perspective has emerged to examine the potential role of conscious awareness of reward information in effective reward pursuit. The present article reviews research employing a newly developed monetary-reward-priming paradigm that allows for a systematic investigation of this perspective. We analyze this research to identify similarities and differences in how consciously and unconsciously perceived rewards impact three distinct aspects relevant to performance: decision making, task preparation, and task execution. We further discuss whether conscious awareness, in modulating the effects of reward information, plays a role similar to its role in modulating the effects of other affective information. Implications of these insights for understanding the role of consciousness in modulating goal-directed behavior more generally are discussed.

Keywords Reward · Motivation · Consciousness · Unconscious processing

People possess a remarkable capacity to increase their performance when it matters most—for example, when valuable rewards are at stake. On a daily basis, people make decisions about what rewards to pursue (a bread roll when hungry, a can of soda when thirsty), and how much effort to invest in trying to attain these rewards. In response to such decisions, people prepare and execute the actions that they expect to be instrumental for attaining the desired rewards. Enabling people to get what they want and need, this reward–performance interface is central to human motivation and behavior. In the present review, we integrate recent findings from psychology and neuroscience to advance our understanding of how human performance is modulated by rewards. In this investigation, we specifically focus on the roles of conscious awareness and unconscious processes in human reward pursuit.

The question of how rewards modulate performance has been a research topic of great interest since the early days of psychology. Much of this research started out from a behaviorist tradition (Skinner, 1953; Thorndike, 1932), in which rewards were assumed to simply reinforce stimulus–response relations, without assumptions or claims about underlying mental processes. Since this behaviorist approach failed to account for the many instances in which valuable rewards do not proportionately improve performance, since the 1950s, psychologists have shifted their interest toward understanding people's ability to reflect on the value of rewards, to make deliberate decisions based on reward value and contextual information, and to use intricate performance strategies (Camerer & Hogarth, 1999; Deci, 1976; Festinger, 1961;

C. M. Zedelius (✉)
Department of Psychological and Brain Sciences, University of California Santa Barbara, Santa Barbara, CA 93106-9660, USA
e-mail: claire.zedelius@psych.ucsb.edu

H. Veling
Department of Psychology, Radboud University Nijmegen, Nijmegen, The Netherlands

R. Custers
Department of Cognitive, Perceptual and Brain Sciences, University College London, London, Great Britain

R. Custers · E. Bijleveld · H. Aarts
Department of Psychology, Utrecht University, Utrecht, The Netherlands

K. S. Chiew
Department of Psychology, Washington University in St. Louis, St. Louis, MO, USA

Gendolla, Wright, & Richter, 2011; Koopmans, 1960). As a result, the dominant approach to studying reward effects on performance today is to consider human beings as goal-directed and conscious information processors, who carefully weigh reward- and task-related information in order to optimize their performance.

A striking finding by Pessiglione et al. (2007), however, suggests that this approach may not always capture the way that people respond to, and deal with, their pursuit of rewards. Specifically, it was found that people's performance improved in response to reward cues, even when these cues were presented subliminally (below the threshold of conscious perception). Suggesting that conscious information processing is not needed in order to become motivated by and act on rewards, this research stirred several exciting questions regarding the role of consciousness in human motivation and reward pursuit. Can unconsciously perceived rewards influence performance through the same psychological processes as consciously perceived rewards do? Or do conscious processes have unique influences on performance? The present review offers tentative answers to these challenging new questions, which have broader implications for the role of consciousness in human motivation.

Before we turn to our review of the literature, let us first define the most important concepts and the scope of this review. *Reward* is defined as a desirable outcome attainable through instrumental performance (see Maunsell, 2004). Thus, our definition of *reward* follows in line with much neurocognitive research in which rewards are seen as tools to elicit motivation for performance, where motivation stands for the level of energization to recruit resources and exert effort to work on a task (e.g., Berridge, 2000; Pessiglione et al., 2007; Pessiglione, Schmidt, Palminteri, & Frith, 2011; Pessoa, 2009; Schmidt, Lebreton, Cléry-Melin, Daunizeau, & Pessiglione, 2012; Schmidt, Palminteri, Lafargue, & Pessiglione, 2010). *Performance* refers to the style in which a task is accomplished. The most common elements of performance, in various types of tasks, are *speed* and *accuracy* (Förster, Higgins, & Bianco, 2003; Green & Swets, 1966; Niemi & Näätänen, 1981; Woodworth, 1899). *Consciousness* is an umbrella term spanning a number of different constructs. In the present review, we use the term to refer to awareness of the content of one's experience (e.g., Lau & Rosenthal, 2011). Thus, when we talk about conscious and unconscious processing of rewards, we are primarily concerned with whether or not an individual is aware of (and potentially able to report on) the stimulus conveying reward value (i.e., the reward cue). One could make other distinctions—for instance between experiential consciousness and meta-consciousness (i.e., something could be experienced consciously with or without the experiencer reflecting on this experience; see, e.g., Rosenthal, 2002; Winkielman & Schooler, 2011). However, most of the studies reviewed below manipulated people's awareness of the content of their experience—and not other aspects of consciousness. For that reason, we define *consciousness* in terms of awareness of content for the purpose of this review, but we should add that other perspectives on consciousness exist, and are clearly worth exploring, too.

Another note on the scope of this review: We want to highlight that we do not examine the issue of how rewards may influence performance indirectly—that is, *after* they are attained. Thus, we do not discuss processes such as reinforcement and learning, through which a reward, once it is attained, may affect future choices or actions (e.g., Berridge, 2000; Dayan & Balleine, 2002; O'Doherty, 2004). Instead, our focus is on how the conscious or unconscious perception of a reward cue influences processes that play a direct role in attaining the reward that is at stake.

Methodological approach and initial findings

Only recently have studies begun to systematically compare the effects of consciously and unconsciously perceived rewards on performance. Pessiglione et al. (2007) played a major role in this shift, because they employed a novel "reward-priming" paradigm that proved very suitable for making this direct comparison. In this paradigm, participants are presented with monetary rewards of different values, indicated by coins, which they can earn by performing well on the same trial. Whether these coins—which are presented in-between visual masks (i.e., pictures of scrambled coins)—are perceived consciously or unconsciously is manipulated by varying the duration for which the coins are shown. This manipulation is built on the idea that weaker stimuli, in terms of their input, are less likely to permeate into consciousness (see Dehaene, Kerzberg, & Changeux, 1989). So, when coins are shown for a relatively long duration (i.e., strong input; supraliminal presentation), they are perceived with awareness (i.e., the value of coins is processed consciously), but when they are presented extremely briefly (i.e., weak input; subliminal presentation), people fail to perceive them with awareness (and they process the value of the coins unconsciously). It is important to note that, in the reward-priming paradigm, participants are always aware of the fact that a coin is presented on every trial, and that they have knowledge about the task they have to perform to obtain the monetary reward. What varies is only their awareness of the identity of the coin, which indicates the reward value of that trial. Thus, the reward-priming paradigm allows for a systematic and well-controlled comparison of conscious and unconscious reward processing.

In their initial experiment with this paradigm, Pessiglione et al. (2007) tested the effects of supraliminal and subliminal presentation of coins on a physical force task, in which participants were asked to squeeze a handgrip. The harder participants squeezed, the greater the proportion of the reward they would earn. The results indicated that people squeezed harder for high-value coins, even when these were presented subliminally. Moreover, squeezing force correlated with blood oxygenation level dependent activation in the basal ganglia network, specifically the ventral pallidum, a brain area commonly associated with reward anticipation and effort mobilization. These findings provided evidence that subliminal rewards can increase physical effort and performance in a way similar to the way that consciously perceived rewards do. Follow-up research using the reward-priming paradigm showed that the performance-enhancing effects of subliminal rewards were present right from the beginning of a rewarded task, even when the first block contained no supraliminal rewards (Pessiglione et al., 2011). This is important, because it suggests that the effects of subliminal rewards are not merely the result of habitualized responses to consciously perceived rewards presented in the same context, but the result of unconscious reward processing.

After Pessiglione et al.'s (2007) initial study, different laboratories quickly expanded the study of conscious and unconscious reward processing, replicating the initial effects with different cognitive tasks and different kinds of rewards (e.g., Bijleveld, Custers, & Aarts, 2009; Capa, Bustin, Cleeremans, & Hansenne, 2011; Ziauddeen et al., 2012), and addressing questions about the underlying processes. Recent experiments have looked not only at the similarities, but also at differences in the ways that conscious and unconscious processing of reward cues can affect individuals' decisions, task strategies, and execution of effortful tasks. Before turning to the details of this research, we will now briefly outline our theoretical framework, which was developed to better understand the similarities and differences between conscious and unconscious reward processing.

A perspective on (un)conscious reward processing

Central to our framework on (un)conscious reward processing (Bijleveld, Custers, & Aarts, 2012b) is the idea that reward cues are initially processed in ontogenetically old, subcortical brain systems that operate independently of conscious awareness (e.g., Öhman, Flykt, & Lundqvist, 2000; Tamietto & de Gelder, 2010). Indeed, several studies have shown that the value of rewards is initially encoded by a dedicated subcortical reward network that includes the ventral striatum (Phillips, Walton, & Jhou, 2007; Salamone, Correa, Farrar, Nunes, & Pardo, 2009), a structure that is unlikely to be involved in producing conscious perception. This subcortical network has extensive projections to many higher-level cortical areas involved in goal-directed behavior (Haber & Knutson, 2010). Which particular of those cortical areas are activated depends on the specific (e.g., motor or cognitive) demands of a given task (Liljeholm & O'Doherty, 2012; Schmidt et al., 2012). In this way, *initial reward processing* (i.e., reward processing without conscious awareness) has the potential to increase performance on a broad range of tasks.

After being processed in this initial stage (i.e., unconsciously), reward cues can also be processed more fully. That is, when stimuli are attended to for an extended period of time (e.g., >50 ms), they are known to trigger sustained activity in a widely distributed set of cortical neurons (e.g., Dehaene et al., 1989). Importantly, this cortical network is thought not only to enable all sorts of advanced cognitive processing (e.g., greater integration of information or more strategic control over behavior; Baars, 2002; Cleeremans, 2008; Dehaene & Naccache, 2001), it is also thought to lie at the basis of conscious experience and reflection. Building on and extending this previous theorizing, we propose that the performance consequences of *full reward processing* (i.e., reward processing with conscious awareness) differ from those of *initial reward processing* when different sources of task- and reward-related information have to be integrated. Moreover, we propose that initial and full reward processing have distinct consequences when good task performance relies on flexible and strategic decisions (Bijleveld et al., 2012b).

Structure of this review

As we will show in this review, behavioral and neuroscientific research comparing the effects of conscious and unconscious rewards supports the basic premises of the framework. Our aim for this review, however, goes farther than validating the framework. Specifically, we aimed to gain more insight into how conscious and unconscious rewards influence the specific cognitive processes relevant to performance. To structure this investigation, we chose to focus on three task aspects relevant to the pursuit of rewards through performance: *decision making*, *task preparation*, and *task execution*. These aspects involve specific processes that often unfold successively and that may influence performance in quite different ways (Deecke, 1996; Haggard, 2008; see also Gollwitzer, 1990). Past research has clarified how each of these processes is affected by consciously perceived rewards (Brehm & Self, 1989; Camerer & Hogarth, 1999; Deci, 1976). It is less clear, however, whether and how unconsciously perceived rewards modulate these processes. In the following three sections, on decision making, task preparation, and task execution, we discuss studies that have used the reward-priming paradigm to examine this question. Finally, we situate these findings in a broader context by exploring whether the proposed psychological processes are specifically induced by reward cues, or whether they might generalize to any cues that signal positive affect.

Decision making

Performance is usually thought to start with the decision to perform. For example, people make decisions about which tasks to engage in and how much effort to invest (Deci & Ryan, 2009; Gold & Shadlen, 2007; Rangel, Camerer, & Montague, 2008; Schwartz, 2000). These performance decisions are usually oriented toward *efficiency*, meaning that people invest only as much effort as is necessary to attain a reward and is justified on the basis of the reward value (Gendolla, 1998; Wright, 2008). Therefore, reward decisions are influenced by factors such as how demanding a task is, how well one can perform the task, and how likely it is that a reward can be attained through the task (Bandura, 1982; Brehm & Self, 1989; Heckhausen, 1977). After all, increasing one's effort for a valuable reward is efficient only if the reward is attainable. Moreover, it may be justifiable to invest effort even for low rewards when a task requires very little effort, but it makes sense to invest effort only for reasonably high rewards when a task is very demanding (Gendolla & Silvestrini, 2011; Rangel et al., 2008; Wright, 2008).

According to traditional theories of motivation and decision making, such decisions involve a deliberative calculation process, in which the value of a reward is integrated with available information on task demands and reward attainability (Atkinson, 1957, 1964; Brehm & Self, 1989; Rangel et al., 2008; Vroom, 1964). Today, however, accumulating evidence is suggesting that performance decisions are initially rooted in unconscious processes, and that conscious deliberation and reflection come into play only later (Bechara, Damasio, Tranel, & Damasio, 1997; Brass & Haggard, 2007; Libet, Wright, & Gleason, 1982; Soon, Brass, Heinze, & Haynes, 2008). Since the reward-priming paradigm can be used to test performance in response to varying reward values while also varying other factors (e.g., task demands), it offers an elegant way to investigate conscious and unconscious processes in efficiency-oriented performance decisions.

The most commonly examined factors relevant to efficiency-oriented decision making are task demands and the likelihood of reward attainability. Recent research has addressed how these factors relate to conscious versus unconscious reward pursuit. One experiment dealt with the question of how performance decisions are influenced by varying task demands. In the experiment, participants were rewarded for a memory task in which they had to maintain digits in working memory over a short period of time (Bijleveld et al., 2009). The task demands were manipulated by varying the numbers of digits that had to be kept active in memory. Rewards were presented following the procedure of Pessiglione et al.'s (2007) reward-priming paradigm. So, on every trial, participants were first presented supraliminally (i.e., for 300 ms) or subliminally (i.e., for 17 ms) with a relatively high- (50 cents) versus a low- (1 cent) value coin shown between visual masks (scrambled coins). Next, participants were shown either three (low task demands) or five (high task demands) digits, which they were asked to recall 4 s later. Pupil dilation, a well-validated correlate of mental effort (Kahneman, 1973), was measured in order to tap the amount of effort that was recruited for the task. The results showed that—for both supraliminal and subliminal rewards—valuable rewards increased effort only when the task was relatively demanding. This finding provided first evidence that, even when the reward value is processed outside of awareness, performance decisions are influenced by a combination of reward value and task demands.

In a follow-up experiment that addressed physical effort, participants were rewarded for their performance on a finger-tapping task. Rewards were presented on every trial, following the same reward-priming procedure as before. After being exposed to the reward cue, participants had to tap a key on a computer keyboard 25 times. In this experiment (Bijleveld, Custers, & Aarts, 2012a, Exp. 1), task demands were manipulated by varying the time that participants had available to complete the 25 finger taps. That is, the time limit was either 10 s (low task demands) or 3.5 s (high task demands), which varied between blocks of trials. Participants were informed about the task demands at the beginning of each block. The results replicated the earlier finding that both supraliminal and subliminal high-value rewards increased effort, especially under high task demands. Thus, this experiment provided further evidence that some integration of reward value and task demands is possible without being consciously aware of a reward cue.

The question remained, however, how exactly this unconscious integration—which apparently takes place—works. One possibility, which was examined in another follow-up experiment (Bijleveld et al., 2012a, Exp. 3), was that people simply become more sensitive to reward cues whenever their body feels that more effort is required (see also Kiefer, 2012). This experiment was similar to the finger-tapping experiment described above. Again, participants repeatedly tapped on a computer key 25 times to attain a reward. However, this time, the task demands were varied not by changing the time limit for completing the 25 taps, but by having participants perform a second, unrelated physical task at the same time. Specifically, while participants tapped the key on the keyboard to attain rewards, they were also asked to either forcefully squeeze (high demand) or loosely hold (low demand) a handgrip with their free (nontapping) hand.

Interestingly, for subliminal reward cues, the results were the same as in the previous experiments. So, even though the task demands were not relevant for attaining any reward, these still affected people's performance on the tapping task. For supraliminal reward cues, however, performance was unaffected by the demands of the irrelevant secondary task. This pattern of results suggests that when rewards are perceived without awareness, greater effort requirements increase sensitivity to the value of rewards in a nonstrategic way—that is, even when the demands are irrelevant for reward attainment. By contrast, conscious processing of reward cues seems to specifically enable the integration of various types of reward information. This interpretation fits with the general notion that conscious awareness plays a special role in the information integration (Baars, 2002; Dehaene & Naccache, 2001; Kouider & Dehaene, 2007), as well as with our theoretical framework (Bijleveld et al., 2012b).

The issue of integration was addressed more directly in a further study using accuracy on a visual working memory task as a performance measure (Zedelius, Veling, & Aarts, 2012, Exp. 1). This time, the consciously and unconsciously perceived rewards varied not only in their value, but also in their attainability. That is, at the beginning of every trial, participants were cued as to whether a subsequently presented reward would be attainable or unattainable (see Fig. 1 for an overview of the procedure). Efficient performance thus required the trial-by-trial integration of reward value and attainability. As in the study described in the previous paragraph, subliminal cues signaling high-value rewards enhanced performance, even when these rewards were unattainable. By contrast, supraliminal high-value reward cues selectively improved performance when the rewards both were of high value and could be attained. Again, this pattern of findings supports the idea that processing of the rewards that are at stake enables a more strategic mode of reward pursuit (Zedelius et al., 2012).

In conclusion, by comparing performance in response to consciously and unconsciously perceived rewards under different task demands and attainability conditions, new insight can be gained with regard to the role of consciousness in efficiency-driven decision making. Specifically, the findings discussed in this section support the basic premise of the theoretical framework that full reward processing is required in order to enable flexible integration of reward information with other performance-relevant information (i.e., task demands or attainability information).

Although this section has been devoted to decision-making processes, it is important to note that the eventual implementation of performance decisions is an issue that falls under the topics of preparation and task execution. That is, when deciding to engage in or keep performing a task, or to invest extra effort, the logical consequence is to prepare appropriate responses and task strategies, an issue discussed in the following section.

Task preparation

Preparation entails the allocation of attention to the kind of stimuli to follow and the kind of operations and actions to be

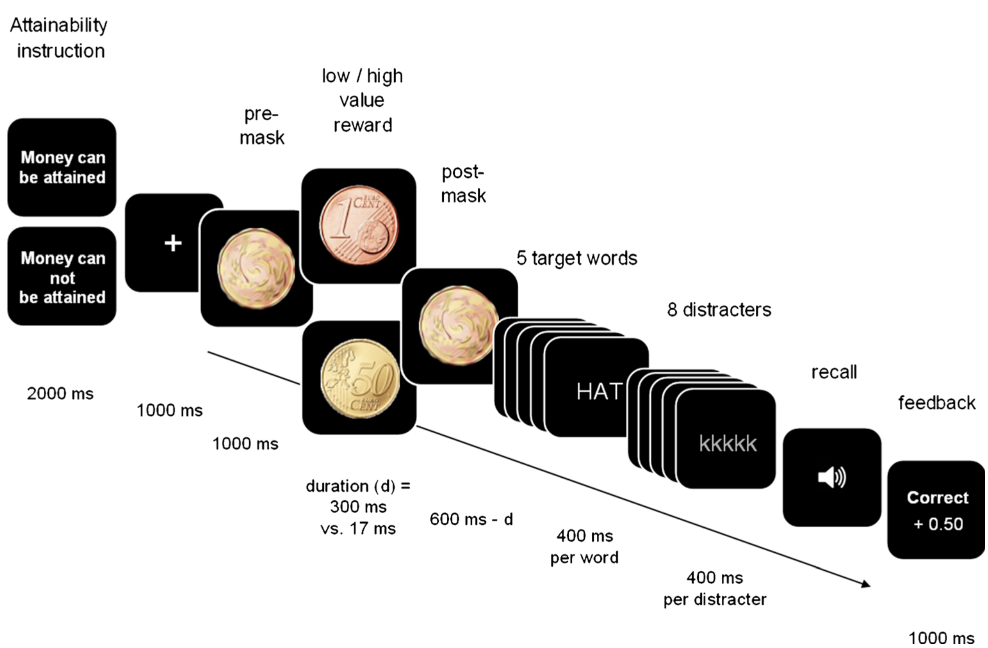

Fig. 1 Experimental paradigm from Zedelius et al. (2012a). At the beginning of each trial, instructions indicated whether the upcoming reward would be attainable or unattainable. Next, a masked 1-cent or 50-cent coin was presented either supraliminally (for 300 ms) or subliminally (for 17 ms). The reward presentation was followed by a trial of a verbal active maintenance task. Participants were shown five consecutively presented target words, followed by a delay period during which mildly distracting letter strings were flashed on the screen. After the delay, participants were asked to verbally recall the target words. A trial was scored correct if all of the words were recalled correctly in any order (for a discussion of this performance measure, see Zedelius, Veling, & Aarts, 2011a). From "When Unconscious Rewards Boost Cognitive Task Performance Inefficiently: The Role of Consciousness in Integrating Value and Attainability Information," by Zedelius et al. (2012a), *Frontiers in Human Neuroscience*, *6*:219. Copyright 2012 by Zedelius, Veling, and Aarts

performed, and it begins before an individual has all of the information necessary to actually execute an action (Miller, 1987; Min & Herrmann, 2007; Min & Park 2010; Monsell & Driver 2000; Tandonnet et al., 2012). Successful performance depends crucially on preparation (e.g., Meiran & Daichman, 2005; Niemi & Näätänen, 1981; Rolke, 2008). Thus, not surprisingly, preparation is enhanced when performance is rewarded (e.g., Nieuwenhuis & Monsell, 2002).

Yet, previous studies that have investigated how rewards affect preparation have mostly employed consciously presented reward information. For example, studies have shown that the promise of monetary rewards facilitates responses on simple and choice reaction time tasks and reduces the time for task switching, but only when task cues are provided that enable preparatory processing prior to response execution (Mir et al., 2011; Veling & Aarts, 2010). Only recently have studies begun to use the reward-priming paradigm to investigate how initial and full reward processing affect task preparation, and to try to understand how these processes might be different.

One study addressed this issue by using a task-switching paradigm (Capa, Bouquet, Dreher, & Dufour, 2013). Participants were presented with high- and low-value reward cues followed by long sequences of single digits, which they had to use to perform different tasks. The tasks involved making simple judgments such as whether the numbers were odd or even or whether they were less or greater than 5. To stimulate preparation, task cues presented before each digit indicated which task would have to be performed next. Preparation was measured by assessing event-related potentials (ERPs) in response to these task cues. Stronger frontocentral ERPs to these cues on high- as compared to low-value reward trials indicated increased task preparation for high-value rewards. Intriguingly, the findings indicated that preparation increased regardless of whether the rewards were presented consciously or unconsciously.

Other findings provided indications that initial and full reward processing differ in initiating less-specific preparation. In one study using the reward-priming paradigm (Schmidt et al., 2010), participants were rewarded for squeezing a handgrip as hard as they could. An important feature of this task was that the reward cues were always flashed only in one visual hemifield (left or right), thus initially entering only one brain hemisphere. Replicating the previous findings (Pessiglione et al., 2007), the study showed that grip force increased proportionately to the value of the presented rewards. For subliminal rewards, however, this effect was limited only to the (left or right) hand controlled by the stimulated brain hemisphere. This finding suggests that unconscious reward processing initiates fairly localized preparatory processes. Although this processing may facilitate quick responding to the source of reward information, it does not influence behavior on a more global level. Thus, this study provides a further indication that conscious awareness of reward cues is helpful when good performance not just depends on the preparation of simple responses, but also requires flexible adjustments in strategy.

Often, such strategy adjustments are made when a rewarded task is difficult to perform both quickly and at high accuracy. That is, people may choose to sacrifice response speed for greater accuracy, or vice versa, depending on what is more important in the context at hand (e.g., Dambacher, Hübner, & Schlösser, 2011; Hübner & Schlösser, 2010). Research suggests that making such *speed–accuracy trade-offs* (SATs) is a matter of preparation. That is, an emphasis on speed or accuracy influences preparatory processing in brain areas responsible for the encoding of anticipated task stimuli. Such preparatory processing, in turn, influences how quickly the activation elicited by incoming stimuli reaches a psychological threshold at which a behavioral response is executed (e.g., Bogacz, Wagenmakers, Forstmann, & Nieuwenhuis, 2010; Ivanoff, Branning, & Marois, 2008; van Veen, Krug, & Carter, 2008). A focus on speed increases the baseline activation, such that the threshold will be reached faster—at the risk of making mistakes. A focus on accuracy lowers the baseline activation, such that the threshold will be reached later—a rather cautious strategy.

Recent studies have compared how conscious and unconscious varieties of reward processing affect the strategic use of SATs. In a first series of experiments, participants were rewarded for quick performance on a math task performed under different accuracy criteria (Bijleveld, Custers, & Aarts, 2010). In this task, participants were presented with relatively simple equations that they had to judge as being correct or false (e.g., 2 + 3 + 9 = 14). Across experiments, subliminally presented high as compared to low rewards sped up responses without any changes in accuracy. Supraliminal rewards, on the other hand, led to more strategic performance adaptations, as revealed through changing SATs in response to changing accuracy criteria. First, when both speed and accuracy were emphasized, participants tended to become selectively more cautious (i.e., slower but more accurate) in response to high relative to low supraliminal rewards. However, when overall high accuracy over all trials (regardless of the reward value) became a precondition to obtain rewards, participants abandoned this strategy and sped up responses on high-supraliminal-reward trials without any changes in accuracy. These results indicate that, whereas both conscious and unconscious processing of high rewards can increase performance, conscious processing of reward information is necessary to make strategic performance adjustments in line with the current performance context.

From these experiments, one could still argue that the differences between conscious and unconscious rewards with regard to strategic SATs reflect differences in decision making, with preparation simply following as a necessary consequence from these different decisions. To evaluate this question, a more recent study investigated how preparatory processes aimed at attaining future task rewards affect immediate performance adjustments (Zedelius, Veling, Bijleveld, & Aarts, 2012). The hypothesis was that, since high-value rewards increase task preparation already before a rewarded task can be executed (Mir et al., 2011), response strategies prepared with the aim to attain rewards contingent on future performance should already become apparent during an unrewarded intermediate task, even without the decision to invest immediate effort.

To test this hypothesis, participants were presented on each trial with a series of two tones, and they were asked to indicate for each tone whether it was high or low in pitch. Importantly, participants could only gain rewards for fast and accurate responding to each *second* tone in a series. Responses to each first tone were not rewarded (see Fig. 2 for the procedure). As in the study by Bijleveld et al. (2010), the results showed that subliminal high rewards sped up responses without changes in accuracy, and that only supraliminal high rewards led to strategic SATs. More remarkable was that these effects occurred not only for the rewarded task, but also for the first, unrewarded task (see Fig. 3). Thus, these findings indicate that the differences between initial and full reward processing surface not only during decision making, but also during task preparation.

Task execution

Once people decide to invest effort in a task and to prepare a specific response or task strategy, what remains critical for good performance is how the task is executed. Although task execution is heavily influenced by preparation, events that occur during task performance itself may also change that performance, for better or worse. On the one hand, reward cues can facilitate task execution by stimulating nonspecific effort investment during ongoing tasks, and thereby facilitate performance (Veling & Aarts, 2010). On the other hand, reward cues have been shown to capture attention, leading them to interfere with successful task execution (Anderson, Laurent, & Yantis 2011; Krebs, Boehler, Egner, & Woldorff, 2011; Krebs, Boehler, & Woldorff, 2010). The question is whether these effects of rewards on task execution are caused by consciously and unconsciously perceived rewards alike.

When measuring effects of rewards through performance outcomes, it can be difficult to tease apart the effects caused by processes operating at the stage of task execution or during task preparation. One solution to this can be the additional use of physiological measures (Coles, 1989; Leuthold & Jentzsch, 2002). In a study that was already described in the context of task preparation (Capa et al., 2013), participants performed a number of different tasks, all of which required simple judgments on digits (e.g., odd or even; less or greater than 5). Task

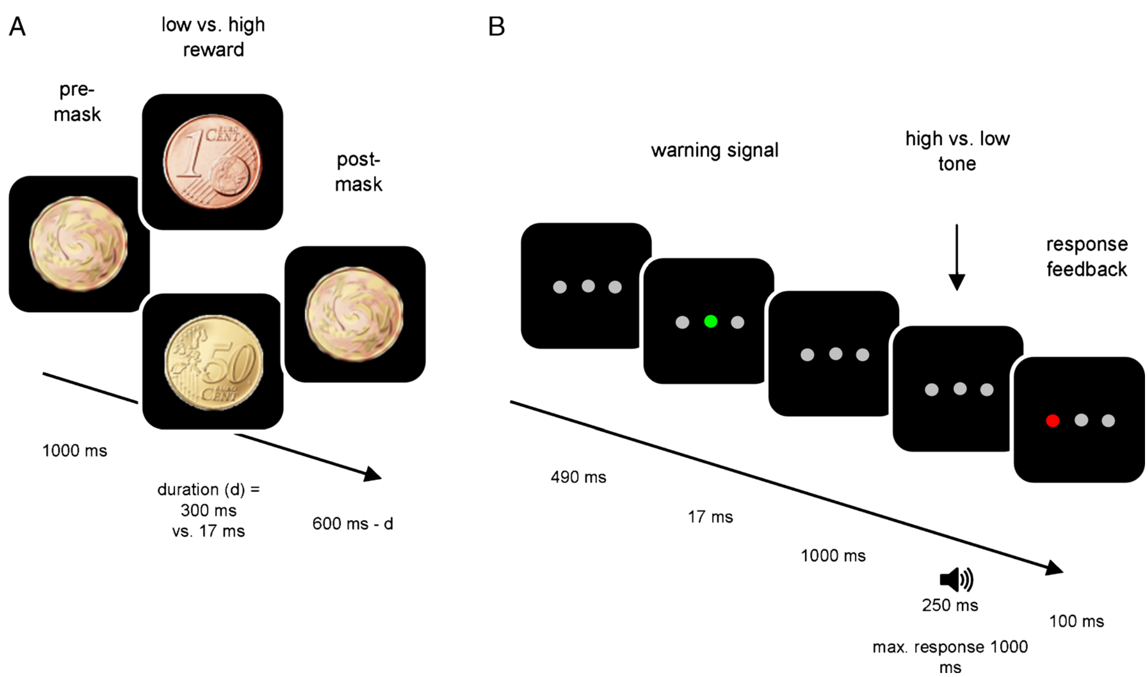

Fig. 2 Experimental paradigm from Zedelius et al. (2012a). After supraliminal or subliminal presentation of a masked 1-cent or 50-cent coin (**a**), participants performed two consecutive trials of a reaction time task (2 × **b**), in which they were asked to quickly respond with a right versus a left key to a high- or a low-pitched tone. Participants were instructed prior to the experiment that correct responses to each *second* tone would be rewarded if the response time lay within a predefined limit. The responses to each preceding tone were unrelated to attaining rewards. From "Promising High Monetary Rewards for Future Task Performance Increases Intermediate Task Performance," by Zedelius et al. (2012a), *PLoS ONE, 7*, e42547. Copyright 2012 by Zedelius et al.

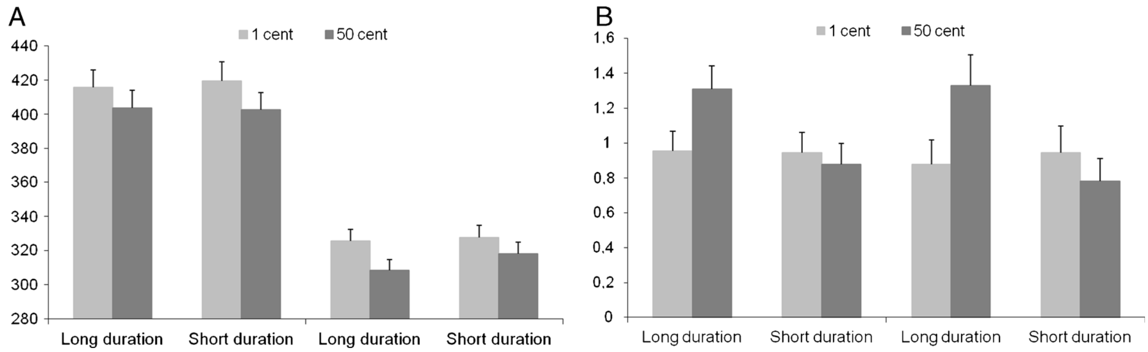

Fig. 3 Reaction times (**a**) showed that high-value rewards sped up responses to both rewarded responses (second tone) and intermediate, unrewarded responses (first tone) relative to low-value rewards, regardless of whether the values were presented supraliminally (long duration) or subliminally (short duration). The combination of these reaction time results with error rates (**b**) further revealed that supraliminally presented rewards led to a strategic speed–accuracy trade-off for both rewarded and unrewarded tones. That is, participants made more errors on high- than on low-reward trials. Subliminally presented rewards sped up responses to rewarded and unrewarded tones without this trade-off. Error bars represent standard errors. From "Promising High Monetary Rewards for Future Task Performance Increases Intermediate Task Performance," by Zedelius et al. (2012a), *PLoS ONE*, *7*, e42547. Copyright 2012 by Zedelius et al.

cues, presented before each digit, indicated which task was to be performed on that digit. ERPs in response to those task cues were assessed in order to measure preparatory processes, whereas ERPs in response to the target digits were assessed to measure the processes involved in task execution.

As we discussed above, cue-related fronto-central ERPs indicated similar effects of supraliminal and subliminal rewards during preparation. Nevertheless, this study also revealed that task execution was influenced differently by rewards that were processed with versus without awareness. That is, on supraliminal-reward trials, high as compared to low reward value led to stronger parietal ERPs in response to the task stimuli—an indicator that greater attention and working memory resources were recruited during processing of these stimuli. This effect was absent on subliminal-reward trials. Moreover, the reaction time (RT) results (which correlated with the measured alpha activity) showed that performance was increased only by consciously presented high-value rewards. This finding suggests that conscious awareness of rewards uniquely affects task execution, independent of preparation. It seems that the ability to reflect on and remind oneself of high-value rewards during task execution may help to stimulate the recruitment of additional mental effort.

A remarkable fact about this finding was that valuable conscious rewards sped up RTs even though the task did not require particularly fast responses (2 s), and most responses (on both supraliminal- and subliminal-reward trials) were well within the required time. This raises the possibility that conscious awareness of high rewards may lead people to recruit much more effort than is actually required—a tendency that may not always be helpful, and might at times even damage performance (e.g., see Bijleveld, Custers, & Aarts, 2011). Thus, these findings suggest that when it comes to facilitating task execution, conscious processing does not always outperform unconscious processing.

Following up on this discussion, in a recent study we examined whether task execution may even be impaired by conscious reward processing (Zedelius, Veling, & Aarts, 2011b). This test was based on previous research suggesting that, because valuable rewards are highly significant stimuli for people, directing conscious thoughts and attention to valuable rewards can distract attention away from other ongoing processes, thereby impairing performance (Beilock, 2007; Kahneman, 1973; Lavie, 2005; Navon, 1984; Pashler, 1998). However, because previous research on such interference effects had been done only with consciously presented rewards, it was unclear whether people's conscious awareness of valuable rewards is indeed what drove interference with performance.

To examine this question (Zedelius et al., 2011b), participants were rewarded for a verbal working memory task in which they were asked to actively maintain series of five words for later verbal recall after a short delay period. To show that conscious (but not unconscious) reward processing specifically interfered with ongoing task *execution*, as opposed to task preparation, rewards were presented either just before the beginning of a trial (i.e., before the to-be-remembered words were presented) or during the maintenance phase. And indeed, although both supraliminal and subliminal high-value rewards increased performance when presented before the beginning of a trial, when they were presented during the task, only subliminal high (vs. low) rewards still improved, but supraliminal high (vs. low) rewards now impaired, performance. Apparently, the minimal input from a briefly presented reward cue is sufficient to trigger processes that facilitate performance without leading to conscious awareness or reflection and related processes that interfere with task execution.

These findings illustrate that unconscious reward processing can have specific merits for task execution, in comparison to conscious reward processing. Relating the discussed findings to the framework, it is likely that conscious reward processing enables people to reflect on and remind themselves of high-value rewards while they are engaged in a task. This ability can support the recruitment of additional effort, if needed, but it can also distract from ongoing processes, and thereby interfere with task execution.

The role of consciousness in reward processing: A matter of value or affective processing?

The studies discussed so far all focused on the role of consciousness in the effects of rewards (defined previously as desirable outcomes attainable through instrumental performance). But are the conclusions drawn from these sections in fact specific to rewards? Or do they generalize to other stimuli that are not rewards according to the above definition, but share features with rewards (e.g., in that they are desirable, valuable, or otherwise charged with positive valence)? Just like rewards, such stimuli are often highly salient. As such, they can elicit automatic affective or motivational reactions that in turn affect cognitive processes relevant to task performance (e.g., Ashby, Isen, & Turken, 1999; Brosch, Sander, Pourtois, & Scherer, 2008). For instance, research has shown that the perception of positively valenced stimuli (e.g., words like "ecstasy," "thrill," or "promotion") leads to neural responses in dorsal and ventral striatal regions linked to reward processing (Hamann & Mao, 2002). Thus, is there anything special about reward processing? Or do the effects generalize to responses to other affective, but nonrewarding, stimuli?

The role of consciousness has been addressed previously in the literature on human goal pursuit. This research indicates that positively valenced cues (e.g., words referring to positive objects (e.g., "beach") or evaluations (e.g., "good"), when associated with behaviors (e.g., studying), can implicitly elicit the same effortful goal-directed behavior previously found to result from consciously set goals (Aarts, Custers, & Marien, 2008; Capa, Cleeremans, Bustin, Bouquet, & Hansenne, 2011; Custers & Aarts, 2005; Fishbach & Labroo, 2007; Holland, Wennekers, Bijlstra, Jongenelen, & van Knippenberg, 2009; Marien, Aarts, & Custers, 2012; Veltkamp, Custers, & Aarts, 2011). A proposed explanation is that the positive affect elicited by these stimuli functions as a reward signal that can boost cognitive processes involved in goal attainment (e.g., goal maintenance), and that this process can occur independently of conscious awareness (Custers & Aarts, 2010; Fishbach & Ferguson, 2007). This literature thus suggests that human goal pursuit does not result only from conscious processes. However, it is important to note that, in these studies, affective cues alone have not been found to motivate behavior. Instead, they only did so when they were associated with the representation of a particular behavior (Custers & Aarts, 2005). So, affective cues can add desirability or reward value to previously neutral behaviors—which, in turn, motivates goal-directed behavior when the representation of that behavior is activated.

Another line of research that addressed the question of how affective stimuli can affect performance suggests that affective stimuli do not just signal value, but can also activate representations of affective states relevant to performance. For example, exposure to positive affective stimuli has been proposed to lead to a "feeling of ease," or relative effortlessness, when working on a task (e.g., Carver, 2003; Gendolla, 1998; Gendolla & Silvestrini, 2010, 2011). Consequentially, incidentally presented positive affective cues can influence the amount of effort that people invest when performing a task via that route, even though this is not instrumental for attaining any additional goal other than the primary task goal (Gendolla, 2012). Although this work has not manipulated the input of the affective stimuli within a single experiment (cf. Veling, Ruys, & Aarts, 2012), a comparison across studies suggests that unconsciously presented affective cues have effects on effort recruitment that are very similar to those of consciously presented affective cues (for a discussion, see Silvestrini & Gendolla, 2011).

Nevertheless, other recent research has pointed to important differences in the mechanisms through which affective cues and reward cues affect goal-oriented cognition (reviewed in Chiew & Braver, 2011). Whereas positive affective cues have been shown to lead to more creative thinking (Isen, Daubman, & Nowicki, 1987), greater breadth of attention (Fredrickson & Branigan, 2005; Rowe, Hirsh, & Anderson, 2007), reduced maintenance, and increased distractibility (Dreisbach, 2006; Dreisbach & Goschke, 2004), rewards have been shown to lead to more focused selective attention (Padmala & Pessoa, 2011) and enhanced maintenance during cognitive-control tasks (Locke & Braver, 2008; Veling & Aarts, 2010).

Looking at these striking differences, it appears that rewards and other affective cues influence performance differently because of differences in what these cues signal and how they relate to goal progress. Whereas rewards signal value and require instrumental performance, other positive affective cues can be construed as either signaling the value of an associated action or signaling the ease and progress of current pursuits. Unfortunately, little research has investigated how conscious awareness affects the effects of these different signals. It is possible that the interpretation of affective cues, and the selection of appropriate responses, depends on people's ability to reflect on these cues.

In one recent study, we explored this possibility (Zedelius, Veling, & Aarts, 2013). Participants were subliminally or supraliminally presented with coins of high or low value during a verbal working memory task (as in Zedelius et al., 2011b). In Experiment 1, the critical manipulation was that the coins were either presented as rewards or explicitly introduced as nonrewards. In the nonreward condition, the coins still shared crucial characteristics with the rewarding coins, in that they had a particular value and might thus still function as affective cues, even though they were not instrumentally related to performance. Importantly, whether the coins were presented as rewards or nonrewards was manipulated between participants to prevent any carryover effects from the rewards to the nonrewards.

Replicating previous research, the results indicated that supraliminally and subliminally presented high- versus low-value coins led to increased performance when they were presented as rewards. However, when the coins were explicitly introduced as nonrewards, an interesting dissociation was found. For supraliminal coins, high-value coins no longer enhanced performance, but instead tended to cause a drop in performance. Subliminally presented high- (as compared to low-) value coins, however, still improved performance, even when they were presented as nonrewards.

A follow-up study was conducted to better understand the mechanism behind these results. On the basis of previous research showing that the rewarding value of stimuli is highly subjective, and depends greatly on people's current needs (Berridge, Robinson, & Aldridge, 2009; Knutson, Delgado, & Phillips, 2009; Lebreton, Jorge, Michel, Thirion, & Pessiglione, 2009), we expected that affective reactions to nonrewarding coins would result in increased effort when an individual was in need of money. Critically, however, when the nonrewards were consciously perceived and could be reflected on, individuals should be able to down-regulate this affective reaction (Beauregard, 2007; Clore & Hustinger, 2007; Gross, 1999; Posner & Rothbard, 1998).

In the follow-up experiment, the coins were always presented as nonrewards, and people's need for money was measured with a scale. For participants with high need for money, the results showed the same pattern as before. That is, subliminal high-value coins increased performance, whereas supraliminal high-value coins caused a trend in the opposite direction. However, participants with low need for money were not affected by the value of the nonrewarding coins. These results suggest that when cues are not rewards, but are relevant to an individual's current needs, they initially elicit the same reaction as rewards. To what extent this initial reaction is driven by positive affect requires further investigation. Nevertheless, these studies have indicated that the reward-priming paradigm offers a useful way to investigate the role of consciousness in the distinctive effects of affect and reward.

Summary and conclusions

The comparison between conscious and unconscious reward processing is a recent and novel enterprise in research on human motivation and reward pursuit. The aim of the present review was to give an overview over the existing literature on this topic, and to compare the effects of consciously and unconsciously perceived rewards on decision making, task preparation, and task execution.

The reviewed research can be summarized as yielding two main conclusions. First, in relatively simple contexts, both consciously and unconsciously perceived rewards can improve performance by influencing people's decisions to invest effort in a task and by increasing their preparedness to perform a task well. Second, unconscious reward processing is rather limited when it comes to improving performance *strategically* and *efficiently* in more complex contexts. This limitation becomes apparent during decision making, task preparation, and task execution. In investigating the effects of rewards on decision making, it was found that conscious, as compared to unconscious, reward processing allows for more strategic performance decisions, in line with contextual information about effort requirements and reward attainability. In investigating the effects of rewards on task preparation, conscious as compared to unconscious reward processing allows for more flexible adaptation of performance strategies. In investigating the effects of rewards on task execution, conscious, but not unconscious, reward processing leads people to recruit additional effort for high-value rewards during task execution.

We further showed that, although stimuli that share characteristics with rewards but are not in fact rewards can have effects similar to those of actual rewards, people respond differently to rewards and nonrewards when they can consciously reflect on them. Thus, all in all, the findings discussed in this review suggest that whereas both conscious and unconscious reward processing facilitate effortful performance, conscious awareness of rewards elicits unique processes that facilitate flexible, strategic, and efficient reward pursuit.

Several theoretical implications follow from these findings. First, the systematic comparison between conscious and unconscious rewards is a new and useful approach to understand the mechanisms through which *consciously* communicated rewards improve or impair performance. Much previous research has focused on deliberative processes in reward pursuit (Bandura, 1982; Brehm & Self, 1989; J. D. Cohen, McClure, & Yu, 2007; Heckhausen, 1977; Nieuwenhuis & Monsell, 2002; Wright, 2008). The role of conscious awareness in these processes has usually been suggested, but not addressed explicitly. One example illustrating this has come from research on instances in which consciously presented valuable rewards are detrimental to performance (e.g., Ariely, Gneezy, Loewenstein, & Mazar, 2009; Camerer & Hogarth, 1999; Mobbs et al., 2009). It has been suggested that conscious awareness of a reward, and the ability to reflect on it, causes these performance decrements, because the process of reflecting can interfere with the ability to perform another task at the same time (Beilock, 2007). However, performance decrements may equally likely be caused by unconscious reactions to valuable rewards, such as increased physiological arousal (see, e.g., Camerer & Hogarth, 1999). Thus, a direct comparison between the effects of consciously and unconsciously presented rewards is a useful approach to disentangle these explanations and shed new light onto the roles of conscious awareness in different aspects of conscious reward pursuit.

The present review also raises important questions about topics that we think should receive more attention in future research. For instance, the comparison of the reward literature with the literature on affective cues raises the question of the extent to which subliminal reward cues induce actual motivated behavior. That is, the effects of positive affective cues, such as a broadening of attention or flexibility, may be adaptive (Dreisbach, 2006; Dreisbach & Goschke, 2004; Fredrickson & Branigan, 2005; Rowe et al., 2007), but they may best be considered as responses to a cue (e.g., dopamine release in reaction to positive stimuli; see Ashby et al., 1999) rather than as motivated or goal-directed instrumental actions. Although conscious reward cues do seem to instigate such goal-directed actions (i.e., aimed at obtaining the reward), this is less clear for subliminal reward cues. Findings such as prevalent responses to clear nonrewards (Zedelius et al., 2013) seem more similar to the responses to cues observed in the affective-cue literature. That is, subliminal reward cues may be seen as changing the state of the neurocognitive system (which may increase its capacity or readiness to deliver effort for the task at hand), rather than cueing a goal to obtain the reward and instigating action in service of that. As such, one may doubt whether the effects of subliminal reward cues are indeed mediated by the goal to obtain the reward. On the other hand, the fact that responses to clear nonrewards are critically dependent on personal needs suggests that these responses are at least somewhat goal-oriented and context-sensitive, and not *just* responses to a cue.

A related, yet somewhat different, question concerns the difference between the reviewed research on conscious and unconscious reward processing and the literature on conscious and unconscious goal pursuit (e.g., Custers & Aarts, 2010; Fishbach & Ferguson, 2007). As we discussed in the section on affective processing, the positive affect associated with goals can be conceptualized as a reward signal that facilitates goal attainment. However, the literature on goal pursuit has pointed out that representations of behavioral goals (e.g., studying) are often very complex, involving hierarchical structures of subgoals and means (e.g., Förster, Liberman, & Friedman, 2007). So, activating a goal representation not only motivates behavior, because of its rewarding properties, but also triggers the associated action patterns that give direction to behavior.

It is striking that the literature on conscious versus unconscious goal pursuit has overwhelmingly focused on similarities—for instance, by showing that processes essential for goal-directed action (e.g., keeping goal-relevant information active in mind and recruiting cognitive resources) occur automatically, and likely do not require that a goal be activated and set in full conscious attention (e.g., Custers & Aarts, 2010; Goschke & Kuhl, 1993: Hassin, Aarts, Eitam, Custers, & Kleiman, 2009). But since processes such as decision making, preparation, and execution are relevant to pursuing behavioral goals, just as for obtaining rewards, the strategic nature of unconscious goal pursuit may have limits, just as there are limits to processing unconscious rewards. This could be addressed empirically in a number of ways. For instance, it would be interesting to investigate the effects of conscious and unconscious goal activation for unattainable goals or for goals that cannot be attained in a particular context (e.g., the goal of winning in a context requiring cooperation). Here, it could be expected that consciously adopted goals would lead to more functional behavior (e.g., giving up on the goal and cooperating instead) than would unconsciously activated goals.

The findings reviewed here are relevant not only to the literatures of motivation and reward and goal pursuit, but they have a broader relevance to the topic of consciousness and its potential functions or advantages. Much cognitive research on the topic has focused on the relationship between consciousness and cognitive-control functions, and has looked at which particular kinds of cognitive processes (e.g., conflict resolution or information integration) require conscious awareness of information, and which functions can be performed without this awareness (e.g., Ansorge, Fuchs, Khalid, & Kunde, 2011; Hassin, Bargh, Engell, & McCulloch, 2009; Kunde, 2003; Lau & Passingham, 2007; Mayr, 2004; Mudrik, Breska, Lamy, & Deouell, 2011; van Gaal, Lamme, & Ridderinkhof, 2010; Williams, Bargh, Nocera, & Gray, 2009). More recently, research has also started to focus on the more general role of conscious awareness in broader goal-directed behavior (Baumeister, Masicampo, & Vohs, 2011; Dijksterhuis & Aarts, 2010; Gendolla, 2012; Morsella & Bargh, 2010). The present review and analysis combines both of these perspectives, by investigating which cognitive processes involved in the attainment of rewards require conscious awareness of reward information, and which can operate independent of it. The results suggest that conscious awareness plays a unique role in the integration of reward information and flexible adaptation of behavior.

Future directions

A recurring finding in the research discussed here was that conscious reward processing facilitates more strategic processes than does unconscious reward processing. However, we also showed that conscious reward processing has no universal value in facilitating instrumental performance. This claim is limited at present, because most research has focused disproportionately on situations in which the strategic processes that go along with conscious as compared to unconscious reward processing are beneficial for efficient effort investment. Thus, it will be interesting to examine more closely the functionality of conscious as compared to unconscious reward pursuit in future research.

A starting point for such research could be the issue of disengagement in situations in which rewards require excessive amounts of effort or are altogether unattainable. We suggest here that the greater ability to integrate reward value and contextual information relevant to reward attainability enables people to not waste resources and to invest their effort efficiently (e.g., Bijleveld et al., 2012a; Zedelius et al., 2012a). This seems, at first glance, to be the most adaptive way to respond, from a personal as well as a social perspective. However, in many situations it is not entirely clear whether a desired reward is or is not attainable. Thus, it is not, in principle, dysfunctional to be persistent when desired rewards appear difficult to get (Amsel, 1958; Amsel & Ward, 1965; Dudley & Papini, 1997). The relatively greater rigidity characterizing unconscious as compared to conscious reward pursuit may be beneficial in situations in which persistence is needed to obtain rewards. Future research will therefore be needed to get a more complete picture of the functionality of conscious and unconscious reward processing with regard to persistent performance.

Another issue concerning the functionality of conscious reward processing is the observation that the additional, and often more sophisticated, processes elicited by conscious as compared to unconscious reward processing may come at the cost of a greater potential to cause interference. If it were shown that conscious perception of valuable rewards puts heavy load on working memory resources, a relevant practical implication would be that conscious reward processing may be especially detrimental to performance in environments where irrelevant distractors are present (see Baumeister, Schmeichel, DeWall, & Vohs, 2008). There is the potential here for future research to relate the present investigation of conscious and unconscious reward pursuit to the question of how people deal with distraction or mind-wandering (e.g., Schooler et al., 2011; Smallwood & Schooler, 2006).

Another topic for future research concerns the distinctiveness of conscious and unconscious reward pursuit. In this review, the two were presented as clearly separable. However, that might not always be the case. For instance, it is possible that the motivation elicited by unconscious reward cues can, under some circumstances, affect people's conscious experience. That is, it could be that unconscious reward cues bring about psychophysiological changes in an individual (e.g., mood or arousal) that, if attended, may become consciously accessible to an individual (Chartrand, Cheng, Dalton, & Tesser, 2010; Knutson, Taylor, Kaufman, Peterson, & Glover, 2005; cf. Bornemann, Winkielman, & van der Meer, 2012). If this is possible, it could offer a mechanism for exercising strategic control over one's responses to unconscious reward cues. The effectiveness of such control in impacting decision making, task preparation, and task execution would then likely depend on the time course of the transition from unconscious motivation to a conscious experience. Since the observation of experienced reactions to reward cues is an introspective process (Overgaard & Sandberg, 2012) that may require considerable time, it may impact task execution proportionately more than decision making and task preparation. Further research will be needed to explore this possibility.

Although the research reviewed here has been devoted to understanding the processes involved in gaining rewards, the concepts of *gain* or *reward* often logically invoke their opposites, *loss* or *punishment.* Organisms are as much driven by the motivation to attain rewards as by the motivation to avoid loss. Thus, it would be interesting for future research to address whether consciousness plays a similar role in dealing with avoiding losses as it does in obtaining rewards. Thus far, the literature comparing gains and losses has focused only on consciously perceived gain or loss information (e.g., McGraw, Larsen, Kahneman, & Schkade, 2010). Neuropsychological studies have suggested that even though the brain systems that evaluate gains and losses overlap to a great extent, they also have differences (e.g., different involvement of striatum, OFC, and amygdala in predicting and evaluating gains and losses; see O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001; Seymour, Daw, Dayan, Singer, & Dolan, 2007; Yacubian et al., 2006). Thus, it remains an open question whether consciousness would affect loss avoidance in the same way as reward attainment. It would be interesting to investigate this question in future research using an adapted version of the reward-priming paradigm. On a related note, it is clear that the opportunities to gain rewards or to avoid losses are only two particular sources of motivation. Motivation can derive from various other sources, such as the sense of having control over one's environment (Eitam, Kennedy, & Higgins, 2013) or the inherent pleasantness of tasks (see Ryan & Deci, 2000). For these types of motivation, too, it would be interesting to address the role of conscious awareness in future research.

Another issue that has thus far not received much attention is how the processes involved in conscious and unconscious reward processing might be affected by individual-difference factors. We have briefly discussed research taking into account individual differences in need for money, which affect whether or not a valuable cue is seen as an incentive (Zedelius et al., 2013). However, more trait-level variables may affect how a reward cue is perceived and reacted to by an individual. For instance, research on consciously presented rewards suggests that responses to rewarding stimuli or drugs are affected by differences in reward sensitivity or impulsiveness, or by the individual's personal history with or exposure to related rewards (e.g., Cohen, Young, Baek, Kessler, & Ranganath, 2005). Moreover, a recent study by Pas, Custers, Bijleveld, and Vink (in press) suggests that responses to unconscious reward cues rely on individual differences in striatal dopaminergic functioning. Likewise, social factors, such as power, also play a role in how sensitive individuals are to the value of a reward, and in what aspects of a reward besides its value drive their reactions (Lea & Webley, 2006). Although the question is beyond the scope of the research reviewed here, it would certainly be interesting to take into account such individual differences when further investigating conscious and unconscious reward pursuit.

To conclude, the systematic comparison of conscious and unconscious reward pursuit is an important endeavor, because it can improve our understanding and examination of how to improve human performance through rewards. We hope that the focus on similarities and differences between the effects of conscious and unconscious rewards on distinct psychological processes will inspire further research following this novel approach to studying the role of consciousness in human reward pursuit.

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