Investigating Consciousness in Reward Pursuit

Comparing the Effects of Consciously and Unconsciously Perceived Reward Cues on Human Performance

De rol van bewustzijn in het streven naar beloningen
Een vergelijking van de effecten van bewust en onbewust waargenomen beloningsstimuli op menselijke prestatie

(met een samenvatting in het Nederlands)

Proefschrift

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Chapter 1

Introduction

Pecunia non olet[1]— that must have been the credo behind "Money", a perfume with the cold, hard scent of money. The product is designed to stimulate its wearer to work harder to accumulate more money. At least, that is what the creative head behind the perfume, Patrick McCarthy, a former vice president of the Microsoft sales department, is excited to explain (see Moye, 2011). While one may doubt that the fragrance really has an effect (or at least one that is different from that of, say, "Paper Passion", a perfume smelling of freshly printed books), I bring up the story around this perfume because it illustrates two important points. First, the fact that there may be a market for the perfume illustrates how much people desire money, and how extremely eager they are to do whatever they can to obtain great amounts of it. This may not come as a surprise. Money is in this society not only valued in and of itself, it also serves as an all-purpose tool to attain all kinds of other desired things, such as food and other goods or social status. This is also why money is frequently and effectively used as a reward to motivate people to increase their performance. Second, and more interestingly, the story around the money perfume also relates to the intriguing idea that very subtle, and likely unconsciously processed cues signaling desired monetary rewards may cause people to improve their performance with the aim to attain the desired reward. The marketing strategy for "Money" merely illustrates that there is *intuitive* plausibility to this idea.

Based on psychological and neuroscientific reward research examining the architecture and cognitive processes involved in human reward processing, recent research has provided evidence that visual cues indicating valuable monetary rewards may prompt instrumental performance even when these cues are processed without conscious awareness (e.g., Knutson, Adams, Fong, & Hommer, 2001; Liljeholm, & O'Doherty, 2012; Pessiglione et al., 2007). This raises many interesting and important questions. For one, do unconsciously processed rewards affect instrumental performance in the same way, and through the same mechanisms, as consciously processed rewards do? Or does the ability to consciously reflect on the value of a reward add something unique to human reward pursuit? Moreover, are conscious and unconscious reward processing influenced in the same way by relevant contextual factors? For instance, do consciously and unconsciously processed rewards have the same or different effects depending on whether the rewards are currently attainable or unattainable? And do conscious and unconscious processing of monetary cues lead to the same effects in contexts where money does *not* serve as a performance reward, but is merely a stimulus? The present dissertation aims to answer these questions by systematically investigating the effects of consciously and unconsciously presented visual monetary cues in different performance contexts. Before giving a more detailed overview of this investigation, I first want to give some background information about human reward pursuit and the potential role of consciousness herein.

Human reward pursuit

People's striving for rewards such as money is often proposed to be rooted in the fundamental and universally shared motivation of all living organisms to approach positive or pleasurable outcomes and avoid harm and discomfort (Elliot, 2006). This is not a new idea. William James already argued that pleasure and pain are the ultimate "springs of action" (1890). This idea follows logically from Charles Darwin's theory of evolution, which was an important inspiration for James' work (Wallace & Gruber, 1992). Whether applied to biology or psychology, the evolutionary perspective focuses on factors that in some way determine or influence the propagation of genes. Throughout the human evolutionary history, stimuli that have undoubtedly had great significance for survival and reproduction, and thus for the propagation of genes, are food, water, and sexual stimuli. Thus, from an evolutionary perspective, the significance of these stimuli for survival and reproduction may explain why we have become so extremely eager to seek out and invest effort in obtaining these stimuli, and why we have come to find them particularly rewarding. In fact, food, water and sexual stimuli seem to carry such strong innate value for humans that they are often labeled "primary rewards", in contrast to "secondary" rewards, such as money, whose rewarding value has to be learned (e.g., Walter, Abler, Ciaramidaro, & Erk, 2005).

People's eagerness to obtain rewards is also reflected in the brain. That is, researchers have proposed that the human brain is equipped with a so-called "reward system", a subcortical network that emerged early on in our evolutionary history (Knutson, Delgado, & Phillips, 2008; Schultz et al., 1995; Wickens, 1990) and supports the rapid and efficient detection and evaluation of potentially rewarding stimuli in the environment (Lebreton, Jorge, Michel, Thirion, & Pessiglione, 2009; Montague & Berns, 2002; Seymour & McClure, 2008). Interestingly, while early on this system was likely responsive only to primary rewards, it is now found responsible for processing secondary rewards as well, whether their rewarding value is learned through idiosyncratic experiences (e.g., your lucky letter opener; Bray, Shimojo, & O'Doherty, 2010; O'Doherty, Buchanan, Seymour, & Dolan, 2006) or culturally acquired (e.g., licorice, a good reputation, fancy sports cars, or money; Izuma, Saito, & Sadato, 2008; Knutson, Adams, Fong, & Hommer, 2001; Peters & Büchel, 2010; Walter et al., 2005).

The general responsiveness of the reward system to all of these different kinds of rewards might explain why people so readily compare different rewards when trading, bargaining, or complaining about the disproportionate price of a cup of coffee (Plassmann, O'Doherty, & Rangel, 2007; Saxe & Haushofer, 2008). It may also explain why people often respond to secondary rewards as if they carried the same innate value as primary rewards do. Money is a good example for this. In principle, money has no value in and of itself. It acquires value only through its function as a commodity for other goods. Nonetheless, people seem to get *immediate* pleasure from obtaining money, and their behavior suggests that they value it for much more than its exchange function (e.g., Lea & Webley, 2006). This is one of the reasons why money is a convenient tool to study the effects of rewards on human performance.

Obtaining rewards such as money usually requires some kind of performance. Research suggests that the way rewards can impact such instrumental performance is through the connection of the subcortical reward system with the frontal cortex, a part of the brain that is critically involved in the execution of goal-directed cognition and behavior. More specifically, research suggests that after the value of a reward is encoded, activation in the reward system projects directly to the specific cortical regions responsible for regulating cognitive and motor processes relevant to the kind of instrumental performance required in the current context (Liljeholm & O'Doherty, 2012; Salamone, Correa, Farrar, Nunes, & Pardo, 2009; Schmidt, Lebreton, Cléry-Melin, Daunizeau, & Pessiglione, 2012). Interestingly, the connectedness between reward system and frontal cortex seems to have increased through the course of human evolution (Hills, 2006; Real, 1991). This might explain why information processing in the reward system can influence not only relatively simple instrumental actions, but also more complex performance relying on sophisticated economic analyses and deliberate performance strategies (e.g., Camerer, 2007; Phillips, Walton, & Jhou, 2007; Rangel, Camerer, & Montague, 2008; Rowe, Eckstein, Braver, & Oven, 2008). In light of this sophistication, the above-raised idea that our behavior could be influenced by rewarding cues (e.g., the smell of money or the sight of valuable currency) even when these cues are processed outside of conscious awareness becomes especially interesting.

Is there a role for consciousness in human reward pursuit?

Considering the great significance people ascribe to rewards, and considering that the attainment of rewards is regulated by an evolutionarily old yet sophisticated brain network, it may sound conceivable that reward cues could instigate instrumental performance without one being consciously aware and able to reflect on them. However, this would not imply that conscious awareness cannot play an important role in influencing these processes. As the above-raised questions around the potential effects of the money cues on performance have pointed out, reactions to money might be very complex and context dependent. For instance, I wondered whether the reactions to monetary cues in the environment would depend on whether or not these cues actually serve as performance rewards, and whether they are currently attainable or unattainable. Could the ability to consciously reflect on those cues help to decide whether they are worth investing effort or whether one would be better of saving one's energy? Given people's eagerness to earn money, it is conceivable that subtly presented money cues, such as dollar bills flashed on a computer screen (e.g., when working in an office) could motivate a person to perform better without being aware of it. But if that person would suddenly become aware of these flashes of bills, would this awareness not lead the person to try her best to *not* be influenced by it and, as a result, work *less* hard? After all, hard work usually requires investing great physical or mental effort, and thus expending limited resources, and it does not make sense to do this when the effort is not justified. Thus, more generally speaking, the question is whether conscious awareness of reward cues can influence the regulation of behavior above and beyond unconscious processing, for instance by down-regulating one's initial behavioral reactions to reward cues so as to respond more efficiently.

The potential function of consciousness for human cognition and behavior is subject to ongoing debate (e.g., Seth, 2009). Part of this debate stems from the question of when and how in the human evolutionary history consciousness has emerged. Although it is extremely hard to pinpoint the emergence of different facets of consciousness (e.g., Damasio, 1999; Panksepp, 2005), when it comes to consciousness in the sense of being able to reflect on one's experiences of internal and external events, many researchers assume (e.g., based on archaeological records signifying the development of the human brain) that it has emerged only relatively late in human evolutionary history (e.g., Cabanac, Cabanac, & Parent, 2009; Dennett, 1991; Reber, 1992). This late emergence has caused researchers to wonder if consciousness plays any causal role in regulating behavior or whether it is purely a by-product. Empirical research relevant to this question has yielded converging evidence that much of our decisions and actions are determined by unconscious processes, and conscious reflection kicks in only *after* the preparation for action is already well under way (Bechara, Damasio, Tranel, & Damasio, 1997; Brass & Haggard, 2007; Libet, Wright, & Gleason, 1982). Moreover, research has shown that unconsciously perceived cues can trigger and influence even the execution of rather complex goal-directed behavior (Bargh & Morsella, 2008; Custers & Aarts, 2010; Hassin, in press; Lau, 2009).

Surprisingly, the question whether unconsciously perceived *reward* cues can stimulate effortful performance has only very recently been addressed in research. In a first study testing this idea, Pessiglione and colleagues (2007) presented participants with an effortful performance task, in which participants had to squeeze into a hand grip as hard as they could. For each trial of this task, participants were informed that they could gain a monetary reward, which could either be very low (1 penny), or relatively high (1 pound). The reward value was indicated by pictures of the corresponding British coins. The crucial factor in this experiment was that these coins were either presented long enough to be seen, or too briefly to be consciously perceived. Not surprisingly, the results showed that participants squeezed the handgrip harder for a relatively higher reward. More remarkable was that this effect occurred regardless whether the coins were perceived consciously or not. This finding was the first to show that conscious and unconscious perception of valuable reward cues are equally effective in instigating effort investment and raising performance. This finding also provided the starting point for more research on the effects of consciously and unconsciously perceived reward cues on physical and cognitive performance (e.g., Bijleveld, Custers, & Aarts, 2009; Capa, Bustin, Cleeremans, & Hansenne, 2011), and thus obviously also for the current dissertation.

However, as remarkable and inspiring as this initial finding is, it does not imply that consciousness has *no* role in regulating human behavior, and the pursuit of rewards in particular. Notably, the setup of the experiment by Pessiglione et al. (2007) was rather simple, in that a greater reward value always warranted greater effort investment. Thus, it is entirely possible that conscious and unconscious perception of rewards leads to different effects in contexts that afford more complex and strategic behavior. In fact, some researchers have argued that the ability to consciously reflect on information may in fact have evolved so relatively late not because it is a mere by-product, but because it developed in reaction to the growingly complex social environment (Ardila, 2008, Dunbar & Shultz, 2007). Moreover, empirical evidence also suggests that, while consciously and unconsciously perceived stimuli often lead to similar behavioral effects, consciously perceived stimuli have a greater capacity to elicit flexible cognitive control processes (Ansorge, Fuchs, Khalid, & Kunde, 2011; van Gaal, Lamme, & Ridderinkhof, 2010; Hassin, Bargh, Engell, & McCulloch, 2009; Lau and Passingham, 2007; Kunde, 2003). Based on such evidence, theories of consciousness suggest that conscious, compared to unconscious information processing allows for more flexible control of behavior (Baars, 2002; Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Lamme, 2006). Thus, it is conceivable that, while consciously or unconsciously perceived reward cues can influence performance in the same way in relatively simple contexts, conscious perception elicits different behavioral effects in contexts that require more flexible and strategic behavior regulation. To investigate this hypothesis, the current dissertation focuses on the direct comparison of the effects of conscious and unconscious rewards on subsequent processes relevant to reward attainment.

The current approach to investigating conscious and unconscious reward pursuit

It is worth noting that the focus in the current dissertation differs in an important respect from the focus of the historically predominant behaviorist approach to reward research. Following the behaviorist approach, a lot of research investigates the effects of rewards starting out with *behavior* and testing how the subsequent (and often unexpected) exposure to rewards affects future actions, decisions, or performance strategies through processes such as conditioning, and learning (e.g., Blodgett, 1929; Pavlov, 1927; Skinner, 1953; Thorndike, 1927; 1932).

However, in everyday life it is often unnecessary to learn through new experiences that something is desirable and that it can be attained through effortful instrumental performance. When it comes to familiar, socially shared rewards such as money, people have, through a history of learning, acquired a rich cognitive representation of its rewarding value and its relationship with performance (Dickinson & Balleine, 2000). Moreover, in everyday contexts, people often get very explicit instructions from which they learn instantly whether, when, and how monetary rewards can be attained. For example, an employer might promise a call center employee a particular bonus for every newly recruited customer; or a parent may make a deal with their kid to carry out the trash for 50 cents a week. In light of such clear reward expectancies, the focus of the current investigation is different than that of the historically predominant approach. Specifically, the current investigation focuses on the effects (conscious and unconscious) perception of reward cues has on subsequent *instrumental* behavior aimed at attaining those rewards. Thus, instead of starting out with *behavior*, the research presented in this dissertation starts out with the *perception* of valuable or reward-related cues, and investigates the effects such cues have on people's subsequent actions, decisions, and performance strategies.

Throughout the last decades, there has been ample research following this approach. However, this research has usually made use only of consciously communicated rewards. This is because the distinction between conscious and unconscious processes in reward pursuit was not a primary topic of interest in much of this research. Instead, this research focused on questions around the circumstances under which rewards are most effective in raising performance efficiently (e.g., Bonner & Sprinkle, 2002; Oah & Dickinson, 1991). For instance, researchers have investigated how people manage to make efficiency-based performance decisions based on the value of a potential reward, but also on other information, such as how likely it is that the reward can be attained and how effortful a task is (Bonner and Sprinkle, 2002; Brehm & Self, 1989; Vroom, 1964). Moreover, researchers have investigated the underlying mechanisms that can explain why, ironically, the promise of high rewards for performance can sometimes backfire (Ariely, Gneezy, Loewenstein, & Mazar, 2009; Camerer & Hogarth, 1999; Mobbs et al., 2009).

As mentioned above, it is only recently that researchers have begun to investigate the effects of unconsciously perceived reward cues and compare them to those of consciously perceived reward cues. The following chapter will present a detailed review of the research that has been done on this topic until now, covering the research that makes up this dissertation project but also that of other researchers. The later chapters zoom in on more specific questions around the similarities and differences between the effects of consciously and unconsciously perceived rewards. Investigating these effects is important for several reasons. First of all, it may teach us valuable insights into new ways to increase performance, for instance by identifying situations where it helps to consciously reflect on the value of rewards and identifying situations where such reflection may actually be detrimental to performance. Moreover, by comparing the effects of consciously communicated rewards to those of unconsciously perceived ones, we also get a better understanding about what role consciousness plays in the mechanisms through which *consciously* communicated rewards can influence performance. Finally, comparing the effects of consciously and unconsciously perceived reward cues on performance has more fundamental value as well, as it can improve our general understanding of the much-debated role of consciousness in guiding goal-directed behavior in social contexts. With these aims in mind, I now want to give an overview of the work that makes up this dissertation.

Overview of the chapters

Chapter 2: A new perspective on human reward research—How conscious and unconscious reward processing influence decision making, task preparation, and task execution. This chapter gives a detailed overview of the existing research on the topic of conscious and unconscious reward pursuit, which also includes the studies presented in the empirical chapters of this dissertation. The central goal of this chapter is to identify how consciously and unconsciously perceived rewards can influence specific cognitive processes that in turn affect task performance. Our focus herein is on three distinct, often subsequently unfolding processes: Decision making, task preparation, and task execution. We focused on these processes because they can influence performance in very different ways. The perception of a high value reward can cause people to *decide* to engage in or to invest more effort in a task, it can render people more *prepared* to respond to task stimuli or employ certain performance strategies, and it can boost the recruitment of additional effort during task *execution*. Interestingly, while both consciously and unconsciously perceived high compared to low value rewards were repeatedly shown to facilitate performance, our analysis also shows interesting differences between the effects of consciously and unconsciously perceived rewards, which become apparent in decision making, task preparation, and task execution. After discussing these differences, the chapter addresses the question of whether the discussed effects are due to properties specific to rewards, or whether the same effects can be produced by environmental cues that signal value but are not attainable as rewards. The chapter can also be read as a general discussion of the research presented in the remaining chapters of this dissertation and future directions for research on the topic of conscious and unconscious reward pursuit.

General methodological approach. Chapters 3 to 6 present the empirical research that led to this dissertation. The studies presented in these chapters all make use of the same basic reward priming paradigm, which was inspired by an initial study on the topic by Pessiglione and colleagues (2007). In this paradigm, participants are presented with high and low value coins, which can usually (though not always!) be gained through good performance on the following trial of a performance task. To get a better grip on the processes through which these cues can influence performance, we made different adaptations to the paradigm, for instance by manipulating whether and when the presented coins could be attained and when the coins were presented. We also used different tasks to measure how performance is affected by these reward manipulations. Moreover, we manipulated variables in the experimental context, such as what subjective meaning the coins had for participants. These manipulations allowed us to test the specific research questions and hypotheses addressed in the different chapters.

Chapter 3: Preparing for a rich future—How consciously and unconsciously perceived rewards contingent on future performance affect immediate performance. This chapter addresses the question whether consciously and unconsciously perceived high value rewards contingent on performance on a *future* task increase not only performance on that rewarded future task, but also performance on an intermediate, unrewarded task. The idea behind this study is that rewards can enhance performance by increasing task preparation. Because task preparation has been found to start long before a person actually engages in a task (Miller, 1987; Min & Herrmann, 2007), we reasoned that rewards could affect preparatory processes from the moment the reward value is encoded. Therefore, we expected that increased preparedness to work for a high value reward in the future should facilitate immediate performance along the way, even if this immediate performance is not rewarded. To test this hypothesis, we conducted an experiment in which participants performed two consecutive trials of a reaction time task in which they were asked to quickly respond to different tones. Before performing the task, participants were instructed that fast and correct responses to each *second* tone would be rewarded, while responses to each preceding tone were unrelated to attaining rewards. The prediction was that both consciously and unconsciously presented high compared to low rewards would speed up responses not only to each second but also to each first tone. Moreover, the study also tests whether conscious and unconscious perception of reward cues have different effects on the preparation of task strategies. Previous research has shown that conscious but not unconscious reward processing leads to strategic speed accuracy tradeoffs on reaction time tasks (Bijleveld, Custers, & Aarts, 2010). Thus, we predicted to find the same in the present experiment. More interestingly, however, we predicted that the differences in strategy would be a matter of preparation, and should therefore also already become apparent in reactions to both rewarded and unrewarded tones.

Chapter 4: You can't always get what you want—The role of consciousness in integrating reward value and attainability information. This chapter investigates how consciously and unconsciously perceived rewards affect performance when they differ in whether or not they are attainable at all. From an efficiency point of view, people should invest effort for rewards only when these rewards are both of high value and attainable (Brehm & Self, 1989; Wright, 2008). This logically requires a process of integrating reward value and attainability information. Because consciousness is often proposed to play an important role in the integration of information (Baars, 2002; Dehaene & Naccache, 2001; Kouider & Dehaene, 2007), we expected that conscious compared to unconscious reward processing would allow for greater integration of reward value and attainability information, and would thus lead to more efficient effort investment in contexts that require such integration. To test this hypothesis, two experiments were conducted in which participants were presented with attainable and unattainable rewards during a verbal working memory task. In Experiment 4.1, the attainability of rewards was varied within participants. That is, on every trial, participants were instructed that a subsequently presented reward would be either attainable or unattainable. Efficient performance thus required trial-by-trial integration of reward value and attainability. We predicted that only conscious reward processing would lead to efficient performance in this context, while unconscious processing would lead participants to increase performance and thus waste their effort in response to high value unattainable rewards.

In Experiment 4.2, attainability information was manipulated between participants. Participants thus were instructed that rewards were either always attainable, or always unattainable. In this context, participants could prepare a single response strategy, thus removing the requirement to integrate incoming information about the value and attainability of rewards. Therefore, in this context, we predicted that both consciously and unconsciously perceived rewards would lead to efficient effort investment.

Chapter 5: Boosting or choking—How conscious and unconscious reward processing modulate the active maintenance of goal-relevant information. In this chapter, we aim to show that conscious reward processing is not by default superior to unconscious processing when it comes to improving performance. Because people are so eager to attain rewards, conscious reflection on a valuable reward may cause people to recruit additional resources and prepare strategies to get the desired reward. However, because of this same eagerness, conscious reflection on valuable rewards can also occupy people's attention, and therefore tax the very attentional resources needed to successfully execute a task (e.g., Beilock, 2007). Based on this reasoning, we argued that conscious, but not unconscious reward processing can interfere with ongoing processes relevant for task performance. To test this idea, we conducted two experiments, in which participants were rewarded for actively maintaining verbal information in working memory. Crucially, we varied the timing of the presentation of reward cues across experiments. In Experiment 5.1 reward cues were presented before the beginning of each trial, and thus at a moment where it should not interfere with ongoing task processes. In this experiment, we expected that consciously and unconsciously perceived rewards would equally improve performance. In Experiment 5.2, reward cues were presented at a time where participants were already engaged in the task. In this experiment, we expected that unconsciously perceived rewards would still improve, but consciously perceived rewards would interfere with performance. The results are followed by a commentary by other authors and our reply to this commentary.

Chapter 6: All that glitters is not gold— Success and failure in behavioral regulation toward consciously and unconsciously perceived monetary cues. This final chapter addresses the question of how people react to consciously and unconsciously perceived monetary cues when these cues do not function as rewards in the context at hand. People may view the same monetary stimulus very differently depending on whether they are in a context where they strive to attain money (e.g., at work) or whether they are currently not concerned with money at all (e.g., during a holiday). And indeed, research has shown that the rewarding value of environmental stimuli depends greatly on personal variables, such as people's current needs (Berridge, Robinson, & Aldridge, 2009; Lebreton et al., 2009). Moreover, there is evidence that the mere perception of need-rewarding stimuli spontaneously elicits effortful responses aimed at obtaining these stimuli (Gupta & Aron, 2011; Veling & Aarts, 2011). Based on this research, we expected that valuable monetary cues could improve performance even if they do not objectively function as rewards, as long as people are in need of money. However, based on the notion that conscious compared to unconscious reward processing allows for more flexible control of behavior (Baars, 2002; Dehaene et al., 2006), we further expected that people would be able to down-regulate their effortful reactions to *consciously* presented non-rewards.

Two experiments were conducted to test these hypotheses. In both experiments, participants were presented with high and low value coins during a visual working memory task. In Experiment 6.1, the presented coins were explicitly introduced either as rewards for performance or as non-rewards. We predicted that performance would be enhanced by unconsciously perceived high compared to low value coins, but would be unaffected by consciously perceived coins. Experiment 6.2 followed up on this experiment by testing the moderating role of participants' current need for money in the effects of consciously and unconsciously perceived non-rewards. We again expected to find performance enhancement through unconsciously perceived high value non-rewards, but only for participants in need for money. Participants without this need were expected to remain unaffected by the coins.

Please note that the empirical chapters 3 to 6 are based on published articles. This means that it is unavoidable that there will be some overlap between the chapters in terms of the theoretical background. It also means that the chapters can be read independently and in any order.

Footnotes

[1] Money does not stink

Chapter 2

A new perspective on human reward research — How conscious and unconscious reward processing influence decision making, task preparation, and task execution.

The question of how human performance can be improved through rewards is a recurrent topic of interest in psychology. Cognitive approaches to this topic originally focused solely on consciously communicated rewards. Recently, however, a new perspective has emerged. That is, researchers have started questioning whether rewards affect performance similarly or differently depending on whether reward information is perceived consciously or outside of conscious awareness. Yet, only a few studies have directly compared and contrasted the effects of consciously and unconsciously perceived reward information in a systematic way. The present chapter reviews research employing a recently developed paradigm that allows for such comparison. We analyze this research to identify similarities and differences in how consciously and unconsciously perceived rewards impact three distinct processes relevant to performance; decision making, task preparation, and task execution. We further discuss whether conscious awareness plays a similar role in modulating the effects of reward information as it does in modulating the effects of other affective information. This review provides important new insights into the role of consciousness in different mechanisms through which rewards influence performance for better or for worse. Implications of these insights for understanding the role of consciousness in modulating goal-directed behavior more generally are discussed.

This chapter is based on Zedelius, C. M., Veling, H., Chiew, K. S., & Aarts, H. (submitted). A new perspective on human reward research: How consciously and unconsciously perceived reward information influences performance.

There is a long tradition of research on how human performance can be improved through rewards. Much of this research started out from a perspective on the relationship between rewards on performance as a simple input-output relationship, whereby rewards increase performance proportionately to their value (Skinner, 1953; Thorndike, 1932). Because this behaviorist approach failed to account for the many instances in which higher rewards do not proportionately improve performance, and sometimes even undermine performance (e.g., Ariely, Gneezy, Loewenstein, & Mazar, 2009; Mobbs et al., 2009), researchers have since started investigating the cognitive processes mediating the relationship between reward value and performance (Camerer & Hogarth, 1999; Deci, 1976; Festinger, 1961; Koopmans, 1960). In this investigation, the emphasis has shifted away from a focus on the mere value of rewards, and towards a focus on people's ability to consciously reflect on the value of rewards, make deliberative performance decisions, and employ complex performance strategies.

Recently, however, a new development in reward research has emerged, which may seem reminiscent of the traditional behaviorist approach. Specifically, following the discovery that a large part of human behavior unfolds unconsciously, rewards have been proposed and shown to affect performance even when they are perceived outside of conscious awareness, with conscious reflection thus entirely lacking (Pessiglione et al., 2007). This research raises important and challenging questions regarding the role of consciousness in reward effects on human performance. Most notably, can unconsciously perceived rewards influence performance in the same way, and through the same psychological processes as consciously perceived rewards do? Or are there important qualitative differences? And if so, what might these differences look like? The current chapter investigates these questions by reviewing recent research systematically comparing the effects of consciously and unconsciously perceived reward cues on performance.

Investigating these questions is relevant for several reasons. First, it can contribute to the development of new methods to motivate people and raise performance through unconsciously presented reward cues (e.g., in school or work settings). For such methods to be effective, it is important to understand which particular psychological processes can be improved by unconsciously perceived rewards, and in which respects unconscious reward processing is limited. It is also important to understand how contextual variables modulate the effects of unconsciously perceived rewards. The present review addresses these questions.

A second and at least equally important reason why this investigation is relevant is that it may provide new insights into the mechanisms through which *consciously* communicated rewards influence performance. Past research has already paid ample attention to the effects of consciously presented rewards on performance. However, since the comparison between consciously and unconsciously presented rewards was not an issue in this research, it does not tell us much about the role of conscious awareness in reward pursuit. Moreover, the current investigation is relevant to the role of consciousness in regulating human behavior more generally. There is an ongoing debate in the psychological literature about whether conscious awareness has any causal role in influencing our behavior, and if so, what exactly that role may be (e.g., Baumeister, Masicampo, & Vohs, 2011; Baars, 2002; Dehaene & Changeux, 2011; Morsella & Bargh, 2010; Lau & Rosenthal, 2011; Suhler & Churchland, 2009). By zooming in on the effects of conscious awareness in the influence of rewards on instrumental task performance, the current investigation contributes in a unique way to this broader topic.

Before we turn to our review of the literature on the effects of consciously and unconsciously perceived rewards on performance, 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 (e.g., Manusell, 2004). Thus, according to this definition, processes affected by rewards should also be sensitive to information about reward attainability and performance requirements.

Performance refers to the style in which a task is accomplished. Although the measurement of performance depends on the particular task at hand, 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). Performance (in terms of speed and accuracy) is the most frequent outcome measure in the research reviewed here, although some studies focus instead on physical or mental *effort* (the use of physical or mental energy to (attempt to) do something), which can be inferred either from performance or from (neuro-) physiological measures (e.g., Gendolla, 1998). More information on these measures is given as the respective studies are discussed.

Consciousness is an umbrella term spanning a number of different constructs. In the present review, we use the term as referring to *access consciousness*, or awareness of the content of one's experience of internal states or external stimuli (e.g., Lau & Rosenthal, 2011). With regard to rewards, we are thus primarily concerned with whether or not an individual is aware of a stimulus conveying reward value. As for the scope of this review, it is important to note that we do not aim to examine the issue of how rewards may influence performance indirectly, that is, *after* they are attained, for instance through learning and the reinforcement of rewarded choices or actions (e.g., Berridge, 2000; Dayan & Balleine, 2002; O'Doherty, 2004). Instead, our focus is solely on how the—

conscious or unconscious—perception of a reward influences subsequent processes that play a role in attaining that reward.

Methodological approach and initial findings

Most traditional theories of motivation and decision making (explicitly or implicitly) reserve a role for consciousness in the proposed mechanism through which rewards influence performance (Loewenstein, 1992; Ryan & Deci, 2000). However, few studies have systematically compared the effects of consciously and unconsciously perceived rewards. Recently, a paradigm has been developed that allows for such comparison (Pessiglione et al., 2007). In this paradigm, participants are presented (on a trial-by-trial basis) with monetary rewards of different values, which can be gained through good performance on a task. Different reward values are indicated by different coins. Whether these coins are perceived consciously or unconsciously is manipulated by varying the duration for which the coins are shown in-between visual masks. This manipulation is a manipulation of stimulus *input*, whereby weaker input is used to reduce the chance that the stimulus permeates into consciousness (see Dehaene, Kerzberg, & Changeux, 1989). Thus, when the coins are shown for a relatively long duration (i.e., the input is strong), they are clearly visible (i.e., supraliminal), but when they are presented extremely briefly (i.e., the input is weak) they usually cannot be consciously perceived (i.e., presentation is subliminal).

An important issue with respect to this procedure of subliminal versus supraliminal stimulus presentation concerns the fact that it yields differences in the strength of signals. Thus, failures to demonstrate effects of supraliminal and subliminal reward cues on performance may be either attributed to limitations of the capacity of unconscious processing, or to the weakness of the signal (Bargh & Morsella, 2008; Hassin, in press; Lau, 2009). Moreover, while the presence of subliminally presented coin stimuli can be verified technically (e.g., by using a high speed camera; see Zedelius, Veling, & Aarts, 2012), verifying unconscious perception requires a measure that is sensitive yet exclusive enough to rule out conscious awareness. Conscious and unconscious perception of the coin stimuli is usually measured by so-called objective identification measures (in which participants are simply asked to identify the coins) and/or subjective self-report measures (in which participants are asked to report on their subjective experiences of the presented coins). A more detailed discussion on these measures is beyond the scope of the current review (but see Overgaard & Sandberg, 2012; Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008; Vermeiren & Cleeremans, 2012; Winkielman & Schooler, 2011). However, in light of these different ways of measurement, we wish to stress that it is important to examine different *behavioral* effects of supraliminally and subliminally presented cues in theoretically informed experiments (see Cheesman & Merikle, 1986; Reingold, & Merikle, 1990). Thus, the research discussed here contributes to our understanding of conscious and unconscious information processing by focusing on this comparison.

There are two noteworthy aspects about the reward priming paradigm. First, it is important to note that participants are always aware of the fact that a coin indicating a reward is presented on each trial. In other words, participants are always aware of the opportunity to gain rewards. What varies is only their awareness of the cues indicating the *reward value* on each given trial. That way, the paradigm allows for a systematic and well-controlled comparison of conscious and unconscious reward processing within the same task and context. Another important feature of this paradigm is that the reward information is always displayed *before* measuring the performance on which the attainment of this reward is contingent. This is essential for testing how conscious and unconscious perception of reward cues influences subsequent psychological processes relevant to attaining the reward.

In a first series of experiments using this paradigm, Pessiglione and colleagues (2007; 2011) tested the effects of supraliminally and subliminally presented rewards on a physical force task in which participants were asked to squeeze into a handgrip. They found that performance increased proportionally to the value of rewards, regardless whether the rewards were presented supraliminally or subliminally. Moreover, supraliminally and subliminally presented rewards led to similar patterns of activation in brain areas involved in reward processing of and the mobilization of effort. These findings provided first evidence that unconsciously perceived rewards can increase physical effort and performance in a similar way as consciously perceived rewards do. This study also provided the basis for more recent research programs in different laboratories, in which the effects were replicated with different cognitive tasks (e.g., Bijleveld, Custers, & Aarts, 2009; Capa et al., 2011). Moreover, the reward effects were observed right from the beginning of an experiment, even when the first experimental block contained only subliminal rewards (Pessiglione et al., 2011). This suggests that the effects of unconsciously perceived rewards on performance constitute genuine motivational effects, which are not conditional on learned and habitualized responses to consciously perceived rewards in the same experimental context.

What remains unclear from these first studies, however, is which particular psychological processes underlie the behavioral effects of consciously and unconsciously perceived rewards. Does the perception of a high reward make people decide to work harder? Does it render people better prepared to respond to task stimuli or employ successful task strategies? Or does it boost the recruitment of effort once people are engaged in a task? And do the answers to these questions differ for conscious and unconscious rewards? By making different alterations to the reward priming paradigm and examining effects of contextual manipulations, more recent experiments have yielded new findings that help answer these questions. To better understand these findings, we will first briefly outline a theoretical framework dealing with similarities and differences between conscious and unconscious reward processing.

Theoretical framework

Central to this framework is the distinction between initial reward processing, which is thought to occur in the absence of awareness of reward information, and full reward processing, which is thought to depend on conscious awareness (Bijleveld et al., 2012-b). The idea that initial reward processing is unconscious is based on the notion that ecologically important stimuli, such as rewards, are initially processed by ontogenetically old, subcortical brain systems that operate independently of conscious awareness (e.g., Tamietto & de Gelder, 2010; Öhman et al., 2000). In line with this notion, neuroscientific research has shown that the value of rewards is initially encoded by a dedicated subcortical reward network, including the ventral striatum (VS; Phillips, Walton, & Jhou, 2007; Salamone et al., 2009; Pessiglione et al., 2007; 2011). Importantly, this network is found to project directly to higher cortical areas involved in goal-directed performance; which particular cortical areas are activated depends on the (motor or cognitive) demands of a given task (Liljeholm & O'Doherty, 2012; Schmidt et al., 2012). Thus, these observations help explain the finding that rewards can facilitate performance on both physical as well as cognitive tasks regardless whether the rewards are perceived consciously or outside of conscious awareness.

However, because the framework is largely informed by research identifying differences between conscious and unconscious perception, the framework can account for divergent effects of consciously and unconsciously perceived rewards as well. Research on visual perception has shown that, while supraliminally and subliminally presented stimuli initially elicit the same neural activation, after a short time the greater input from supraliminal stimuli (leading to conscious perception) elicits additional, qualitatively different brain activation compared to that elicited by subliminal stimuli. In a nutshell, the most important differences are that the activation elicited by supraliminal stimuli is more sustained and more globally distributed in the brain (e.g., Dehaene, et al., 1989). This is thought to cause fuller processing of information, enabling greater integration of information and more flexible control over behavior

(Baars, 2002; Cleeremans, 2008; Dehaene & Naccache, 2001). Based on this research, the framework predicts that consciously perceived rewards should have unique effects in contexts that require integration of different sources of reward information and flexible adaptation of performance.

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 further than validating the framework. Specifically, we aim to gain more insight into how conscious and unconscious rewards influence specific cognitive processes relevant to performance. To structure this investigation, we chose to focus on three distinct processes relevant to the pursuit of rewards through performance; decision making, task preparation, and task execution. We focus on these particular processes because they usually unfold successively, and can influence performance in strikingly different ways (Deecke, 1996; Haggard, 2008; see also Gollwitzer, 1990). First, people decide whether or not to engage in and how much effort to invest in a task. Once they decide that effort is warranted, they prepare appropriate responses and task strategies. Finally, when engaged in the execution of these responses or strategies, they constantly adapt their behavior to deal with momentary obstacles or opportunities. Past research has already shed much light on how each of these processes is influenced by consciously perceived rewards (Brehm & Self, 1989; Camerer & Hogarth, 1999; Deci, 1976). Though much less is known about the effects of unconsciously perceived rewards on these processes, a number of recent studies using variations of the reward priming paradigm provide valuable insights into this question. We discuss these studies in detail in the following sections. Finally, we address the important question of whether the discussed effects of conscious and unconscious rewards indeed depend on qualities specific to rewards, or whether they generalize to other information that signals value or positive affect.

Conscious and unconscious reward processing and decision making

Performance is primarily a matter of decision making. People decide whether or not to engage in a task and, if they do, how much effort they will invest (Deci & Ryan, 2009; Gold & Shadlen, 2007; Schwartz, 2000). Importantly, such performance decisions are usually oriented toward *efficiency*, meaning that people usually decide to invest only as much effort as is necessary to attain a reward and justified given the reward value

(Gendolla, 1998; Wright, 2008). Reward decisions are thus naturally 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 given that one expects that 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.

To better understand how consciously and unconsciously perceived reward information can influence performance, it is important to examine how people make efficiency-oriented performance decisions in response to rewards. According to traditional theories of motivation and decision making, making such decisions involves a deliberative calculation process whereby the value of a reward is integrated with available information on task demands and reward attainability (Atkinson, 1957; 1964; Brehm & Self, 1989; Vroom, 1964). However, there is now accumulating evidence that performance decisions rely much more on unconscious processes, and conscious deliberation and reflection only come into play much later (Bechara, Damasio, Tranel, & Damasio, 1997; Brass & Haggard, 2007; Libet, Wright, & Gleason, 1982; Soon et al., 2008). Because the reward priming paradigm can be used to test performance in response to varying reward values while also varying other factors that determine the likelihood of reward attainment, the paradigm 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. Both these factors have been addressed in studies comparing conscious and unconscious reward pursuit. A first experiment dealt with the question of how performance decisions are influenced by varying task demands. Participants were rewarded for maintaining digits in working memory for later recall after a few seconds (Bijleveld et al., 2009). Task demands were manipulated by varying the numbers of digits (three vs. five) to be maintained. Dilation of the pupil, a common measure for activation of the sympathetic nervous system and a correlate of mental effort, served as an indicator of the amount of effort recruited for the task. The results showed that, for supraliminal and subliminal rewards alike, high compared to low reward value increased effort only when the task was fairly demanding. This finding provided first evidence that, even when the reward value is processed unconsciously, performance decisions are influenced by a combination of reward value and task demands.

A series of follow-up experiments further investigated whether unconscious reward processing can give rise to more strategic decisions of the kind traditionally associated only with deliberate processes. This time, physical effort was measured. Specifically, participants performed a tapping task, in which they had to move a target on a computer screen from left to right by tapping on a button. In a first experiment, (Bijleveld et al., 2012-a, Experiment 1), task demands were manipulated by varying the available time (10 sec vs. 3.5 sec) to move the target. To inform participants about the task demands, the length of the time window was communicated at the beginning of each block of trials. The results replicated the earlier finding that both supraliminal and subliminal high value rewards increased effort only under high task demands. Thus, this experiment provided further evidence that some basic integration of reward value and task demands is possible without being consciously aware of a reward cue.

Bijleveld and colleagues proposed that a mechanism for this integration is increased sensitivity toward reward cues when the body detects greater (cognitive or physical) effort requirements (Bijleveld et al., 2012-a). If this explanation is indeed accurate, it raises the interesting question of how strategic such integration is when reward cues are perceived unconsciously. That is, do greater task demands increase the sensitivity to reward cues unconditionally or only when the task demands are in fact relevant to attaining rewards or also when the task demands are completely irrelevant to reward attainment?

This question was addressed in another follow-up experiment (Bijleveld et al., 2012; Experiment 3). Participants performed the same tapping task as described above, but with one important adaptation: to render task demands irrelevant to reward attainment, the researchers kept the time window for moving the target from left to right constant, but they instead varied the demands of an unrelated, secondary task. Specifically, while performing the tapping task, participants were now instructed to either forcefully squeeze or loosely hold a handgrip with their free (non-tapping) hand. This change in procedure yielded an interesting dissociation between the effects of consciously and unconsciously presented reward cues. For supraliminal rewards, performance improved with increased reward value, but this performance improvement was unaffected by the demands of the irrelevant secondary task. For subliminal rewards, however, performance was once again found to improve more strongly in response to high (vs. low) rewards when the demands of the irrelevant task were high than when the demands were low. Thus, when rewards were unconsciously perceived, increased effort requirements still increased participants' sensitivity to the value of these rewards even when the demands were entirely irrelevant for reward attainment.

Taken together, the findings discussed above show that unconscious reward processing is flexible and—to some degree—adaptive in that it is sensitive to varying task demands (see also Kiefer, 2012; Van Opstal et al., 2011). At the same time, it becomes clear that unconscious reward processing is rather limited when it comes to a more strategic assessment of the informational value of task demands in the current performance context. This difference between conscious and unconscious reward processing suggests that the greater input (i.e., in terms of longer presentation time) that renders reward information accessible to conscious awareness also instigates additional processes that enable strategic decision making.

An explanation for these findings consistent with the theoretical framework outlined above may lay in the notion that conscious awareness plays a special role in the integration of information (Baars, 2002; Dehaene & Naccache, 2001; Kouider & Dehaene, 2007). Although unconscious reward processing seems to enable at least very basic integration of reward value with task demands, the more strategic use of information in conscious reward processing is suggestive of more sophisticated integration when rewards are more fully processed.

This issue of integration was addressed more directly in another study (Zedelius, Veling, & Aarts, 2012). Here, participants performed a rewarded visual working memory task, after which accuracy on a recognition test was measured. Task demands were kept constant. However, consciously and unconsciously perceived rewards now varied not only in their value, but also in whether or not they were attainable. In a first experiment, participants were instructed at the beginning of every trial whether a subsequently presented reward would be attainable or unattainable (see Figure 2.1 for an overview of the procedure). Efficient performance thus required trial-by-trial integration of reward value and attainability. The results showed that supraliminal rewards selectively improved performance when they were both valuable and attainable. In contrast, when rewards were presented subliminally, performance was increased for high value rewards even when these were unattainable.

To verify that these differences indeed reflect differences in the integration of reward value and attainability information, a second experiment was conducted in which the demands for integration were removed. That is, participants were instructed that rewards were either always attainable or unattainable. They could thus decide upon a single valid response strategy for all trials without the need to combine value information with attainability information. In this context, both supraliminal and subliminal rewards led to efficient performance in the sense that performance was increased only when rewards were both valuable and attainable. Thus, these findings support the notion that conscious reward processing facilitates the integration of reward

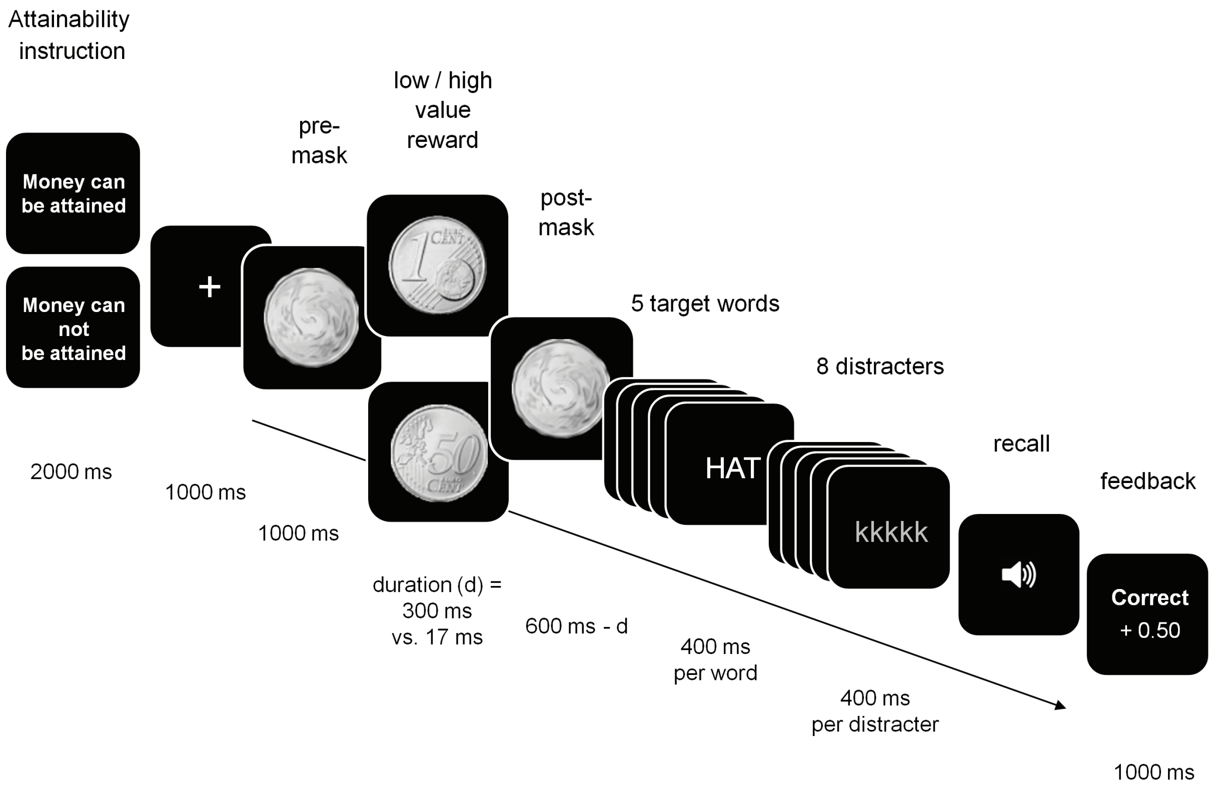

Figure 2.1. At the beginning of each trial, instructions indicated whether the upcoming reward would be attainable or unattainable. Next, a masked 1 cent or 50 cents coin was presented either supraliminally (for 300 ms) or subliminally (for 17 ms). The reward presentation was followed by a trial of a 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 words were recalled correctly in any order (for a discussion on this performance measure, see Zedelius, Veling, & Aarts, 2011-a, Chapter 5).

value with relevant contextual information, which establishes the basis for decisions on efficient effort investment.

Performance is not only influenced by decisions on whether to engage in a task and how much effort to invest in a task. People also frequently decide to disengage from ongoing tasks when they turn out to be too demanding and not rewarding enough to justify great effort (Brehm & Self, 1989; Cohen, McClure, & Yu, 2007; Wright, 2008). Just like decisions to engage, such disengagement decisions also require the integration of reward value with information on task demands; thus, it is plausible that these decisions may also be influenced differently by supraliminal and subliminal rewards.

This hypothesis was tested in another experiment using the tapping task described above (Bijleveld et al., 2012-a; Experiment 2). As in previous experiments, participants could gain rewards by tapping a button to move a target from left to right. This time, however, the task was rendered more or less demanding by varying the number of taps required to move the target. Because the focus of this experiment was not on *a priori* decisions to engage in the task but on decisions to disengage, information about task demands was now revealed during performance, rather than before engaging in the task. That is, instead of instructing participants beforehand about how quickly they had to tap to move the target, participants now had to observe online how quickly the target moved upon making button press responses. To investigate how rewards affected decisions to disengage in this context, the researchers analyzed those instances in which participants quit tapping altogether early on in a trial. While supraliminal low value rewards frequently caused participants to quit when the task turned out to be very demanding, subliminal low value rewards almost never led to quitting. These findings on decisions to disengage again show that conscious compared to unconscious reward processing leads to more efficient performance, likely due to greater integration of reward value and online information on task demands. The results fit well with research on quitting behavior during gambling, which indicates that disengaging from a no-longer-rewarding task relies on deliberate decision making processes that engage higher cortical brain areas (Campbell-Meiklejohn et al., 2008).

In conclusion, by comparing performance in response to consciously and unconsciously perceived rewards under different task demands and attainability conditions, new insight is 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 relatively strong input of reward information, increasing the chance of conscious processing, is required to enable flexible integration of reward information with other performance-relevant information (e.g., task demands or attainability information). Moreover, the findings suggest that this flexible integration facilitates strategic use of reward information in decision making to arrive at efficient effort investment and to adapt or quit one's initial course of action in accordance with newly acquired information.

Although this section was 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.

Conscious and unconscious reward processing and preparation

Preparation entails the allocation of attention to the kind of stimuli to follow and the kind of operations and actions to be performed, and begins before an individual has all 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, there is evidence that preparation is enhanced when performance is rewarded (e.g., Nieuwenhuis, & Monsell, 2002; Savine & Braver, 2010). However, this evidence is largely based on research using consciously presented reward information. For instance, studies have found that the promise of monetary rewards facilitates responses on simple and choice reaction time (RT) tasks and reduce the time for switching between different tasks, but only when task cues are provided that enable preparatory processing prior to response execution (Mir et al., 2011; Savine & Braver, 2010; Veling & Aarts, 2010). Recent studies have used the reward priming paradigm to investigate whether unconsciously perceived rewards can facilitate task preparation in the same way as conscious rewards do.

One study addressed this issue by using a task switching paradigm (Capa et al., in press). Participants were presented with high and low value reward cues followed by long sequences of single digits on which they had to perform different tasks. The tasks all required relatively simple judgments (e.g., odd or even; smaller or greater than five). 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 ERPs to these cues on high compared to low value reward trials indicated increased task preparation for high value rewards. Importantly, this increased preparation was the same whether rewards were presented consciously or unconsciously. Thus, this study suggests that strong input and, consequentially, conscious awareness of reward information is not necessary to initiate specific preparatory processes to facilitate quick responses to task stimuli.

Interestingly, other studies have provided evidence that conscious and unconscious reward processing differ when it comes to initiating less specific preparation. In one study, participants were again rewarded for squeezing a handgrip. An important adaptation to this task was that, this time, the reward cues were always flashed only in one visual hemifield (left or right), and thus initially entered only one brain hemisphere (Schmidt et al., 2010). Replicating previous findings (Pessiglione et al., 2007), the study again showed that grip force increased proportionately to the value of the presented rewards. Remarkably, however, for subliminal rewards, 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, which may facilitate quick responding to the source of reward information, but do not influence behavior on a more global level. This is in line with the findings reported in the previous section on decision making (Zedelius, Veling, & Aarts, 2012), which support the basic premise of the framework that only the relatively stronger input of supraliminal reward presentation elicits the widely distributed cortical activation needed to integrate information and coordinate processes that otherwise operate independently (Baars, 2002; Dehaene & Naccache, 2001; Kouider & Dehaene, 2007).

Building on this premise, it is conceivable that conscious compared to unconscious reward processing is superior in facilitating performance in contexts where good performance depends not just on the preparation of simple responses, but requires flexible adjustments in strategy. Since performance is a multifaceted term, and the requirements for good performance (e.g., speed, accuracy) can vary, strategic performance adaptations can crucially influence performance outcomes and thus also reward attainment. For instance, when a rewarded task is difficult to perform both quickly and at high accuracy, people often decide to sacrifice response speed for greater accuracy, or the reverse, depending on which of those performance dimensions is emphasized more strongly in the context at hand (e.g., Dambacher, et al., 2011; Hübner & Schlösser, 2010).

Although such "speed-accuracy tradeoffs" (SATs) are often conceived of as the result of a *decision* (Ivanoff et al., 2008), research shows that making these tradeoffs 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. This 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, et al., 2009; Ivanoff et al., 2008; van Veen, et al., 2008). A focus on speed, for instance, increases the baseline activation such that the threshold will be reached faster—a strategy conveying eagerness but coming at the risk of making mistakes. A focus on accuracy, on the other hand, lowers the baseline activation such that the threshold will be reached later—a rather cautious strategy.

Recent studies have compared how conscious and unconscious rewards influence 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, et al., 2010). In this task, participants were presented with relatively simple equations they had to judge as correct of false (e.g., 2 + 3 + 9 = 14). Across experiments, subliminally presented high 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 compared to low rewards. However, when overall high accuracy (regardless of the reward value) became a precondition to obtain rewards, participants abandoned this strategy and sped up responses on high rewards trials without any changes in accuracy. These results indicate that while both conscious and unconscious processing of high rewards can increase performance, the relatively stronger input that enables conscious processing of reward information seems to be necessary to make strategic performance adjustments that fit the current performance context.

From these first 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 resolve this issue, a more recent study investigated how preparatory processes aimed at attaining future task rewards affect immediate performance adjustments (Zedelius, Veling, Bijleveld, & Aarts, 2012). The idea behind this study 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, participants were presented with series of tones, and were asked to indicate for each tone whether it was high or low. Importantly, participants could gain rewards for fast and accurate responding to each *second* tone in a series. Responses to each first tone were not rewarded (see Figure 2.2 for a more detailed overview of 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 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 intermediate, unrewarded task (see Figure 2.3). Thus, these findings indicate that the differences between conscious and unconscious rewards in affecting strategic performance adjustments reflect differences that operate not only during decision making, but also at the stage of task preparation.

The finding that conscious compared to unconscious reward processing facilitates strategic performance adjustments fits well with the frequently-raised assumption that the higher cognitive functions restricted to conscious information processing may have developed to render behavior more flexible and efficient (e.g., Dennett, 1995; Morsella & Bargh, 2010; Milner & Goodale, 1995). However, in light of the presently discussed findings, it is important to note that the tendency for conscious reward processing to affect strategic performance adjustments does not necessarily constitute a general advantage of conscious over unconscious reward processing when it comes to obtaining rewards. In fact, the experiments presented in this section show that the non-strategic performance boost elicited by unconscious rewards may be just as effective (i.e., in terms of reward attainment), or perhaps even more effective, than the strategic performance boost after conscious reward processing. Thus, from the current data, we cannot draw the conclusion that conscious compared to unconscious reward processing is by default superior in facilitating reward attainment (see also Bijleveld, Custers, & Aarts, 2011).

Conscious and unconscious reward processing and task execution

Once people decide to invest effort in a task and prepare a specific response or task strategy, what remains critical for good performance is how the task is executed. Task execution is heavily influenced by preparation, but also by events that occur during a task. For instance, during task execution, attention may be captured by the appearance of salient task stimuli (Della Libera & Chelazzi, 2006; 2009; Jonides, 1981; Posner 1980). Such changes in the focus of attention often trigger the recruitment of additional mental effort, a 'late correction' mechanism operating once obstacles to successful performance are detected (e.g., Braver, 2012; Jacoby, Kelley, & Mcelree, 1999). Research has shown that both these processes can be influenced by rewards. However, once again, most of this research has relied solely on consciously perceived reward presentation. For instance, supraliminally presented task cues associated with rewards have been shown to capture attention and interfere with successful task execution (Anderson et al., 2011; Krebs et al., 2010; 2011). On the other hand, consciously perceived reward cues can

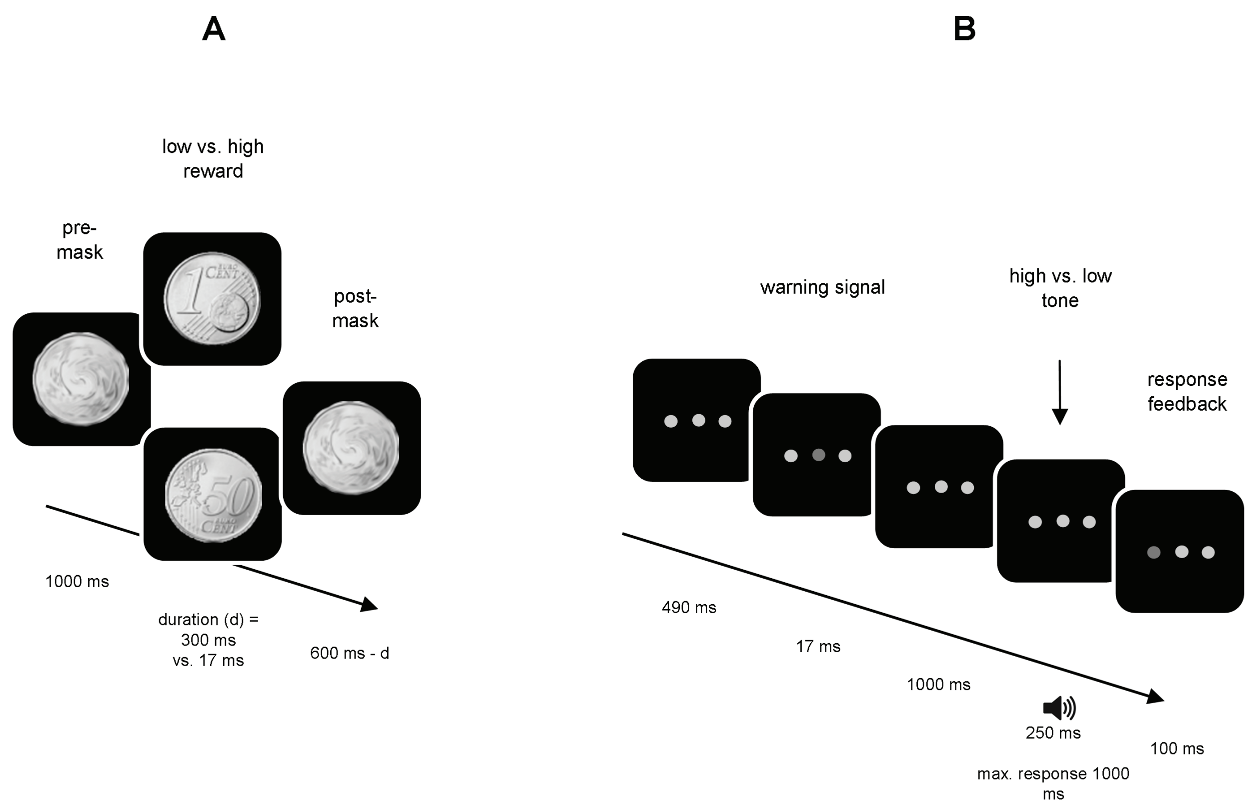

Figure 2.2. After supraliminal or subliminal presentation of a masked 1 cent or 50 cents coin (A), participants performed two consecutive trials of a reaction time task (2 x B), in which they were asked to quickly respond with a right versus left key to a high or low pitch tone. Participants were instructed prior to the experiment that correct responses to each ***second*** tone would be rewarded if the response time lay within a predefined limit. Responses to each preceding tone were unrelated to attaining rewards.

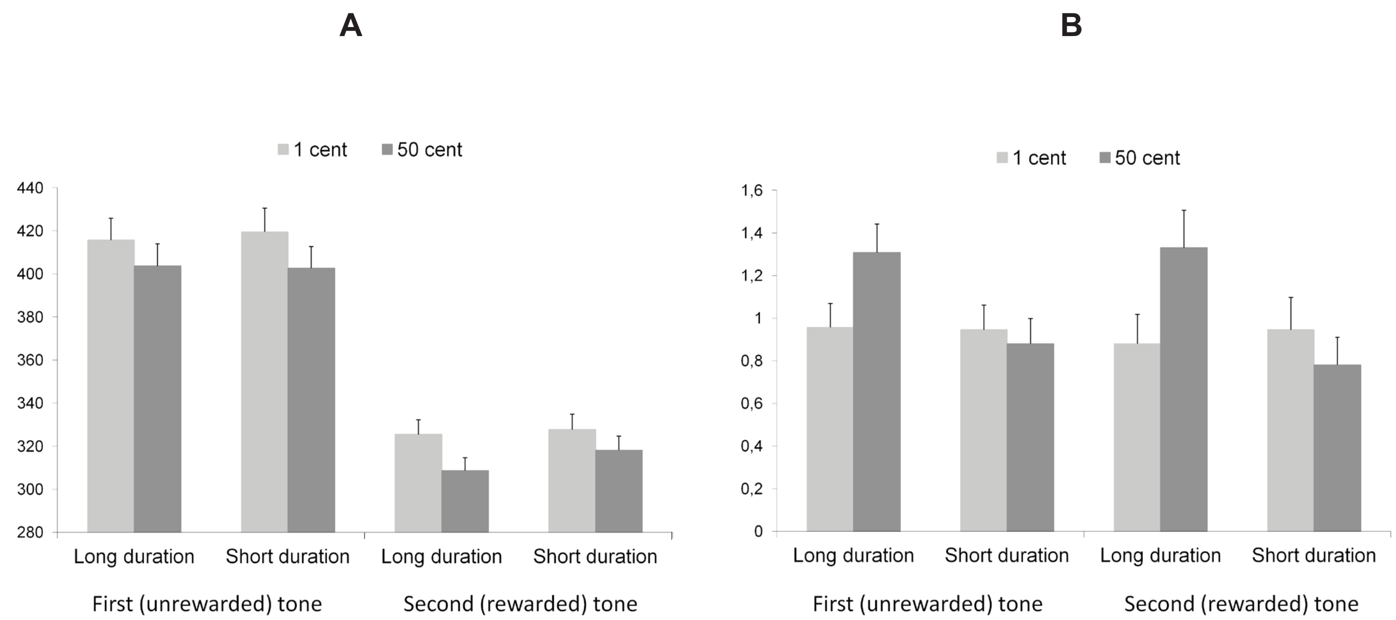

Figure 2.3. Response times (A) showed that high compared to low value rewards sped up responses to both rewarded responses and intermediate, unrewarded responses, regardless whether they were consciously or unconsciously perceived. The combination of these reaction time results with error rates (B) further revealed that consciously perceived rewards led to a strategic speed-accuracy tradeoff for both rewarded and unrewarded tones. That is, participants made more errors on high compared to low reward trials. Unconsciously perceived rewards sped up responses to rewarded and unrewarded tones without this tradeoff.

also facilitate task execution. This is because, in addition to increasing task preparation, reward cues can stimulate non-specific effort investment during an ongoing task, and thereby facilitating prepared as well as unprepared responses (Veling & Aarts, 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 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). Thus, to examine the specific effects of consciously and unconsciously perceived reward cues on task preparation and execution, one study looked at ERPs in response to different events in a cued task switching paradigm (Capa et al.; in press). Participants performed a number of different tasks, all of which required simple judgments on digits. Task cues presented before each digit indicated which task was to be performed on the next digit. ERPs in response to those task cues were assessed to measure preparatory processes, while ERPs in response to the target digits were assessed to measure processes involved in task execution.

As mentioned earlier, cue-related ERPs indicated parallel effects of supraliminal and subliminal rewards during preparation. Interestingly, however, ERPs following target stimuli showed divergent patterns. That is, on supraliminal reward trials, high compared to low reward value led to stronger suppression of alpha activity—an indicator of greater mental effort. This effect was absent on subliminal reward trials. Moreover, 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.

An interesting fact about this finding was that valuable conscious rewards sped up RTs even though the task did not require particularly fast responses. This raises the possibility that conscious awareness of high rewards may lead people to recruit too much effort—a tendency that may not always be helpful, and might at times even hinder performance (e.g., see Bijleveld et al., 2011). Thus, paralleling our discussion on the functionality of conscious reward processing with regards to task preparation, the currently discussed findings seem to imply that when it comes to facilitating task execution, conscious processing is again not necessarily superior to unconscious processing.

Following up on this discussion, it was proposed that task execution may even be impaired by conscious reward processing (Zedelius, Veling, & Aarts 2011-b). This idea was based on previous research suggesting that, because valuable rewards are highly significant for people, directing conscious thoughts and attention to a valuable reward can distract from other ongoing processes that rely on the same scarce attentional resources, and thereby impair 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, the question remained whether it is indeed people's conscious awareness of valuable rewards that leads to interference with performance.

Two experiments were conducted to examine this question (Zedelius, Veling, & Aarts 2011-b). Participants were rewarded for a verbal working memory task in which they were asked to actively maintain series of words for later verbal recall after a short delay period. To show that conscious (but not unconscious) reward processing specifically interferes with ongoing task *execution*, as opposed to task preparation, rewards were presented either just before the beginning of a trial, or during the maintenance phase. And indeed, while both supraliminal and subliminal high value rewards increased performance when presented before beginning of a trial, when 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. Thus, this effect illustrates that unconscious reward processing can be superior to conscious processing in facilitating performance.

In summary, the research discussed in this section shows that conscious reward processing produces unique effects on task execution. 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 is needed, but it can also distract from ongoing processes and thereby interfere with task execution.

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

The studies discussed in the above sections all focus on the effects of rewards (defined previously as desirable outcomes attainable through instrumental performance). An interesting question is whether the conclusions concerning consciousness drawn from these sections are specific to rewards, or whether they generalize to other stimuli that are not rewards according to the above definition but share features with rewards: for instance, in that they are desirable, valuable, or otherwise charged with positive valence. Just like rewards, such stimuli are often highly salient and can elicit positive affect. Moreover, 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 the role of consciousness in reward processing, or does consciousness play a similar role in modulating responses to other affective but non-rewarding stimuli?

The main difficulty with addressing this question is that work on the effects of non-rewarding affective stimuli on performance or effort recruitment has mainly focused either on conscious processing of stimuli (Chiew & Braver, 2011), or on unconscious processing of stimuli (e.g., Gendolla & Sivestrini, 2010; 2011), but not on a direct comparison of conscious and unconscious processing. Thus, although it is conceivable that non-rewarding stimuli that share features with rewards might elicit similar effects on performance as rewards do, the role of consciousness herein is difficult to evaluate. Nonetheless, there are hints in the literature suggesting parallel effects of consciously and unconsciously perceived affective cues on performance and effort investment that resemble the parallel effects often found for consciously and unconsciously perceived rewards.

A prominent line of research implying similarities between the effects of consciously and unconsciously perceived information is concerned with behavioral goals.That is, research has suggested that unconsciously perceived positively valenced cues (e.g., words referring to positive objects (e.g., "beach") or mood states (e.g, "good")), when associated to behavioral goals, can elicit the same effortful goal-directed behavior previously found to result from consciously set goals (Capa, Cleeremans, Bustin, & Hansenne, 2011; Custers & Aarts, 2005; Fishbach & Labroo, 2007; Holland, et al. 2009; Veltkamp, Custers, & Aarts, 2011). These findings fit well with the framework surrounding conscious and unconscious reward pursuit. That is, it has been proposed that the positive affect associated with goals functions as a "reward signal", which can boost cognitive processes involved in goal attainment independent of conscious awareness (Custers, & Aarts, 2010; Ferguson & Fishbach, 2007). In this way, unconsciously perceived positive affective cues related to goals can strengthen the maintenance and accessibility of the respective related goals and facilitate effortful cognitive processes that support successful goal pursuit.

This research on goal pursuit suggests that the effects of unconsciously perceived rewards on performance are not unique to rewards, but can also be elicited by cues related to goals. However, because this work employs paradigms in which stimulus input, and hence conscious awareness of the stimuli is not manipulated, the role of consciousness in driving these effects remains unclear. Moreover, it is important to note that goals share with rewards not only their desirability, but also that they afford instrumental behavior. Thus the definitions of goals and rewards are largely overlapping. Therefore, the question remains whether other affectively toned or salient cues, while not directly linked to instrumental performance, can lead to similar effects on performance.

One line of research approaches this question from the view that affective stimuli cannot only signal value, but they can also implicitly activate representations of related affective states, including information about how demanding a task is experienced to be (e.g., Gendolla, 1998; Gendolla, & Silvestrini, 2011). Thus, positive affective cues are thought to activate a positive affective state, which can be sensed as a signal of relative ease. Following this view, incidentally presented affective cues which are positive have the potential to influence the amount of effort people invest when performing a task, even though this is not instrumental for attaining any additional goal than the primary task goal (Gendolla, in press). Interestingly, although this work has not manipulated the input of the affective stimuli within a single experiment, a comparison between studies suggests that unconsciously presented affective cues can have strikingly similar effects on effort recruitment as consciously presented affective cues (for a discussion see Silvestrini & Gendolla, 2011).

Other work focusing on the comparison between the effects of affective and reward information has pointed to important differences in the mechanisms through which these types of information can affect on goal-oriented cognition (reviewed in Chiew & Braver, 2011). That is, observations from an influential line of research investigating the influence of positive affect on cognition suggest that positive affect is associated with more creative thinking (Isen et al., 1987) and greater breadth of attention (Fredrickson and Branigan, 2005; Rowe et al., 2007), but also with a cognitive tradeoff in terms of reduced maintenance and increased distractibility (Dreisbach, 2006; Dreisbach & Goschke, 2004). Interestingly, such effects have not only been observed when people may have access to the source of the positive affect (cf. Isen et al., 1987), but also after unconscious (subliminal) processing of stimuli that elicit positive affect (e.g., Chartrand, van Baaren, & Bargh, 2006).

In contrast to these findings concerning the effects of positive affect on attention, rewards have been associated with 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 may be that the effects of positive affective cues on goal-oriented cognition are determined by how the affect relates to the given goal (Marien, Aarts, & Custers, 2012). Many of the effects associated with positive affect, such as broadening and increased distractibility, can be accounted for by the 'coasting hypothesis' (Carver, 2003), which posits that positive affect may emerge from signals that goal attainment is progressing faster than expected, in which case one may 'coast' on the goal in question and consider other ideas and alternate goals.

The research reviewed above can be summarized to suggest that incidentally presented cues associated with positive affect can influence performance because they are interpreted as conveying information relevant to performance (e.g., relative ease or goal-progress). This mechanism is very different from the mechanisms proposed to operate in the case of reward or goal pursuit. Moreover, with regard to our question of the potential role of consciousness in modulating these effects, it is important to note that most of the effects found in the above studies on affective information have been observed primarily for consciously presented stimuli, and the studies that did present subliminal stimuli suggest similar effects for consciously and unconsciously perceived affective stimuli (e.g., Chartrand et al., 2006; Gendolla, & Silvestrini, 2010; 2011; Silvestrini & Gendolla, 2011). Thus, unlike the studies reviewed earlier involving reward information, these studies have not (yet) shown an important role of consciousness in driving performance after perception of generally positive affective stimuli.

Interestingly, however, there is one recent study that points to the possibility that consciousness may play an important role in directing behavior toward stimuli that are not rewards but share features with rewards (Zedelius, Veling, & Aarts, in press). In this study, participants were subliminally or supraliminally presented with coins of high and low value during a verbal working memory task (as in Zedelius et al., 2011). In Experiment 1, the critical manipulation was that the coins were either presented as rewards or explicitly introduced as non-rewards. Replicating previous research, supraliminally and subliminally presented high vs. low value coins led to increased performance when presented as rewards. However, when the coins were explicitly introduced as non-rewards, an interesting dissociation was found. For supraliminal coins, high value coins no longer enhanced performance, but instead tended to cause a drop in performance. Subliminal high vs. low value coins, however, still improved performance.

A follow-up experiment was performed to better understand this striking and selective performance enhancement through subliminal non-rewards. Based on research showing that the subjective rewarding value of stimuli depends greatly on people's current needs (Berridge, Robinson, & Aldridge, 2009; David et al., 2005; Lebreton et al., 2009; Knutson et al., 2009), it was tested whether valuable coins, would only motivate people to invest effort when in need of money (i.e., when money represents high incentive cue). Critically, with this hypothesis, it was anticipated that when the non-rewards are consciously perceived and can be reflected on, participants should be able to down-regulate the tendency to enhance their performance in the face of high incentive value (i.e., as effort will not lead to gaining the reward).

To test these predictions, a similar procedure was used as in the first experiment, with the difference that the coins were always presented as non-rewards. Moreover, the researchers measured participants' current need for money. For participants with high need for money, the results showed the same pattern as before. That is, subliminal high value coins increased performance, while supraliminal high value coins caused a trend in the opposite direction. Participants with low need for money were not affected by the value of the non-rewarding coins. These results suggest that positive affective cues may initially elicit the same processes as rewards do, but that these processes may be down-regulated once people consciously reflect on the affective information (cf. Schwarz & Clore, 1983). Although further research is needed to better understand the mechanisms enabling this regulation, this research shows that the reward priming paradigm offers an interesting 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 reward pursuit. The general aim of the present review was to give an overview of the existing literature on this topic, with the more specific goal of comparing the effects of consciously and unconsciously perceived rewards on decision making, task preparation, and task execution as important factors in human performance. The research discussed here can be summarized to yield 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 people's preparedness to perform a task well. The second conclusion is that unconscious reward processing is rather limited when it comes to improving performance *strategically* and *efficiently* in more complex contexts. This limitation becomes apparent in decision making, task preparation, and task execution. In investigating the effects of rewards on decision making, it was found that conscious compared to unconscious reward processing allow 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, it was found that conscious compared to unconscious reward processing allows for more flexible adaptation of performance strategies. And in investigating the effects of rewards on task execution, it was found that conscious but not unconscious reward processing leads people to recruit additional effort for high value rewards during task execution. The present review further showed that although typically observed reward effects can also be produced by stimuli that share characteristics with rewards but are not in fact rewards, people respond differently to rewards and non-rewards when they can consciously reflect on them. Thus, all in all, the findings discussed in this review suggest that while both conscious and unconscious reward processing facilitate effortful performance, conscious awareness of rewards elicits unique processes that facilitate flexible, strategic, and efficient reward pursuit.

These findings have interesting practical and theoretical implications. The most obvious practical implications have to do with the potential application of the insights gained from the research presented here in real life contexts, such as school or work settings. The presented research suggests that subtle reminders of monetary rewards presented without attracting much conscious attention (e.g., on computer screens alongside other work-related information) may be an efficient tool to motivate people to perform well. Importantly, however, this motivation should only facilitate performance in contexts where people know what kind of performance is required of them and that greater effort is likely to lead to better performance. Such a method of performance improvement would be efficient in that, according to research findings, it would be especially effective when people face tasks that are very demanding (e.g., Bijleveld et al., 2009). At the same time, it could be a practical way to prevent the kind of distraction often caused by consciously anticipated rewards (Zedelius et al., 2011). However, when strategic performance adjustments are needed, such as when it is important to concentrate on a particular aspect of one's work (e.g., quality) at the cost of another (e.g., quantity), research suggests that it would be beneficial to give people the opportunity to consciously think of the rewards at stake. Of course the research presented in this review is only a first—though a critical—step to gain a better understanding of the possibilities to influence behavior through unconscious reward cues. More research is needed to make more concrete suggestions for designing applicable unconscious reward strategies.

Of equal importance are the theoretical implications of the research discussed in this review. For one, we have shown that the systematic comparison between the effects of consciously and unconscious rewards not only provides new insights into the mechanisms through which unconsciously perceived rewards influence performance, but also into the mechanisms through which *consciously* communicated rewards do. In much previous research, conscious presentation of rewards was part of the standard procedure, mainly because the distinction between conscious and unconscious processes in reward pursuit was not the primary topic of interest in this research. Instead, the focus was more on deliberative processes in decision making and strategic performance improvements (Bandura, 1982; Brehm & Self, 1989; Cohen et al., 2007; Heckhausen, 1977; Nieuwenhuis, & Monsell, 2002; Savine & Braver, 2010; Wright, 2008). Although the role of conscious awareness in these processes has usually not been addressed explicitly in this research, it has often been suggested implicitly.

One example for this is the frequently observed phenomenon that consciously presented valuable reward can at times be highly detrimental to performance (e.g., Ariely et al., 2009; Camerer & Hogarth, 1999; Mobbs et al., 2009). At first glance, it may seem almost self-evident that conscious awareness of the reward, and the ability to reflect on it, lies at the heart of this phenomenon. After all, reflecting on the value of a reward may make it more difficult to perform a difficult task at the same time (Beilock, 2007). However, it could equally likely be that the effect is caused by reactions to valuable rewards that are independent of conscious awareness, such as for instance increased physiological arousal (e.g., see Camerer & Hogarth, 1999). Thus, as this example shows, the direct comparison of consciously and unconsciously presented rewards in the same experimental context is a useful approach to shed new light onto the role of conscious awareness in different aspects of conscious reward pursuit.

The current investigation was inspired as much by research on reward pursuit as by theories on consciousness. As a result, the implications of this investigation are also relevant to the topic of consciousness. Research on the topic of consciousness originating from a cognitive perspective on human functioning usually focuses on the relationship between consciousness and cognitive control functions. This research is concerned with testing which specific kinds of cognitive processes (e.g., conflict resolution, information integration) require conscious awareness of information relevant to these processes, and which functions can be performed equally well without it (e.g., Ansorge et al., 2011; van Gaal, Lamme, & Ridderinkhof, 2010; Hassin et al., 2009; Lau and Passingham, 2007; Kunde, 2003; Mayr, 2004; Mudrik, et al., 2011; Williams et al., 2009). More recently, research has also started to focus on the more general role of conscious awareness in motivation and goal-directed behavior. The general gist of this research is that people can engage in goal-directed behavior unconsciously, but that conscious awareness of goals may additionally enhance relevant goal-directed processes (Baumeister, Masicampo, & Vohs, 2011; Dijksterhuis & Aarts, 2010; Gendolla, in press; Morsella

& Bargh, 2010). The present review and analysis combines both these perspectives by investigating which cognitive processes involved in the attainment of desired rewards require conscious awareness of reward information, and which can operate independent of it. The results of this investigation 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 compared to unconscious reward processing facilitates more strategic processes. One could be inclined to conclude from this that conscious reward processing is generally superior in facilitating instrumental performance. We argue that this conclusion is not universally true. However, research at present seems to have focused disproportionately on situations in which the strategic processes that go along with conscious compared to unconscious reward processing are beneficial for efficient effort investment. Thus, it would be interesting to examine more closely the functionality of conscious compared to unconscious reward pursuit in future research.

An interesting starting point for such research could be the issue of disengagement in situations where 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 invest their effort efficiently, that is, only when rewards are of high value, attainable, and do not require an unreasonable amount of effort (e.g., Bijleveld et al., 2012-a; Zedelius, Veling, & Aarts, 2012). This seems, at first glance, to be the most adaptive way to respond. In fact, it is often stressed that the ability to disengage from goals is an essential part of functional self-regulation, and that hanging on to unattainable goals causes negative effect, frustration, and is even related to depression (Bandura, 1977; Carver & Scheier, 1998; Wrosch et al., 2003). However, in many situations in everyday life, it is not so clear whether a desired reward is or is not attainable. Moreover, a reward that seems unattainable at first may sometimes turn out to be attainable in the end. Therefore, while frustrating, 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 compared to conscious reward pursuit may thus be beneficial in situations where persistence is needed to obtain rewards, although it should be noted that unconsciously perceived rewards do not always lead to persistence (Zedelius, Veling, & Aarts, 2012, Exp. 2). Future research is therefore 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 compared to unconscious reward processing may come at the cost of a greater potential to cause interference. For instance, research has shown that conscious awareness of high value rewards during an ongoing task impairs performance, while unconsciously perceived high rewards improve performance (Zedelius et al., 2011-b). The proposed explanation for this finding was that conscious reflection on high value rewards taxes the working memory resources actually needed to successfully execute the task. However, it is still unclear why this would be the case. It could be that the mere conscious perception of valuable rewards by default taxes cognitive resources; or it could be that it does so only for people who tend to think or worry about their chances of reward attainment, or prepare particularly taxing performance strategies.

Future research on this research question could have interesting implications for ways to improve performance through consciously and unconsciously presented rewards. For instance, if it were shown that conscious perception of valuable rewards by default taxes a lot of working memory resources, conscious reward processing may be especially detrimental to performance in environments where irrelevant distractors are present (see Baumeister et al., 2008). This idea is in line with research showing that greater working memory load through task-relevant stimuli leaves people more prone to distraction by irrelevant information (e.g., Boot, Brockmole, & Simons, 2005; Lavie, 2005; Lavie & De Fockert, 2005). Thus, there is interesting potential 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., Smallwood & Schooler, 2006; Schooler et al., 2011).

Another interesting 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) which, if attended, may become consciously accessible to an individual (Chartrand et al., 2010; Knutson, Taylor, Kaufman, Peterson, & Glover, 2005). 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), which may require considerable time, it may impact task execution proportionately more than decision making and task preparation. Further research is needed to explore this interesting possibility.

To conclude, the systematic comparison of conscious and unconscious reward pursuit is an interesting endeavor with important implications for improving our understanding and examination of new 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 new and exciting approach to studying the role of consciousness in reward pursuit in particular and in behavior in general.

Chapter 3

Preparing for a rich future — How consciously and unconsciously perceived rewards contingent on future performance affect immediate performance

In everyday life contexts and work settings, monetary rewards are often contingent on future performance. Based on research showing that the anticipation of rewards causes improved task performance through enhanced task preparation, the present study tested the hypothesis that the promise of monetary rewards for future performance would not only increase future performance, but also performance on an unrewarded intermediate task. Participants performed an auditory Simon task in which they responded to two consecutive tones. While participants could earn high versus low monetary rewards for fast responses to every second tone, their responses to the first tone were not rewarded. Moreover, we compared performance under conditions where reward information was presented supraliminally, and expected to prompt strategic performance adjustments to conditions where reward information was presented subliminally. Results showed that high (vs. low) rewards sped up both rewarded and intermediate, unrewarded responses, and the effect was independent of reward presentation. Moreover, supraliminal presentation led to a speed-accuracy trade-off for both rewarded and unrewarded tones, whereas subliminal presentation sped up responses to rewarded and unrewarded tones without this trade-off. These results suggest that high rewards for future performance boost intermediate performance due to enhanced task preparation, and they do so regardless whether people respond to rewards in a strategic or non-strategic manner.

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The promise of rewards, such as money, for good performance is a powerful tool to get the best out of people, especially when the to-be-performed task is boring, repetitive, or otherwise not intrinsically interesting . In line with this principle, rewards are widely used to entice people to increase their performance, that is, the speed or accuracy with which people execute a task. For instance, corporations offer monetary bonuses, schools offer awards, and sports tournaments offer prizes. Importantly, more often than not, such real-life rewards are not attainable right away, but are contingent on *future* performance. Nevertheless, previous research on the effects of rewards has focused exclusively on rewards that can be earned immediately. As a result, it is currently unclear how the promise of future rewards affects performance on reward-unrelated tasks that people encounter in the mean time. The present research aims to provide first insight into this topic by examining how rewards for future performance impact performance in terms of speed and accuracy on*ks intermediate tas*—tasks that are carried out after the promise of reward has been made, but before the reward can actually be earned.

In the present study, we test the hypothesis that the promise of rewards for future performance increases performance not only on the task in which the reward can be earned, but also on an intermediate task. We further explore the hypothesis that this boost is not strategic, but occurs as a consequence of increased preparation for a rewarded task. The main aim of the present study is to enhance our understanding of the mechanisms via which rewards shape performance. Moreover, this study also offers interesting practical implications. In work settings, for example, the promise of rewards to be earned in the future may prove a useful and efficient tool to raise performance immediately.

Rewards increase preparation before they can be earned

Previous studies suggest that rewards enhance performance by increasing effort and attention toward a task, which facilitate the execution of goal-directed actions . Importantly, however, increased attention does not only serve successful performance by facilitating the execution of tasks, but also by facilitating preparation. Preparation entails the allocation of attention to the type of stimulus to follow and the type of action to be performed, and takes place even before a person has the necessary information to actually produce the appropriate action . And indeed, studies have shown that rewards can improve performance by enhancing task preparation . Thus, the facilitative effect of rewards on performance materializes already *before* people engage in the execution of a rewarded task. This raises the intriguing possibility that the promise of reward for future tasks facilitates performance already when people carry out an intermediate task, even though this task is not instrumental for attaining the reward.

Based on other previous research, one could argue that this hypothesis is rather counterintuitive. That is, in research on the effects of performance-contingent rewards, it is generally assumed that effort is directed specifically toward rewarded tasks or task dimensions, and not toward unrewarded activities . In fact, research shows that people are generally reluctant to invest unnecessary effort , a tendency that might prevent the potential depletion of mental resources needed for important tasks . From this perspective, people should be inclined *not* to increase performance on an intermediate task when presented with rewards that can be earned only through future performance. However, research has also shown that when people pursue a future reward, the reward information is automatically maintained in memory and remains highly accessible until the reward is obtained . Consequently, we predict that rewards for future performance may immediately lead to preparation for optimal performance—even on tasks that are non-instrumental to the reward.

Some evidence indeed suggests that preparation for future performance can cause immediate performance improvement. In one study, it was found that the anticipation of a difficult (vs. easy) future task led to increased performance on an unrelated intermediate task . However, it is unclear whether the immediate performance boost was caused by the mere expectation of having to perform a difficult task, or by the preparation to perform especially well on the future task (e.g., because rewards are at stake).The present study addresses this issue directly by testing the effects of high and low rewards for future task performance on intermediate task performance.

Strategic and non-strategic performance adjustments

A further critical issue tested in the present study is whether the predicted effect of future task rewards on intermediate task performance is indeed a consequence of the mere preparation for the rewarded future task, and not the result of a deliberate strategy to improve future performance by intentionally raising immediate performance. It may be conceivable that people employ such a strategy to act on the implicit theory that exerting effort now may have an energizing function, and thereby improve performance in the future (e.g., see). However, if people would deliberately improve immediate performance in response to high rewards as part of a strategy, this would be a different mechanism than we predict. According to our prediction, preparation for a highly rewarded future task can improve immediate performance even when people do not act strategically.

To test the potential role of strategic responses to future rewards, we compared performance under a condition in which reward information could lead to strategic performance adjustments to performance under a condition preventing strategic performance adjustments. To do so, we presented the reward information either for a relatively long duration, rendering this information clearly visible, or we presented the reward information too briefly to be consciously perceived. Previous work suggests that very brief presentation of reward information leads to so-called initial reward processing , which is rather rudimentary and very quick, and can unconsciously boost task preparation and performance. However, only full reward processing, which relies on prolonged presentation of reward information, allows for strategic performance adjustments. Indeed, a number of studies has shown that both very short (i.e., 17 ms) and relatively long (i.e., 300 ms) presentation of high (versus low) rewards boost performance on various cognitive and physical tasks . However, only the longer presentation was shown to elicit strategic responses (for a review see Bijleveld,). For instance, in one study, it was found that only relatively long, but not brief reward presentation caused people to make deliberate speed-accuracy trade-offs for high compared to low rewards). Thus, if our hypothesis is true that high rewards for future performance improve intermediate task performance in a non-strategic manner, we should observe a boost in performance on intermediate task performance even when rewards are presented too briefly to be consciously seen.

The present research

To test the effects of future rewards on immediate performance, we used a reaction time task in which we rewarded fast reactions. Specifically, we used an auditory Simon task, in which participants were asked to quickly respond with a right versus left key to the pitch of a tone played through headphones to the right or left ear . We chose this task because it contains an irrelevant stimulus dimension (i.e., the side on which the tone is presented), which renders it demanding in terms of task preparation (e.g., Kane & Engles, 2003; McDonald, 2000), and previous work indicates that task performance under this condition is sensitive to monetary rewards . The irrelevant stimulus dimension also creates congruent trials (i.e., trials on which the side to which the tone is presented matches the to-be-performed response) and incongruent trials (i.e., trials on which the side to which the tone is presented does not match the to-be-performed response). Previous work has found that rewards do not differently speed up responses to congruent and incongruent trials (e.g.,), suggesting that (at least in these kind of tasks) rewards improve task performance through greater task preparation rather than through online adjustments in conflict resolution. Accordingly, we did not expect rewards to differentially affect performance as a function of congruency. Finally, we imposed a demanding response time criterion that had to be met in order to obtain a reward. As explained below, this criterion was included to reveal performance differences between strategic and non-strategic reward processing.

On each trial, we first presented participants with a high (50 cents) or low value (1 cent) coin, followed by a series of two successive tones. The coin was presented between masks, and was shown either very briefly (17 ms) or for a relatively long duration (300 ms). Participants were instructed that rewards could be obtained for sufficiently fast accurate responses (according to a pre-specified response time criterion) to every second tone, while the speed and accuracy of responses to every first tone were irrelevant for obtaining the reward. Because high (vs. low) rewards increase task preparation , and because even before the first tone was presented, participants already knew that they had to respond quickly to the second tone in order to get the reward, preparation for fast responses for high compared to low rewards could take place as soon as the reward was presented . Therefore, we predicted that high (vs. low) rewards would lead to faster responses to both the first and the second tone in a series, even though the first response was not instrumental for the reward.

Because we emphasized the importance of speed by imposing a strict response time criterion for obtaining rewards, we did not predict that high compared to low rewards would also improve the accuracy of rewarded and unrewarded responses. In fact, under the condition where participants were able to strategically adjust performance in reaction to the reward, we predicted the opposite. That is, strategic responding to high rewards should lead to a speed accuracy trade-off—a sacrifice of accuracy for greater speed . Importantly, and in line with our hypothesis that preparation for rewarded future performance affects immediate performance, we predicted that this strategy may already become apparent during intermediate task performance. Therefore, when participants responded strategically to rewards, a speed accuracy trade-off in response to high rewards should occur not only for the second, rewarded tone, but also for responses to the first, unrewarded tone. Because speed accuracy trade-offs induced by high rewards only occur when rewards are presented relatively long and can be fully processed , we did not expect this speed accuracy trade-off in response to high rewards when the reward information was presented briefly.

To sum up, our first hypothesis was that high versus low rewards contingent on fast responses to the second tone in a series of two tones would speed up rewarded responses to this second tone as well as unrewarded responses to the first tone. Furthermore, this speed-up should occur regardless of whether reward information was presented for a relatively long duration, allowing for strategic responses and speed accuracy trade-offs, or very briefly, limiting strategic responding.

Experiment 3

Participants and design

Participants were 91 university students (64 women) with a mean age of 20.49 (*SD* = 2.39). The design was a within-subjects design with the factors reward (high vs. low), exposure (long vs. short), and congruency of the ear–response key combinations (congruent vs. incongruent). Reward and exposure varied randomly over trials (i.e., a trial involved presentation of two tones), and the factor congruency varied randomly for both the first and the second tone within a trial. Dependent measures were reaction times (RTs) and accuracy of responses to the first tone and to the second tone.

Materials and methods

The experimental task was programmed and run using the software package e-Prime 1.2 (Psychology Software Tools Inc., Pittsburgh, Pennsylvania, USA; see). The timing of stimulus presentation was synchronized with the vertical retraces of a 60-Hz monitor, resulting in a vertical refresh rate of 16.67 ms.

Procedure

Participants performed an auditory Simon task , in which they were presented repeatedly with series of high and low pitch tones. For each tone, participants were asked to indicate with a right or left key on the keyboard whether the tone was of high or low pitch (the assigned keys were counterbalanced between participants). Participants were instructed that they would repeatedly be presented with a series of two consecutive tones, and that they could obtain monetary rewards for very fast correct responses on each second tone in a series. They were further told that responses to each first tone in a series were irrelevant for obtaining rewards. To emphasize the need for fast responding, rewards could only be earned if responses to the second tone on a trial did not exceed a pre-specified response time (RT) criterion of 350 ms. The time for this RT criterion was set below the average RT found in previous studies employing this task (e.g.,), and was based on pilot data showing that this criterion yielded about 75% sufficiently fast responses on rewarded trials.

To familiarize participants with the task setup and the RT criterion, participants were given a practice round. The setup of the practice round was identical to the experimental task (see below). All participants completed at least one practice block consisting of 10 trials. If participants did not meet the RT criterion on any trial in this practice block, they performed additional practice blocks of each 5 trials until they met the RT criterion on each trial.

The experimental task consisted of 32 trials. Each trial started with an empty screen shown for 1000 ms, followed by the presentation of a reward in the form of a coin of either 1 cent or 50 cents, which was presented for either 300 ms (supraliminal condition) or 17 ms (subliminal condition). The coins were preceded by a pre-mask presented for 1000 ms and followed by a post-mask for 600 ms minus the duration of the presentation time of the coin. The coins and masking stimuli are depicted in Figure 3.1.

To verify that the coins in the short presentation condition were presented too quickly to be consciously visible, limiting the opportunity for strategic responding (see), a subliminality test was performed: An independent sample of 31 participants were presented with 1 cent and 50 cents coins shown for 17 ms with a pre mask and a post mask, following the same procedure as in the experiment. Participants were asked to indicate for each coin whether they had seen a 1 cent or 50 cents coin. A t-test confirmed that identification of the coins was at chance (M = 0.52, SD = 0.12), t (30) = 0.79, p = .44.

In the experimental task, after the presentation of the coin, a black screen with three horizontally positioned gray circles was presented for 490 ms. Next, a green flash appearing in the middle circle served as a warning signal for the first upcoming tone. 1000 ms after this warning signal, the first high (500 Hz) or low pitch (200 Hz) tone was played for 250 ms. The tone was followed by a response window of 1000 ms, in which participants could respond with a key press. If the RT exceeded 1000 ms, the task continued automatically. Visual response feedback was given via a red flash for 100 ms in the (left or right) circle corresponding to the side of the response. Next, a blank screen was presented for the duration of 1500 ms minus the RT for the first tone. The purpose of the flexible timing of this interval was to ensure that the second tone would occur at a fixed time after the reward information, regardless how fast participants responded to the first tone. After this interval, a second warning signal and a second tone were presented, following the same procedure as before, and again followed by an identical response window and response feedback. Finally, after the second response, performance feedback was shown for 1300 ms, informing the participant about the amount of reward (0, 1, or 50 cents) received for their response to the second tone. This marked the end of a trial. For an overview of the task procedure, see Figure 3.1.

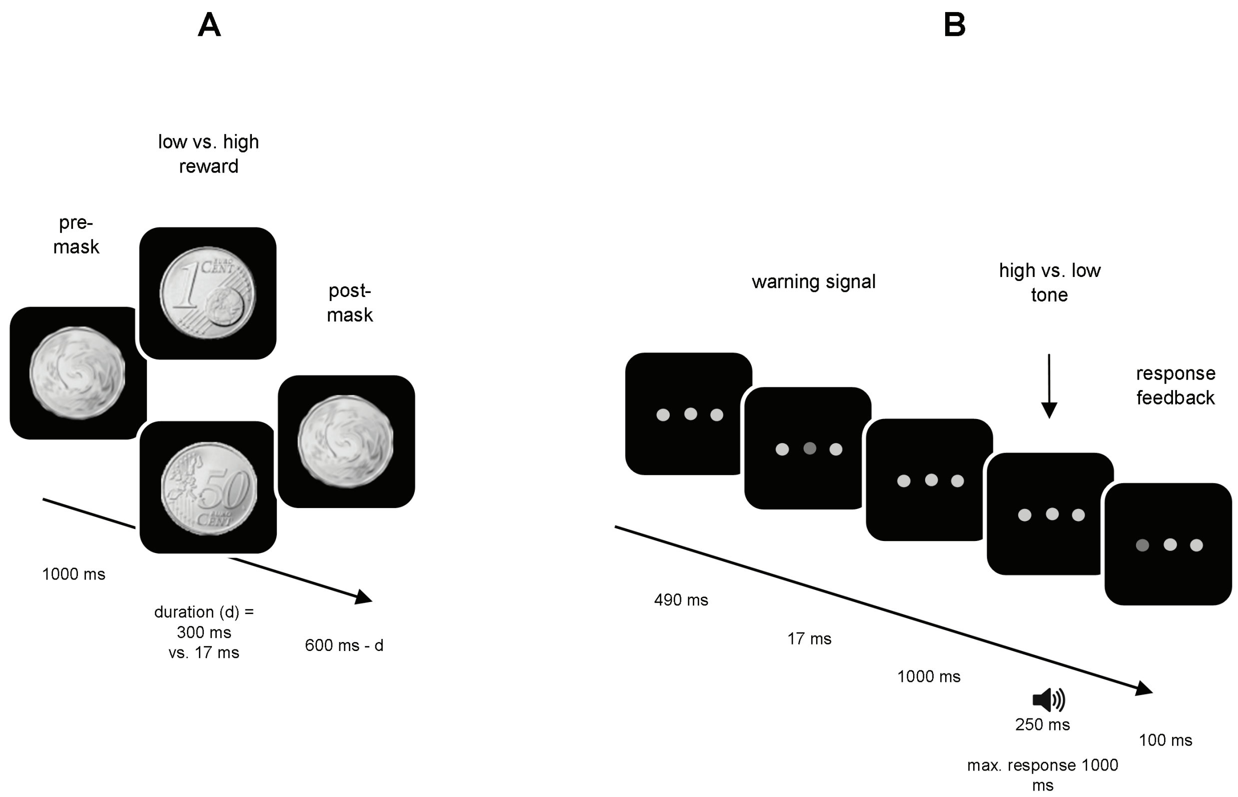

Figure 3.1. Schematic overview of the experimental task. Each trial started with the presentation of a reward, sandwiched between a pre- and a post-mask (A), followed by two repetitions of the auditory Simon task (2 x B). Between the two repetitions, a blank screen was presented for the duration of 1500 ms minus the time of the response to the first tone (if the response time exceeded 1500 ms, the task would continue automatically).

After the task, participants were asked to answer two questions concerning the experimental task. The first question served as an instruction check. Specifically, participants were asked whether they had been aware that the rewards presented during the task could be earned for fast and correct responses to the *second* but not the *first* tone of a trial. Answers were given on a scale from 1 (“no not at all”) to 7 (“yes, very much”). Second, participants were asked whether, for each tone they had heard, it was clear whether it had been the first or the second in a series of tones. Answers were given on a scale from 1 (“no, never”) to 7 (“yes, every time”). After answering these questions, participants were thanked for their participation and dismissed.

Results

To test our experimental hypotheses, we first present the results for the second, rewarded tone and the first, unrewarded tone separately. Then, we present an analysis examining the effects on both tones in one design in order to compare them. Finally, we present analyses involving the post-experimental questions in order to rule out potential alternative explanations.

Performance in response to the second, rewarded tone

Response times. RTs from incorrect responses (M = 12.29%, SD = 13.05) were removed from the response time analyses. Responses that were correct but exceeded the RT criterion of 350 ms, and were thus not rewarded (M = 27.44%, SD = 24.66%), were included in the analysis. (See below for additional analyses without RTs exceeding 350 ms). An initial repeated-measures ANOVA with the factors reward, exposure, and congruency yielded a congruency effect, entailing that responses to congruent ear-response key combinations (M = 296.87, SD = 54.49) were faster than those to incongruent combinations (M = 277.97, SD = 59.18), F (1, 74) = 110.69, p < .001, η_p^2 = 0.60. Congruency did not interact with any of the other factors (all Fs < 1.25). Because the removal of incorrect responses for some participants led to empty cells in the design, and hence reduced the power of the analysis, in the following analyses data were collapsed over the factor congruency.

A repeated-measures ANOVA with the factors reward and exposure yielded the predicted main effect of reward, F (1, 90) = 12.59, p = .001, η_p^2 = 0.12, showing that, when fast responses were rewarded, high (M = 313.33, SD = 55.31) compared to low (M = 326.55, SD = 62.34) rewards led to faster responses (see Figure 3.2). There was no main effect of exposure, F (1, 90) = 2.49, *n.s.*, and no interaction of reward × exposure,

F (1, 90) = 1.39, *n.s.,* indicating that response speed did not differ for relatively long and briefly presented reward information.

Because performance was only rewarded when RTs were correct and below 350 ms, we repeated the above reported analyses after excluding incorrect responses as well as responses exceeding 350 ms. (Note that exclusion of these RTs led to empty cells for a number of participants, and thus reduced the number of participants in the analyses.) The results were similar to those reported above. Specifically, a repeated-measures ANOVA with the factors reward and exposure yielded a main effect of reward, F (1, 81) = 8.37, p = .005, η_p^2 = 0.09 (high rewards: M = 300.81, SD = 39.00; low rewards: M = 311.51, SD = 39.24) but no main effect of exposure, F (1, 81) = 1.21, *n.s.*, and no interaction of reward × exposure, F (1, 81) = 0.38, *n.s.*

Accuracy. Accuracy scores were first subjected to a repeated-measures ANOVA with the factors reward, exposure and congruency. This yielded a main effect of congruency, F (1, 90) = 49.60, p = .001, η_p^2 = 0.36, indicating that participants made less incorrect responses for congruent (M = 0.90, SD = 1.15) than incongruent ear-response key combinations (M = 3.03, SD = 2.53). Congruency did not interact significantly with any of the other factors (all Fs < 1.41), so we again collapsed over congruency in the following analyses.

A repeated-measures ANOVA with the factors reward and exposure yielded no main effect of reward, F (1, 90) = 1.34, p = .25. There was, however, a main effect of exposure, F (1, 90) = 4.57, p = .04, η_p^2 = 0.05, indicating that participants made more incorrect responses on trials with long (M = 2.21, SD = 2.47) compared to short reward presentation (M = 1.73, SD = 2.22). This effect was qualified by an interaction of exposure × reward, F (1, 90) = 6.61, p = .01, η_p^2 = 0.07 (See Figure 3.3). Simple effects analyses showed that when rewards were presented for a relatively long duration, high rewards (M = 1.33, SD = 1.69) led to more incorrect responses than low rewards (M = 0.88, SD = 1.32), F (1, 90) = 6.10, p = .02, η_p^2 = 0.06. For briefly presented rewards, this effect was absent, F (1, 90) = 1.05, *n.s.* (high rewards: M = 0.78, SD = 1.24; low rewards: M = 0.95, SD = 1.46).

Performance in response to the first, unrewarded tone

Response times. To test our hypothesis that rewards for quick responses to each second tone in a series would increase the speed of responses to *preceding* tones, we subjected RTs of each first, unrewarded tone to a repeated-measures ANOVA with the factors reward, exposure, and congruency. RTs from incorrect trials (M = 12.77%, SD = 10.95%) were removed from the analysis. The analysis yielded the typical congruency effect (RTs for congruent combinations: $M = 381.22$, $SD = 94.80$; RTs for incongruent combinations: $M = 440.74$, $SD = 87.76$), $F(1, 84) = 119.63$, $p < .001$, $\eta_p^2 = 0.59$). Again, congruency did not interact with any of the other factors (all $Fs < 1.34$). Thus, we again collapsed over congruency in the following analyses.

A repeated-measures ANOVA with the factors reward and exposure yielded the predicted main effect of reward, $F(1, 90) = 8.84$, $p = .004$, $\eta_p^2 = 0.09$, indicating that even when performance was not rewarded, high ($M = 403.13$, $SD = 93.04$) compared to low rewards ($M = 417.59$, $SD = 94.81$) for fast responses to later tones sped up intermediate responses (see Figure 3.2). Again, there was no interaction of reward x exposure, $F(1, 90) = 0.21$, *n.s.*

Accuracy. As for the rewarded responses, a repeated-measures ANOVA with the factors reward, exposure and congruency on accuracy scores showed a main effect of congruency, $F(1, 90) = 8.05$, $p = .006$, $\eta_p^2 = 0.08$, indicating that participants again made less mistakes for congruent ($M = 1.65$, $SD = 1.61$) than incongruent ear-response key combinations ($M = 2.44$, $SD = 2.66$). Congruency did not interact with any of the other factors, (all Fs < 3.10), so we again collapsed over this factor in further analyses.

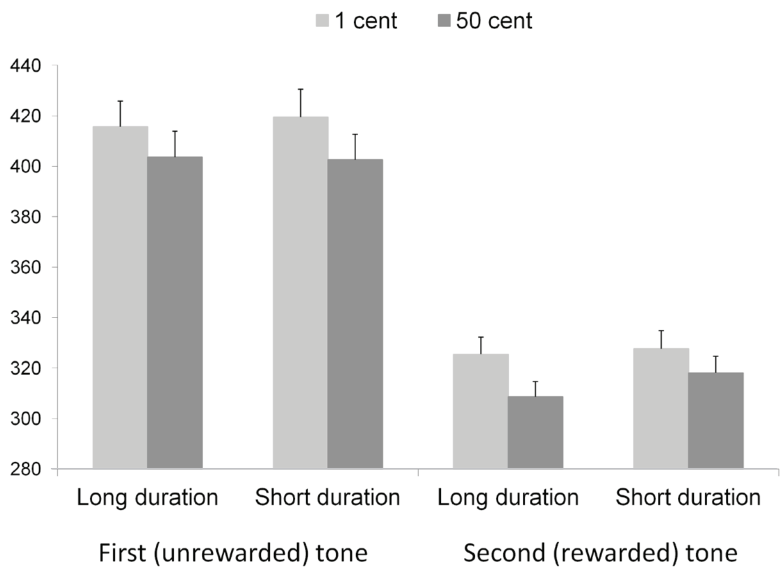

Figure 3.2. Mean reaction times of responses to the first (unrewarded) and second (rewarded) tone in a series as a function of reward value and reward presentation duration. Error bars represent standard errors.

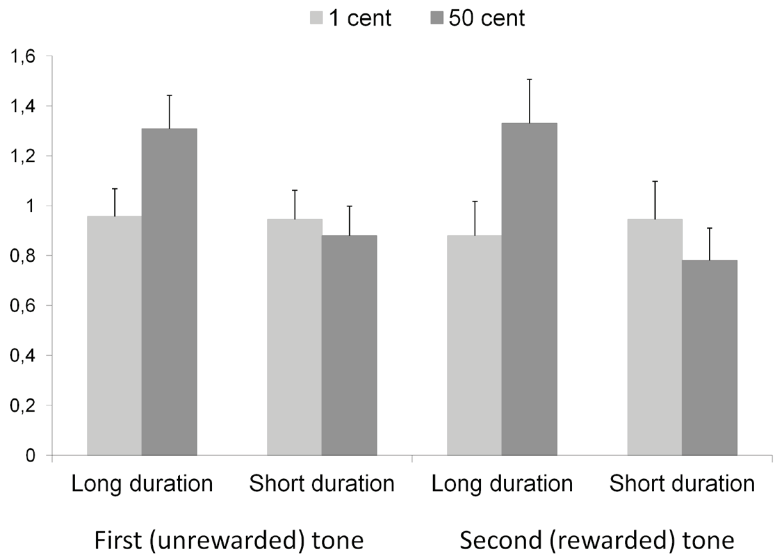

Figure 3.3. Mean number of incorrect responses to the first (unrewarded) and second (rewarded) tone in a series as a function of reward value and reward presentation duration. Error bars represent standard errors.

A repeated-measures ANOVA with the factors reward and exposure revealed a main effect of exposure, F (1, 90) = 4.57, p = .04, η_p^2 = 0.05, indicating that participants made more incorrect responses when rewards were presented relatively long (M = 2.26, SD = 2.07) compared to when they were presented briefly (M = 1.82, SD = 1.83). Moreover, we again found an interaction of exposure × reward, F (1, 90) = 6.61, p = .01, η_p^2 = 0.07 (see Figure 3.3), which showed that when rewards were presented relatively long, high rewards (M = 1.31, SD = 1.28) led to more incorrect responses than low rewards (M = 0.96, SD = 1.07), F (1, 90) = 8.67, p = .004, η_p^2 = 0.09. This effect was again absent for briefly presented rewards, F (1, 90) = 0.23, *n.s.* (high rewards: M = 0.88, SD = 1.13; low rewards: M = 0.95, SD = 1.11).

Performance in response to the first and second tone

Response times. To directly compare the effects of rewards on performance on the first, unrewarded, and the second, rewarded tone, we performed an additional repeated-measures ANOVA including the factors reward, exposure, and tone (first vs. second) on RTs of correct responses to the first and second tone. This yielded a main effect of tone indicating that RTs were generally faster in response to the second, rewarded tone (M =

319.94, *SD* = 56.19) compared to the first, unrewarded tone (*M* = 410.36, *SD* = 91.02), *F* (1, 90) = 182.00, $p < .001$, $\eta_p^2 = 0.67$ (see Figure 3.2). Moreover, as for the separate analyses for the two tones, there was a main effect of reward, *F* (1, 90) = 18.00, $p < .001$, $\eta_p^2 = 0.17$, and no interaction of reward × exposure, *F* (1, 90) = 0.03, *n.s.* Follow-up analyses further confirmed that the main effect of reward was significant regardless whether the reward was presented relatively long, *F* (1, 90) = 9.87, $p = .002$, $\eta_p^2 = 0.10$, or briefly, *F* (1, 90) = 7.04, $p = .009$, $\eta_p^2 = 0.07$. Thus, even though participants responded faster to rewarded than unrewarded tones, reactions to the two tones were influenced in the same way by the long and briefly presented rewards.

Accuracy. The same analysis was performed on accuracy scores for both tones. This yielded no main effect of trial, *F* (1, 90) = 0.45, *n.s.,* but, as was found for the separate analyses for each tone, there was a main effect of exposure, *F* (1, 90) = 5.89, $p = .02$, $\eta_p^2 = 0.06$, and an interaction of exposure × reward, *F* (1, 90) = 7.69, $p = .007$, $\eta_p^2 = 0.08$. This interaction was not qualified by a three-way interaction of exposure × reward × trial, *F* (1, 90) = 1.26, *n.s.* This shows that the differential effects of long versus briefly presented rewards reported above did not differ for reactions to rewarded compared to unrewarded tones.

Post-Experiment questions

To examine whether the effects reported above might have been caused by possible confusion about the task instructions, we first explored participants' answer to the question whether they were aware of the instruction that rewards were contingent on responses to the second but not the first tone. The average score on this question was 5.73 (*SD* = 1.73; 7-point scale). Although this score is quite high, not all participants provided the maximum score. This could mean that for some participants the instructions were not completely clear. However, it is also possible that posing the question evoked confusion or the suspicion that the first tone had been relevant for the reward after all, causing participants who had clearly understood the instructions to call their understanding into question. To make sure that the results were not caused by some participants' insufficient understanding of the instructions, we repeated the above reported analyses, now including participants' answer to this instruction question as a factor ("instruction") using a median split. This allowed us to compare the above effects in a group of participants scoring below 7, for whom we cannot be absolutely certain that they were sufficiently aware of the instructions (mean score = 4.53; *SD* = 1.68; N = 47), to those in a group of participants who scored 7, indicating that they were clearly aware of the instructions (N = 44). Results showed that the factor instruction did not significantly interact with any of the effects of long and briefly presented rewards on response speed and accuracy for responses to both tones (e.g., reward by instruction interaction on reaction times, $F = 0.17$).

Next, we analyzed participants' answers to the question whether it was clear that a tone was the first or second in a trial. The average score was 6.35 ($SD = 1.06$; 7-point scale). This high score indicates that participants were generally not confused about which of the tones was the rewarded one. To provide more evidence for this postulation, we again repeated the above reported analyses on the effects of long and briefly presented rewards on performance on the first and second tone, now including participants' answer to this tone-identification question as a factor using a median split. Again, this yielded one group scoring below 7 (mean score = 5.36; $SD = 1.10$; N = 36), and one group scoring 7 (N = 55). The results showed that tone identification did not interact with any of the effects reported above (e.g., reward by tone-identification interaction on reaction times, $F = 0.24$).

Discussion

Based on evidence that rewards enhance performance by increasing task preparation, and that preparation starts before people actually engage in the execution of a task, the present study tested the novel hypothesis that rewards contingent on future performance lead to immediate performance enhancement on an intermediate task. We tested this hypothesis by offering relatively high and low value monetary rewards for fast responses to each second tone presented in a series of two tones. Crucially, we found that higher rewards sped up not only responses to the second tone, but also responses to the first tone in the series—despite the fact that these earlier responses were unrelated to obtaining the rewards. To our knowledge, this is the first study showing that rewards for future task performance increase performance immediately.

Furthermore, the present data show that the effects of future rewards on immediate performance occurred both when reward information was presented long enough to enable strategic performance adjustments, and when reward information was presented too quickly to be consciously perceived, thus limiting strategic performance adjustments. Importantly, a comparison of the accuracy data for long and short reward presentation durations revealed that participants indeed responded more strategically to rewards when these were presented for a longer duration. This strategic responding became apparent in a speed accuracy trade-off in response to high rewards. This finding conceptually replicates previous work, which also showed speed accuracy trade-offs under conditions of long but not short reward presentation. What is new and particularly interesting about this finding is that the speed accuracy trade-off for long-presented high rewards occurred for both rewarded and unrewarded responses. This suggests that when people prepare a strategy for highly rewarded future performance, this strategy already becomes apparent during intermediate task performance.

As a potential alternative explanation for these effects, one may propose that participants in the current experiment responded in the same way to rewarded and unrewarded tones because they were not aware which tones were rewarded. We can rule out this alternative explanation on several grounds. First, an analysis of the full design showed that, while rewards had similar effects on rewarded and unrewarded task performance, overall responses were much slower for unrewarded than rewarded tones. This suggests that people did not try to perform particularly well on the unrewarded intermediate task. However, the overall slower unrewarded responses may in some way be attributable to the task setup. After all, unrewarded responses always preceded rewarded responses. And indeed, there is evidence from one study, also using an interference task, showing that when participants are presented with series of two consecutive stimuli intermitted by irrelevant neutral information, responses are faster for the second than for the first stimulus . Thus, the slower responses to unrewarded tones in the present study alone are not sufficient to rule out the alternative explanation that participants were confused about which responses were rewarded. However, the data from our post-experiment questions indicate, first of all, that participants were well aware of which responses were rewarded and which ones were not. Moreover, analyses including participants' answers to questions regarding the reward contingencies showed that differences in participants' awareness of the reward-contingencies cannot account for the pattern of results observed in this experiment.

It is interesting to note that the performance-boosting effects of future rewards on immediate performance in this study did not differ as a function of congruency. The observation that rewards do not reduce congruency effects on response times has been found before (e.g.,). This result is consistent with the notion that in response time tasks such as the one employed here, rewards affect performance via task preparation rather than via online-adjustments once response-relevant stimuli are encountered . Another explanation for why rewards did not reduce the congruency effect in the current study may be the application of a strict and specific reward criterion based on response speed, which led to the specific improvement of response speed but not of other control processes. This argument is in line with research showing that when rewards are provided for a specific task dimension, only performance on that dimension is improved.

The finding that rewards for future performance non-strategically enhanced immediate performance on an intermediate task has interesting and important implications for the ongoing discussion about the effectiveness of different incentive schemes. Tying monetary incentives to specific tasks has powerful effects on performance. However, researchers warn that such incentive schemes, when applied in a work context, can harm performance in the long run, because they lead to underperformance on unrewarded tasks (e.g.,). The present study provides a more nuanced view on this idea. While our data confirm previous studies showing that rewards improve performance selectively for rewarded task dimensions , rewards appear to improve performance much less selectively when reward contingencies refer to timing – *when* performance is rewarded. Thus, promising rewards for performance on a specific task at a later time may prove an effective and efficient tool to raise immediate performance along the way.

An interesting question for follow-up research concerns potential limitations to the effects of future performance rewards on intermediate performance. For instance, it may be that these effects depend on the similarity between the intermediate task and the rewarded task. In the present study, the intermediate task was identical to the rewarded task. This setup resembles everyday life and work contexts where people are confronted with repetitive work. However, it is possible that rewards for future performance do not affect performance on an intermediate task in the same way when this task requires very different kinds of responses. We argue that the effect of future rewards on immediate performance is the result of preparation for the rewarded task. Preparation for one type of action likely does not facilitate *any* kind of action in an intermediate task. However, the boundary conditions of this preparation effect are difficult to assess. This is because even when tasks differ considerably, there is usually some degree of overlap in the processes required for good task performance. For instance, even when two tasks involve very different motor responses to different stimuli under different instructions, preparation for good performance on one task does not only include preparing the respective motor responses, but also processes such as the recruitment of executive control, effort, and concentration; processes that probably benefit both tasks. Thus, more research is needed to delineate the conditions under which future rewards affect intermediate task performance.

To conclude, as with any novel finding, the present study raises many new questions. Nonetheless, the present study is the first to show that the promise of future rewards boosts performance immediately, even when people know that immediate performance is not rewarded. More broadly, the present study suggests that the time course of reward effects on performance may prove a fruitful area for further investigation, and that reward effects in general may be more ubiquitous than was previously thought.

Chapter 4

You can't always get what you want — The role of consciousness in integrating reward value and attainability information

Research has shown that high versus low value rewards improve cognitive task performance independent of whether they are perceived consciously or unconsciously. However, efficient performance in response to high value rewards also depends on whether or not rewards are attainable. This raises the question of whether unconscious reward processing enables people to take into account such attainability information. Building on a theoretical framework according to which conscious reward processing is required to enable higher level cognitive processing, the present research tested the hypothesis that conscious but not unconscious reward processing enables integration of reward value with attainability information. In two experiments, participants were exposed to supraliminally and subliminally presented high and low value coins serving as rewards on a working memory task. Crucially, rewards were expected to be attainable or unattainable. Requirements to integrate reward value with attainability information varied across experiments. Results showed that when integration of value and attainability was required (Experiment 4.1), supraliminal reward presentation led to efficient performance, i.e., selectively improved performance for high value attainable rewards. In contrast, in the subliminal presentation condition, performance was increased for high value rewards even when these were unattainable. This difference between the effects of supraliminally and subliminally presented rewards disappeared when integration of value and attainability information was not required (Experiment 4.2). Together these findings suggest that unconsciously processed reward information is not integrated with attainability expectancies, causing inefficient effort investment.

This chapter is based on Zedelius, C. M., Veling, H., & Aarts, H. (2012). When unconscious rewards boost cognitive task performance inefficiently: The role of consciousness in integrating value and attainability information. *Frontiers in Human Neuroscience Research, 6,* 219.

Motivation is an essential determinant of cognitive control and performance (Watanabe, 2007). Accordingly, a vast body of research has studied how rewards affect cognition and behavior (Wood, Atkins, & Bright, 1999). Whereas the neuro-cognitive processes underlying the effects of rewards on human cognition and behavior are not yet entirely understood (Chiew & Braver, 2011), it has become clear that the anticipation of rewards can cause people to increase their effort and performance on various cognitive and behavioral tasks (Bonner & Sprinkle, 2002; Brehm & Self, 1989; Camerer & Hogarth, 1999).

Most research on the effects of rewards on the control of cognition and behavior has focused on consciously communicated rewards. In these studies people are fully aware of the specific reward that can be gained through optimal performance on a task. However, research on unconscious processes in the motivation and control of goal-directed behavior challenges the assumption that conscious awareness of rewards is necessary to boost performance of cognitive control or working memory (WM) processes (Bargh, Gollwitzer, & Oettingen, 2010; Custers & Aarts, 2010; van Gaal, Lamme, & Ridderinkhof, 2010; Hassin, Bargh, Engell, & McCulloch, 2009; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001). For instance, studies have shown that high compared to low rewards boost performance on WM tasks even when they are presented unconsciously (for a review see Bijleveld et al., 2012-b). This intriguing finding offers a new direction to understanding how rewards affect the control of human cognition and behavior, raising the question of whether conscious reward processing plays a unique role in modulating cognitive performance. In the present study, we aim to explore this issue by investigating how people deal with attainable and unattainable monetary rewards when such rewards are consciously or unconsciously processed.

It has long been recognized that presenting valuable rewards does not necessarily improve task performance (e.g., Brehm & Self, 1989; Hull, 1943). An important factor in determining whether a reward will boost performance is whether the reward is perceived as attainable. Studies addressing the expected value analysis of human decision making have found that when attainability information is provided, people no longer base their decisions to invest effort on the reward value alone, but on the combination of value and attainability (Atkinson, 1957, 1964; Bonner & Sprinkle, 2002; Brehm & Self, 1989; Camerer & Hogarth, 1999; von Neumann & Morgenstern, 1947; Vroom, 1964). Performance increases when a reward is both valuable and attainable, but is reduced whenever a reward is of low value or unattainable. This finding is consistent with the general notion that people are conservative in spending their valuable mental resources (Gendolla, Wright, & Richter, 2012; Kool, McGuire, Rosen, & Botvinick, 2010). Thus, from the above studies, it appears that people readily integrate the value of a reward with attainability information in order to avoid wasting effort. However, participants in these studies were always aware of the value of a reward at stake and the potential influence of this reward on their performance. In light of work suggesting that reward pursuit can occur outside of awareness (for a review see Custers & Aarts, 2010), we investigated the question of how cognitive performance is affected by the value of an unconsciously perceived reward in a context where the reward is unattainable.

Recently, researchers have developed an experimental paradigm that allows the examination of this question. In this paradigm, participants are presented with coins of high and low value which can be attained as rewards for successful performance on a task. Importantly, on half of the experimental trials the reward is presented unconsciously (i.e., subliminally), whereas the rewards are consciously visible (i.e., supraliminally presented) on the other trials. This procedure enables the direct comparison of the effects of conscious and unconscious reward processing on task performance. Using this paradigm, studies have shown parallel effects of conscious and unconscious reward presentation. For instance, in the first study employing this paradigm (Pessiglione et al., 2007), participants could gain rewards by squeezing a handgrip. Not surprisingly, high versus low value rewards resulted in harder squeezing. Remarkably, people still squeezed harder for more valuable rewards when these were presented subliminally. Other studies have found enhanced mental effort and performance through consciously and unconsciously presented high rewards on executive control and WM tasks, such as active maintenance and updating of ordered information (Bijleveld, Custers, & Aarts, 2009; Bustin, Quidbach, Hansenne, & Capa, 2012; Capa, Bustin, Cleeremans, & Hansenne, 2011). However, there have also been studies showing that conscious and unconscious rewards in some task contexts can lead to different effects (e.g., Bijleveld, Custers, & Aarts, 2010, 2011; Zedelius, Veling, & Aarts, 2011-b, Chapter 5).

A theoretical framework has been proposed to account for both identical and divergent effects of conscious and unconscious rewards on performance. This framework distinguishes initial (or unconscious) reward processing from full (or conscious) reward processing (Bijleveld et al., 2012-b). According to this framework, people initially process rewards in rudimentary brain structures that respond to the value of rewards and boost task performance directly by causing increased recruitment of effort. This process is thought to operate without requiring conscious awareness, which explains why unconsciously perceived rewards can enhance performance. After initial reward processing, when rewards are consciously perceived (e.g., by prolonging the presentation time from subliminal to supraliminal) rewards may be processed more fully, involving higher-level cognitive processing. In line with previous research on conscious and unconscious perception (Dehaene, Kerszberg, & Changeux, 1989), this higher-level cognitive processing is thought to enable more complex cognitive processes and strategic behavioral responses, which could explain why conscious reward processing in some task contexts leads to unique effects.

In experiments, initial (or unconscious) and full (or conscious) reward processing is commonly manipulated by presenting masked reward stimuli (e.g., 1 cent vs. 50 cents coins) either for relatively short (i.e., 17 ms) or relatively long durations (i.e., 300 ms). Subsequent subliminality tests are usually administered to provide evidence that the short presentation of masked reward stimuli renders participants unable to identify the reward value of the stimuli. However, it is questionable whether such tests provide conclusive evidence that short stimulus presentation time prevents conscious perception throughout an experimental task. In fact, there is an ongoing debate about what kinds of subliminality tests are capable of providing sufficient proof for unconscious processing (e.g., see Sandberg, Timmermans, Overgaard, & Cleermemans, 2010; Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008). In the present research, we took a different approach aimed at distinguishing conscious from unconscious reward processing by investigating a situation in which the two types of reward processing are predicted to produce different behavioral effects. Specifically, we test the hypothesis that conscious and unconscious reward value processing differ with regard to taking into account attainability information.

As explained above, when consciously processed rewards vary in attainability, people base their decisions to invest effort on the combination of reward value and attainability. Integration of these two types of information prevents wasting resources on valuable yet unattainable rewards or attainable yet low value rewards (Atkinson, 1957; 1964; Bonner & Sprinkle, 2002; Brehm & Self, 1989; Camerer & Hogarth, 1999; von Neumann & Morgenstern, 1947; Rushworth, & Behrens, 2008; Vroom, 1964). Research suggests that the value of a reward and the likelihood that a reward can be attained are initially encoded by distinct subcortical brain networks (Dreher, Kohn, & Berman, 2006; O'Neill & Schultz, 2010; Rogers et al., 1999), and that the integration of these different signals involves higher cortical processing (Haber & Knutson, 2009; Knutson, Taylor, Kaufman, Peterson, & Glover, 2005; Rushworth & Behrens, 2008; Tobler, O'Doherty, Dolan, & Schultz, 2007). Therefore, based on the framework outlined above, we predicted that the integration of reward value and attainability requires conscious reward processing. Consequently, when the likelihood of conscious processing is reduced (i.e., by short presentation of rewards), people should fail to integrate reward value and attainability information, resulting in inefficient investment of effort and performance.

The notion that conscious information processing allows for greater integration and more flexible behavioral control is central to several information processing approaches to consciousness (Baars, 2002; Dehaene & Naccache, 2001; Dijksterhuis & Aarts, 2010; Morsella & Bargh, 2010). However, empirical studies have thus far found both support for (e.g., Kunde, 2003; Ansorge, Fuchs, Khalid, & Kunde, 2011) and evidence against (e.g., van Gaal, et al., 2010; Hassin et al., 2009; Lau & Passingham, 2007) the hypothesis that conscious information processing plays a unique role in modulating cognitive performance. For instance, studies have shown that subliminally presented stop cues can slow down, but rarely fully inhibit behavioral responses (van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008; van Gaal, Ridderinkhof, van den Wildenberg, & Lamme, 2009). Moreover, unconscious stop cues failed to elicit the same globally-distributed and sustained pattern of brain activation observed in response to consciously perceived cues. This work suggests that although unconsciously perceived cues can trigger basic cognitive control processes, conscious perception may enable more efficient and flexible control of behavior (Dehaene & Naccache, 2001).

The present study aims to shed more light on possible advantages of conscious over unconscious reward processing by focusing not only on the initial triggering of cognitive performance by consciously and unconsciously perceived rewards, but on how integration of rewards with attainability information affects performance. Because reward value and attainability information are two distinct aspects of rewards (Brehm & Self, 1989; Liu et al., 2007; O'Neill & Schultz, 2010; Tobler et al., 2007), we expect that full or conscious processing of reward information is necessary to integrate these two types of information and arrive at efficient performance. To test this novel hypothesis, we report behavioral data from two experiments in which we presented participants with high and low-value rewards (coins of 50 or 1 eurocents, respectively) that were instructed to be either attainable or unattainable by successfully performing an active maintenance task. To manipulate the likelihood of conscious versus unconscious processing, the coins were masked and presented either for relatively long (300 ms) or short (17 ms) durations. We manipulated conscious processing of the reward value rather than of the attainability information in order to connect our research with previous work on conscious versus unconscious reward processing (Pessiglione et al., 2007; for an overview see Bijleveld et al., 2012-b).

Importantly, in order to provide evidence that differences between the effects of long versus briefly presented rewards are not merely caused by the presentation of attainability information, but are due specifically to differences in the ability to integrate the reward value with attainability information, we manipulated the need for information integration across two experiments. As explained below, Experiment 4.1 was designed to make integration a requirement for efficient performance, whereas

Experiment 4.2 was designed to eliminate the necessity of integration for efficient performance. Based on the theory that conscious and unconscious reward processing differ in the ability to integrate value and attainability, we expected that conscious and unconscious reward processing would lead to different effects in Experiment 4.1 but not in Experiment 4.2. We outline the concrete predictions for the two experiments in more detail below.

Experiment 4.1 was designed to establish different behavioral effects of longs versus briefly presented rewards when integrating reward value and attainability is required for efficient responses. This was accomplished by testing performance in response to attainable and unattainable high versus low value rewards in a full within-subject design. Value and attainability are two distinct sources of performance motivation, and hence performance may be increased by higher reward value, or by the fact that a reward is attainable (e.g., Atkinson, 1957, 1964; Bonner & Sprinkle, 2002; Brehm & Self, 1989; Vroom, 1964). However, when both reward value and attainability vary on a trial-by-trial basis, it is essential to integrate on each trial the two sources of motivation to derive at an optimal decision to invest effort (e.g., Anderson, 1971; Brehmer & Joyce, 1988). In this context, we expected that when rewards were presented for a relatively long duration, enabling conscious processing, performance should be enhanced selectively for high value attainable rewards. This result would constitute a conceptual replication of previous work (Atkinson, 1957, 1964; Bonner & Sprinkle, 2002; Brehm & Self, 1989; Camerer & Hogarth, 1999; Vroom, 1964). Examining effects of consciously processed rewards also serves as a control condition to verify that attainability information was clearly and unambiguously processed and that participants were able and motivated to take this information into account.

When rewards are presented for a shorter duration, reducing the likelihood of conscious processing, we predicted a different pattern of results. Without the ability to integrate value and attainability information, participants were expected to invest their effort based either on the high (vs. low) value of a reward, or on the fact that rewards could be attained (vs. not), but not on a combination of both sources of performance motivation. This led to the following predictions: First, the instruction that a reward is attainable versus unattainable should boost performance. Second, the perception of high versus low value rewards should likewise boost performance. Most importantly, without the ability to integrate value with attainability information, perception of high value rewards should boost performance, even when it is clear that the reward is unattainable. In summary, we expected that performance would be boosted independently by the fact that a reward can be attained and the presentation of a high value coin. This should result in main effects of reward value and attainability.

Experiment 4.2 was designed to provide attainability information without requiring trial-by-trial integration with reward value. To do so, we manipulated the attainability of rewards between participants. The idea behind this was that when attainability information constitutes a stable dimension for an individual (cf. Waltz et al., 1999), participants can employ a general response strategy that is valid on every trial without requiring integration of incoming information. More specifically, when rewards are always attainable, participants can respond efficiently based on reward value alone. Likewise, when rewards are always unattainable, the decision to invest effort can be based on this information alone, neglecting the reward value. Hence, in Experiment 4.2, participants were expected to perform better for high versus low attainable rewards regardless of whether rewards were presented for long or short duration (e.g., Pessiglione et al., 2007; Zedelius et al., 2011-b, Chapter 5). Moreover, we expected participants to perform equally well for unattainable rewards, regardless of whether rewards were presented for long or short duration.

Experiment 4.1

Participants and design

Participants were 41 undergraduate students (28 female). A 2 (presentation duration: long vs. short) × 2 (value: low vs. high) × 2 (attainability: attainable vs. unattainable) within-participant design was employed.

Procedure

Participants performed a verbal active maintenance task in which they were asked to actively maintain word spans of 5 one-syllable nouns in WM while inhibiting mild distraction during a short delay interval (see Conway et al., 2005; Zedelius et al., 2011-b, Chapter 5). For an overview of the procedure including pictures of the reward- and masking stimuli, see Figure 4.1. Participants were told that on every trial of the maintenance task, coins were presented that served as rewards for correct responses. Participants were further told that the coins would sometimes be 'difficult to perceive' (referring to the short presentation condition). Furthermore, participants learned that the money would not always be attainable, and that they would be paid the amount of rewards earned on attainable reward trials at the end of the experiment.

Each trial started with the message, "Reward can be attained" or "Reward cannot be attained", presented for 2000 ms. Following a previously developed procedure, a fixation cross was then shown on the screen for 1000 ms, followed by a mask (a scrambled picture of both 1 and 50 cents coins) for 1000 ms, followed by the presentation of a 1 cent or 50 cents coin. The coin was presented for either 300 ms (long presentation condition) or 17 ms (short presentation condition) and followed by a post-mask presented for 600 ms, minus the duration of the coin. Subliminality of the stimuli was tested in a separate detection task with 25 different participants. On each trial, participants saw a coin (1 cent vs. 50 cents), presented in the same way as in the experiment (17 ms in between masks). After each coin, participants indicated the value of the coin. A t-test indicated identification of the coins was no better than chance (M = 0.51, SD = 0.11), t (24) = 0.43, *n.s.* (see Bijleveld et al., 2009 for another subliminality check of this procedure).[1]

After the coin presentation, the target words were presented for 400 ms per word, with an inter-word interval of 200 ms. The presentation of the target words was followed by a delay period during which mildly distracting letter strings were shown for 800 ms each intermitted by intervals of 500 ms. After this delay period, participants were asked to verbally report the target words. Performance was considered correct when all five words were correctly reported. The order in which the words were reported could be arbitrary (see Zedelius, Veling, & Aarts, 2011-a, Chapter 5, for a discussion on the validity of this measure). Finally, accuracy feedback and, for attainable reward trials, the amount obtained was shown. The task consisted of 56 randomly presented trials (7 repetitions per condition). After the experiment, participants were paid the amount of money they had earned throughout the task. The experiment was conducted according to institutional guidelines and approved by the local ethics committee.

Results and discussion

To test our hypothesis that the duration of reward presentation affects the integration of reward value and attainability information, the proportion of correct trials[2] was subjected to a repeated-measures ANOVA according to the experimental design. The analysis revealed a main effect of attainability, $F(1, 40) = 4.63$, $p = .04$, $\eta_p^2 = 0.10$, qualified by the predicted three-way interaction of presentation duration × value × attainability, $F(1, 40) = 6.20$, $p = .02$, $\eta_p^2 = .13$ (see Figure 4.2). To test the hypothesis that in the long presentation condition effort is selectively increased when rewards are both high and attainable, we performed a specific contrast comparing performance on the long presented high value attainable reward trials with performance on the other trials within the long presentation condition. This contrast was significant, $F(1, 40) = 8.07$, $p = .007$, $\eta_p^2 = .17$, indicating that performance was indeed selectively increased

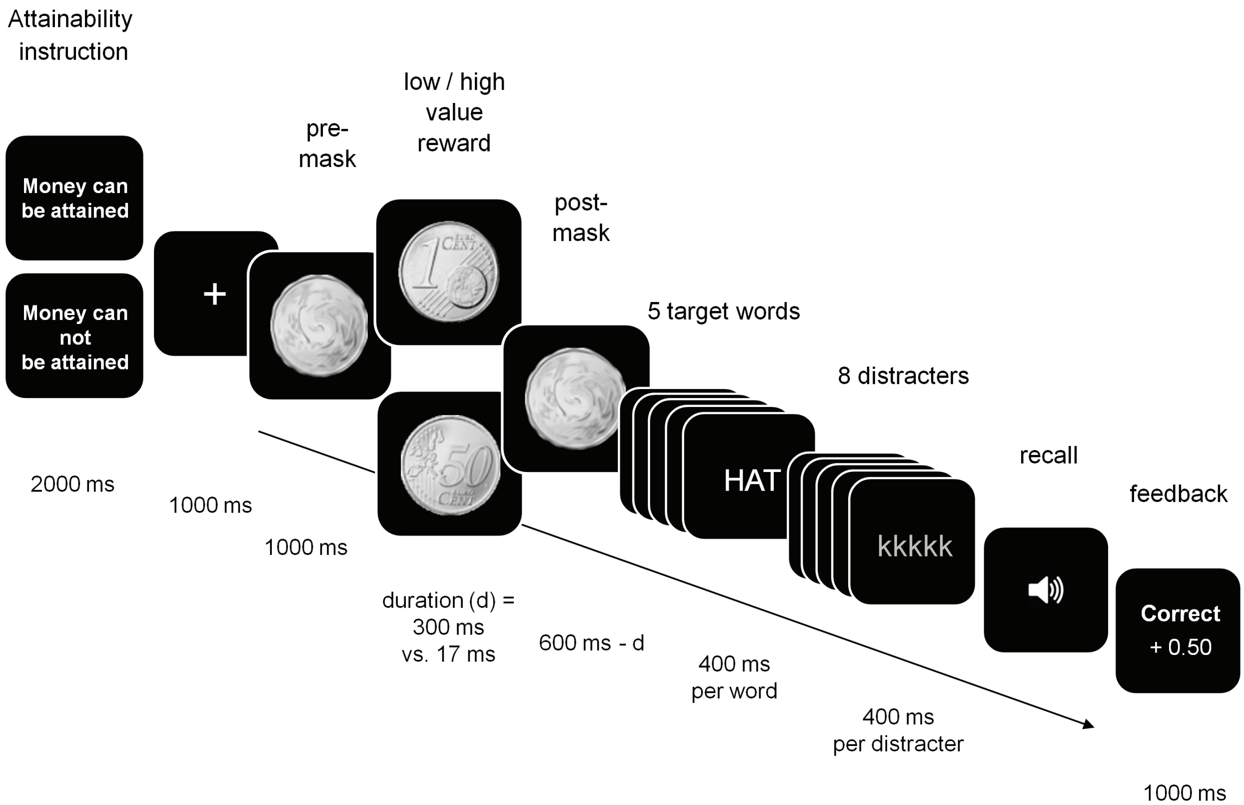

Figure 4.1. Overview of the procedure of Experiment

for high value attainable rewards. This result is in line with classic theories of motivation that predict enhanced effort and performance only when rewards are both valuable and attainable (e.g., Brehm & Self, 1989; Hull, 1943).

In the short presentation condition we expected that reward value and attainability information would boost performance independently, resulting in main effects of reward value and attainability. However, contrary to this prediction, we found no main effect of reward value, $F(1, 40) = 1.25$, *n.s.,* and no main effect of attainability, $F(1, 40) = 2.52$, *n.s.* Instead, we found a marginally significant interaction of reward value and attainability, $F(1, 40) = 3.50$, $p = .07$, $\eta_p^2 = .06$. Further inspection of this interaction with simple effects analyses indicated that performance increased in response to high versus low value rewards when these were unattainable, $F(1, 40) = 4.52$, $p = .04$, $\eta_p^2 = .10$. Thus, consistent with the prediction outlined in the introduction, high reward value of briefly presented coins boosted performance even when the reward was unattainable (note that the clarity of the attainability information can be inferred from the conscious reward condition). Moreover, and consistent with the prediction that the opportunity to obtain a reward would boost performance in the short presentation condition, we found that performance was increased in response to attainable, compared to unattainable low value rewards, $F(1, 40) = 6.31$, $p = .02$, $\eta_p^2 =$ 14.

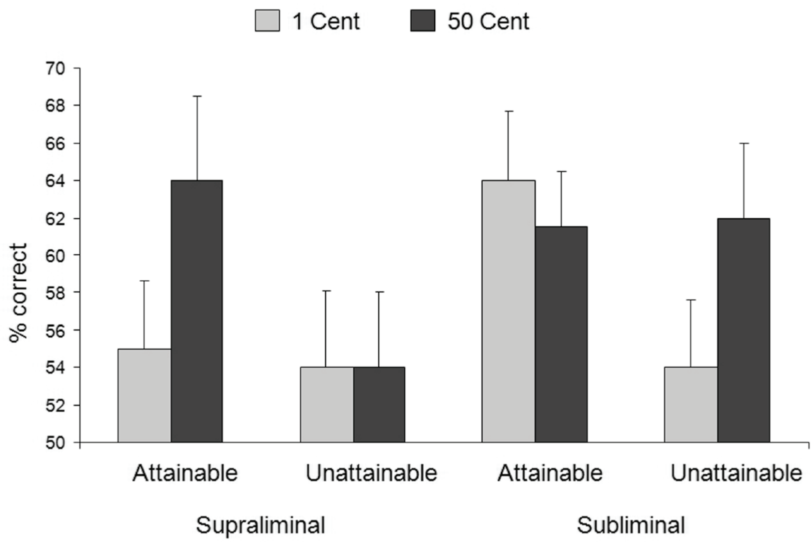

Figure 4.2. Results of Experiment 4.1. Mean and standard error of the percentage of correct trials as a function of reward value, presentation duration, and attainability. Error bars represent standart errors.

However, and contrary to our expectation, we found that performance on attainable reward trials was equally high for both high and low value coins, $F < 1$. The absence of a boosting effect of high value in this latter comparison likely explains why we did not obtain the expected two main effects.

How can we explain the unexpected finding that performance in the briefly presented attainable reward condition was unaffected by the value of the rewards? First, we can rule out that the value of the rewards was not encoded in the short presentation condition. This is attested by the effect of reward value in the briefly presented *unattainable* reward condition. We can also rule out that the absence of an effect of value in the attainable reward condition was merely due to a lack of statistical power. That is, previous research testing the effects of attainable rewards on performance using the same experimental task and procedure (Zedelius et al., 2011-b, Chapter 5, Experiments 5.1 and 5.2; low distraction condition) indicates that the effect of briefly presented rewards is of small to medium size ($d_z = 0.41$; Cohen, 1988). According to a power analysis using the statistical software G*Power 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009), the chance of detecting an effect of this size with a desired statistical power of minimally 0.80 at an alpha level of 0.05 requires a sample of at least 39 participants, which we exceeded in the present experiment.

Accordingly, we think that there may be a theoretical explanation for why performance in the briefly presented attainable reward condition was unaffected by reward value. As argued above, without the ability to integrate reward value and attainability information, the mere fact that a reward is attainable should cause participants to recruit effort to perform well. This hypothesis was confirmed by the fact that performance was boosted in response to low value attainable rewards within the short presentation condition. The question is whether performance can be increased even further by the presentation of an attainable high value reward. The absence of a main effect of value suggests that this may not be possible. One straightforward explanation for the absence of a value effect in this condition is that the mere opportunity to gain a reward already promoted maximal investment of effort, leaving no room for an additive effect of high reward value on performance. This explanation is consistent with other research showing that factors that independently increase motivation for action (e.g., testosterone and reward cues) do not produce additive effects, probably because motivation is already boosted to its limits by one factor alone, minimizing the contribution of a second source of motivation (see Aarts & van Honk, 2009). This argument implies that we should obtain an effect of value when variation in attainability is not a source of performance enhancement. This issue is addressed in Experiment 4.2.

Because this experiment is the first examination of conscious and unconscious reward effects under varying attainability conditions within the same task, one question that comes to mind is whether performance in response to attainable and unattainable rewards was influenced by reward attainability on the previous trial. Although we did not predict this, it is an interesting possibility that should be taken into account in light of evidence for performance adjustments instigated by specific trial sequences (e.g., Ansorge et al., 2011; Boy, Husian, & Sumner, 2010; Kunde, 2003). Therefore, we explored whether attainability sequence (i.e., whether attainability on trial n was the same vs. different from trial n-1) affected the results reported above. Specifically, we performed an additional repeated-measures ANOVA with the factors reward value, presentation duration, attainability, and attainability sequence. The results showed no main effect of attainability sequence, and no interaction effects of attainability sequence with any of the above reported factors (all *F*s < 1.14). These findings indicate that the differential effects of attainable and unattainable rewards were not affected by the presence or absence of the chance to attain a reward on the previous trial.

Another question that may be raised is whether different effects of long versus short presentation of attainable and unattainable rewards may be driven by feedback learning. Although participants received accuracy feedback on all trials, feedback about the amount of reward obtained could only be given on attainable reward trials. Could differences in feedback between the attainable and unattainable conditions account for the effects reported above? We do not expect this for a number of reasons: First, we used reward stimuli that were familiar to participants from everyday life so that the reward value likely did not require learning. Second, on attainable reward trials, the coins presented at the beginning of a trial were 100% indicative of the amount of reward to be earned given optimal performance. Thus, and unlike in some other studies (e.g., Bjork & Hommer, 2007; Dreher et al., 2006; Knutson et al., 2005; Tobler et al., 2007), there was no ambiguity about the amount that could be earned on each trial. Moreover, an explanation in terms of added learning on attainable reward trials would be inconsistent with the finding that the briefly presented high versus low rewards selectively increased performance in the unattainable reward condition, where no feedback was given about the reward value. However, to statistically rule out that learning played a role in driving the above effects, we performed an additional analysis including factors of the experimental design and the additional factor block (i.e., first vs. second half of the trials). The results showed that block did not interact significantly with any of the reported effects, and, most importantly, it did not qualify the above mentioned three way interaction of reward value, presentation duration, and attainability, $F(1, 40) = 1.57$, *ns.* Consequently, differences in feedback learning from attainable and unattainable reward trials do not seem to account for different effects of long versus briefly presented attainable and unattainable rewards.

If our predictions outlined in the introduction are correct, and conscious compared to unconscious reward processing enables greater integration of value and attainability information, differences between the effects of conscious and unconscious rewards should vanish when people do not need to integrate this information. To test this hypothesis in Experiment 4.2, we varied attainability information between, rather than within, participants such that the rewards were either always attainable or always unattainable. When rewards are always attainable, only the value dimension is important to boost performance, and no information integration is required. Therefore, we predicted performance to be enhanced by both long and short presentation of high compared to low value attainable rewards. In contrast, when rewards are always unattainable, and thus never worth the effort, incoming information about the reward value becomes irrelevant. In this case, neither kind of reward should affect performance.

Experiment 4.2

Participants and design

Participants were 33 undergraduates (24 female). The design was a 2 (presentation duration: long vs. short) x 2 (value: low vs. high) x 2 (attainability: attainable vs. unattainable) mixed design with duration and value as within-participant factors and attainability as between-participants factor.

Procedure

The same WM task was used as in Experiment 4.1, with the only difference that reward attainability instructions varied between participants. In the attainable reward condition, participants were told that the coins displayed throughout the task were rewards that could be attained for accurate performance. In the unattainable reward condition, participants were told that the coins had functioned as rewards for performance in a previous experiment, but that in this experiment the rewards were unattainable. In this condition, participants received a flat rate of 5 € for their participation in the experiment. The experiment was conducted in accordance with institutional guidelines and approved by the local ethics committee.

Results and discussion

The proportion of correct trials was subjected to an ANOVA according to the design. There were no main effects of presentation duration, $F(1, 31) = 1.15$, $p = .29$, reward value, $F(1, 31) = 2.16$, $p = .15$, or attainability, $F<1$. However, we did find the predicted interaction between value and attainability, $F(1, 31) = 5.62$, $p = .02$, $\eta_p^2 = 0.15$. This interaction was not qualified by a three-way interaction with presentation duration, $F < 1$. Simple effects analyses showed, first that when rewards were attainable, both long and short presentation of high compared to low value rewards increased performance, $F(1, 31) = 6.75$, $p = .01$, $\eta_p^2 = 0.18$ (see Figure 4.3). This finding is a direct replication of previous studies (e.g., Bijleveld et al., 2010; Capa, Bustin et al., 2011; Pessiglione et al., 2007; see also Zedelius et al, 2011-b, Chapter 5). This replication is particularly important in light of the unexpected finding from Experiment 4.1 that performance for briefly presented attainable rewards was unaffected by the reward value. As argued above, in a context of varying opportunity to attain rewards (Experiment 4.1), the instruction that a reward was attainable caused participants to invest maximal effort in response to briefly presented low value rewards, leaving no room for further improvement by high reward value. The present findings from the second experiment show that the performance boost for briefly presented low value attainable rewards does not occur when attainability is a fixed factor within participants.

The results further showed that, when rewards were unattainable, performance for both long and briefly presented rewards was unaffected by the reward value, $F < 1$. This finding confirms our prediction that short presentation of unattainable high value rewards does not lead to enhanced performance when integration of reward value and attainability information is unnecessary for efficient responding. When it is clear that rewards are never attainable, and hence high value rewards are never worth investing extra effort, people can employ the same general and predefined response strategy throughout the task. That is, they can prepare to ignore the value of rewards even before the rewards are presented. Such a strategy might alter their perception of the rewards such that high value rewards are no longer perceived as valuable or rewarding (Delgado, Gillis, & Phelps, 2008; Staudinger, Erk, Abler, & Walter, 2009). As such, results of Experiment 4.2 converge well with work showing that when rewards are irrelevant for behavioral responses, initial reward processing in the subcortical reward system is unaffected by the reward value (Bjork & Hommer, 2007).

In summary, the results of Experiment 4.2 suggest that both conscious and unconscious reward processing can boost performance efficiently when there is no requirement to integrate value and attainability information. In light of Experiment

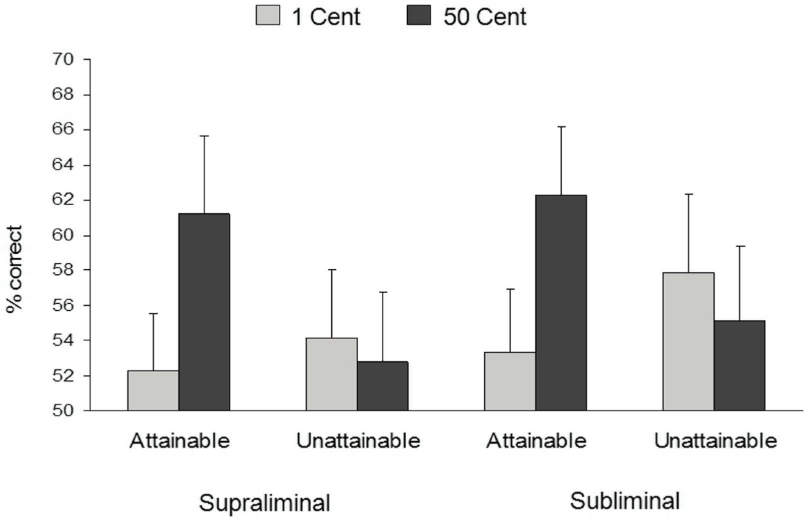

Figure 4.3. Results of Experiment 4.2. Mean and standard error of the percentage of correct trials as a function of reward value, presentation duration, and attainability. Error bars represent standart errors.

4.1, Experiment 4.2 provides further evidence that conscious compared to unconscious reward processing promotes the integration of incoming reward value and attainability information.

General discussion

The aim of the present study was to test whether conscious compared to unconscious processing of rewards leads to more efficient cognitive task performance based on the successful integration of reward value and attainability information. To examine this question, we first examined the situation in which the need for integration was relatively high by varying value and attainability information on a trial-by-trial basis (Experiment 4.1). In line with traditional theories of motivation and decision making (e.g., Atkinson, 1957, 1964; Brehm & Self, 1989; Hull, 1943; von Neumann & Morgenstern, 1947; Vroom, 1964), we found that when coins were presented for a relatively long duration, and could thus be consciously perceived, performance increased selectively for valuable and attainable rewards. In contrast, brief presentation of the coins led to rather inefficient effort investment and performance. First, and most stunning, participants worked harder for high compared to low rewards despite their conscious knowledge that the rewards were unattainable. Second, when participants were instructed that rewards were attainable, performance was increased regardless of the reward value. These findings suggest that brief presentation of rewards, which reduces the likelihood of conscious processing, causes failure to integrate reward value and attainability information. Moreover, our data suggest that in the absence of integration, high reward value and information that a reward is attainable do not improve performance in an additive way. Instead, people invest maximal effort in response to either source of motivation.

The fact that performance was more efficient when reward information was presented for a relatively long duration speaks to the hypothesis that conscious awareness enables processes that lead to more strategic behavior. This finding converges well with the framework outlined in the introduction, according to which initial or unconscious reward processing can directly facilitate task performance, but full or conscious reward processing is needed to modulate performance strategically (Bijleveld et al., 2012-b). Support for the direct facilitation of performance through rewards comes from neuroscience research showing that the value of rewards is first encoded in a subcortical reward network, including most prominently the ventral striatum (VS; Phillips, Walton, & Jhou, 2007; Salamone et al., 2009). The VS is also responsible for translating the reward value into effort by projecting to frontal cortical areas, such as the dorsolateral prefrontal cortex, which modulate executive control processes (Aston-Jones, & Cohen, 2005; Liljeholm & O'Doherty, 2012; Schmidt et al., 2012). This may explain why unconsciously perceived rewards can facilitate effortful cognitive performance. However, according to the framework (Bijleveld et al., 2012-b), conscious awareness of rewards allows for more complex, higher-level cognitive processing (see also Dehaene, Kerszberg, & Changeux, 1989). Such higher level processing likely includes activation of the medial and orbital prefrontal cortex, regions that are involved in evaluating the likelihood that a reward can be attained (O'Neill & Schultz, 2010; Knutson et al., 2005; Rogers et al., 1999). This may explain why consciously processed rewards lead to more efficient effort investment based on the combination of reward value and attainability information.

Further evidence for the crucial role of consciousness in integrating value and attainability information stems from Experiment 4.2, where we show that long and short presentation of rewards lead to parallel effects on performance when integration of value and attainability was irrelevant. That is, irrespective of presentation duration of the reward information, participants performed better for relatively high attainable rewards, but performance was similar for high and low rewards when these were unattainable. An interesting question raised by this latter finding is whether the coins were still perceived as rewarding when they are always unattainable. Although money is generally desirable (Lea & Webley, 2006), it is possible that the perception of money as a performance reward depends on the potential of attaining it (cf. Biner & Hannon, 1988; Richter & Gendolla, 2006). Further research is therefore needed to determine whether cognitive task performance is boosted by unconscious reward cues as a function of the actual or perceived rewarding property of the cues.

It is important to note that a few recent studies have shown that conscious and unconscious rewards can sometimes have different effects on cognitive task performance. For instance, it has been shown that conscious, but not unconscious high rewards impair performance when they are presented during the execution of an active maintenance task, probably due to distraction (Zedelius et al., 2011-b, Chapter 5). Furthermore, while unconsciously presented monetary rewards were shown to reduce the attentional blink effect (assessed by the rapid serial visual presentation task; Raymond, Shapiro, & Arnell, 1992), conscious rewards augmented the attentional blink effect resulting from the (normatively learned) tendency to concentrate too much on task stimuli when one knows that rewards are relatively high (Bijleveld et al., 2011). These previous studies point to an advantage of unconscious reward processing in boosting cognitive control performance. The present study contributes to this research by demonstrating that the advantageous or disadvantageous effects of conscious versus unconscious rewards depend on the ability to combine relevant information to arrive at efficient cognitive task performance.

The results of the present study have important implications for current debates about the role of consciousness in motivation and decision making (Baumeister, Masicampo, & Vohs, 2011; Dijksterhuis & Aarts, 2010). That is, even though information integration is sometimes proposed to be dependent on conscious processing (e.g., Baars, 2002; Dehaene & Naccache, 2001; Dijksterhuis & Aarts, 2010; Morsella & Bargh, 2010; however, see Mudrik, Breska, Lamy, & Deouell, 2011), conscious and unconscious processing are rarely compared directly to test differences in integration. Employing a paradigm where conscious and unconscious reward processing can directly be compared, the present study suggests that conscious awareness plays a crucial role in the integration of reward value and attainability information to arrive at an optimal decision about whether it is worthwhile to invest effort. This ability to integrate different types of reward related information may not be constrained to value and attainability information. Even when valuable rewards are attainable, people may judge them not worth the effort, for instance because they are very hard to get or because they are attainable only after a considerable delay (e.g., Kivetz, 2003; Raynolds, 2006). Such judgments imply the combination of reward value with information about effort and time requirements (Ballard & Knutson, 2009). Although the exact mechanisms behind these judgments go beyond the current research, our findings suggest that they may benefit from conscious awareness of rewards.

Directions for future research

The present findings raise interesting questions for future research. First, given that (attainable and unattainable) unconsciously perceived rewards can motivate people to work harder, this leads to the question of how people might experience this motivation. Although the framework outlined above makes a qualitative distinction between conscious and unconscious reward processing, this framework does not imply that rewards perceived outside of conscious awareness can never gain access to consciousness, or affect conscious experience in any way. For instance, when people become motivated by unconscious rewards, they may become aware of this motivation, either indirectly, by observing their own behavior, or more directly, by noticing potential changes in their mood or arousal which may be related to their motivated behavior (e.g., Chartrand, Cheng, Dalton, & Tesser, 2010; Carver & Scheier, 1990; Knutson et al., 2005). Although this topic goes beyond the scope of the current investigation, it remains an interesting direction for future research. Within the present research, however, there is no evidence that potential downstream effects of unconscious rewards on conscious experience could help the strategic control of efficient effortful performance.

Another interesting topic for future research is how conscious expectations with regard to the value of unconsciously processed rewards affect performance and motivation. For instance, would a person work harder for an unconsciously perceived low value attainable reward when he or she consciously expects it to be of high, rather than low value? In the light of the present studies, we can only speculate about this issue. In the present study, when attainability varied throughout the task, participants based their decisions to invest effort either on the high value of a reward, or the fact that the reward was attainable. This suggests that people are most strongly influenced by information that triggers motivational behavior. Information that should reduce motivated behavior (i.e., the fact that a high value reward was not attainable, or that an attainable reward was of low value) appeared to have less impact. Therefore, we would predict that conscious expectancies related to reward value could overrule the effects of unconsciously perceived rewards when people expect a high value reward, but unconsciously perceived high value should drive behavior when people expect to work for a low value reward. It would be interesting to test these predictions in future work, for instance by manipulating the (perceived) ratio of high to low value rewards.

Conclusion

The present study extended recent research on conscious and unconscious reward pursuit by addressing the issue of how people deal with unattainable rewards. The findings from two experiments with different experimental designs suggest that conscious perception of rewards enables people to integrate the value of monetary rewards with fluctuating attainability information. Thus, while consciousness of rewards is certainly not necessary to boost cognitive task performance, it appears to be crucial to arrive at efficient effort investment when confronted with attainable and unattainable rewards.

Footnotes

1 The fact that coin identification was at chance level calls for an objective assessment that the coins were indeed presented. For this purpose, we ran the experiment again on one of the computers used for data collection, and recorded 18 trials of the 17 ms coin presentation using a camera with a slow motion feature (a Sony NX4), enabling recording of the coin presentation at the rate of 240 frames per second. Inspection of the recordings showed that the coin was visible in each recording.

2 Because earning rewards (on attainable reward trials) was contingent on recalling all words correctly, accuracy was operationalized as the correct recall of all five words. Because this demand was clear from the instructions, we reasoned that the total number of words recalled per trial would be a suboptimal performance measure in the present experiment. (For a more detailed discussion of this argument, see Zedelius et al., 2011-a, Chapter 5). However, for both studies, the pattern of results for the total number of words recalled resembled that of the accuracy data. Specifically, in Experiment 4.1, analysis of the total number of correctly recalled words yielded a marginally significant main effect of attainability, $F(1, 40) = 3.56$, $p = .07$, $\eta_p^2 = .08$, which was qualified by a marginally significant three-way interaction of attainability x reward value x exposure, $F(1, 40) = 3.00$, $p = .09$, $\eta_p^2 = .07$. When rewards were attainable, performance was higher for high ($M = 4.32$, $SD = 0.59$) compared to low value rewards ($M = 4.08$, $SD = 0.72$) in the long presentation condition, $F(1, 40) = 5.18$, $p = .03$, $\eta_p^2 = .11$, but performance was equally high for high ($M = 4.33$, $SD = 0.52$) and low ($M = 4.31$, $SD = 0.46$) value rewards in the short presentation condition, $F < 1$. When rewards were unattainable, performance did not differ for high ($M = 4.16$, $SD = 0.69$) and low value rewards ($M = 4.16$, $SD = 0.61$) in the long presentation condition, $F < 1$. Performance appeared to be somewhat higher for high ($M = 4.19$, $SD = 0.72$) compared to low ($M = 4.12$, $SD = 0.60$) value rewards in the short presentation condition, although this latter increase was not statistically significant ($F < 1$). In Experiment 4.2, we found a significant interaction of attainability x reward value, $F(1, 31) = 5.18$, $p = .03$, $\eta_p^2 = .14$, indicating performance was not influenced by the reward value in the unattainable reward condition (high reward value: $M = 4.16$, $SD = 0.50$; low reward value: $M = 4.20$, $SD = 0.44$), $F < 1$, but performance was increased for high ($M = 4.32$, $SD = 0.40$) vs. low value rewards ($M = 4.13$, $SD = 0.58$) in the attainable reward condition, $F(1, 31) = 6.33$, $p = .02$, $\eta_p^2 = .17$, and this effect did not differ for the long and short presentation conditions, $F < 1$.

Chapter 5

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

Two experiments examined the effects of consciously and unconsciously perceived rewards on the active maintenance of goal-relevant information. Participants were presented with supraliminal and subliminal high and low monetary rewards which they could gain for good performance on verbal active maintenance task. Critically, the rewards presented at different stages during the task. In Experiment 5.1, 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 5.2, 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.

This chapter is based on Zedelius, C. M., Veling, H., & Aarts, H. (2011-b). Boosting or choking—How Conscious and unconscious reward processing modulate the active maintenance of goal-relevant information. *Consciousness and Cognition, 20,* 355-362.

The chapter also contains a commentary on the presented research, which was published under the reference: Vidal, M., & Mossio, M. (2011). Can a 50 cents reward really choke working memory maintenance process? *Consciousness and Cognition, 20,* 363–365.

At the end of the chapter, we reply to this commentary. The reply is based on Zedelius, C. M., Veling, H., & Aarts, H. (2011-a). Beware the reward - How conscious processing of rewards impairs active maintenance performance. *Consciousness and Cognition, 20,* 366-367.

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 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., Baddeley, 1986; Baars & Franklin, 2003; 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 et al., 2009, 2010). 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 & Fietz, 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 the 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; Beilock, 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 & Tiez, 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 or 50 cents by correctly recalling 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 5.1, the coins were presented before participants processed the target words (and thus before they engaged in the maintenance process), and in Experiment 5.2 the rewards were presented after processing of the target words, and hence when participants were already engaged in the active maintenance process.

Experiment 5.1

The goal of Experiment 5.1 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 5.2, 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 versus 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.

Method

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) x 2 (reward presentation duration: supraliminal vs. subliminal) x 2 (interference: low vs. high) within-participants design was used.

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’.

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 Figure 5.1. A trial started with the presentation of a fixation cross for 1 sec. 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.

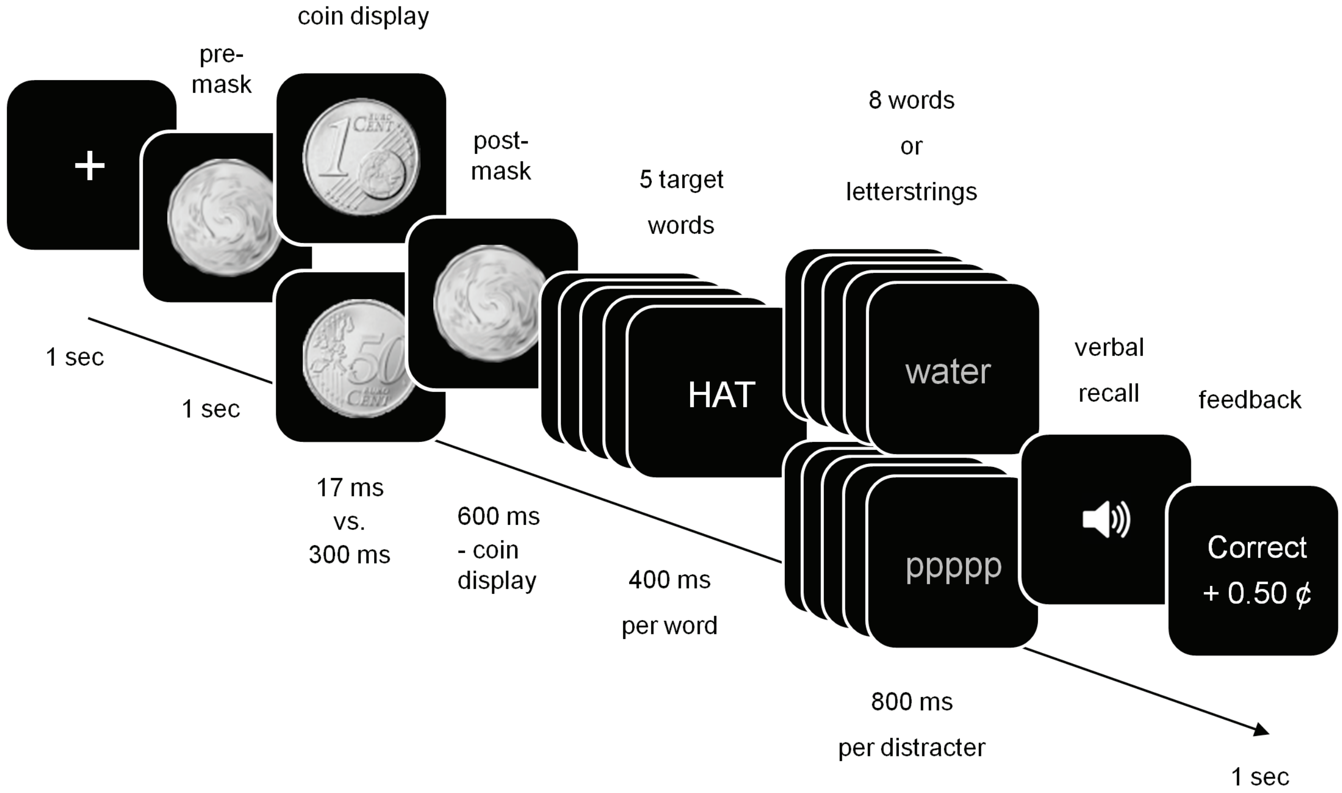

Figure 5.1. Overview of a trial.

Results and discussion

To test performance on the word span task as a function of surpaliminally 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, $F(1, 25) = 8.14$, $p < .01$, $\eta_p^2 = .25$, as can be seen in Figure 5.2. Consistent 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, $F(1, 25) = 6.88$, $p = .02$, $\eta_p^2 = .22$, as well as for the subliminal condition, $F(1, 25) = 4.39$, $p = .05$, $\eta_p^2 = .15$. 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, $F(1, 25) = 6.07$, $p = .02$, $\eta_p^2 = .20$; 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.

Experiment 5.2

Experiment 5.1 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

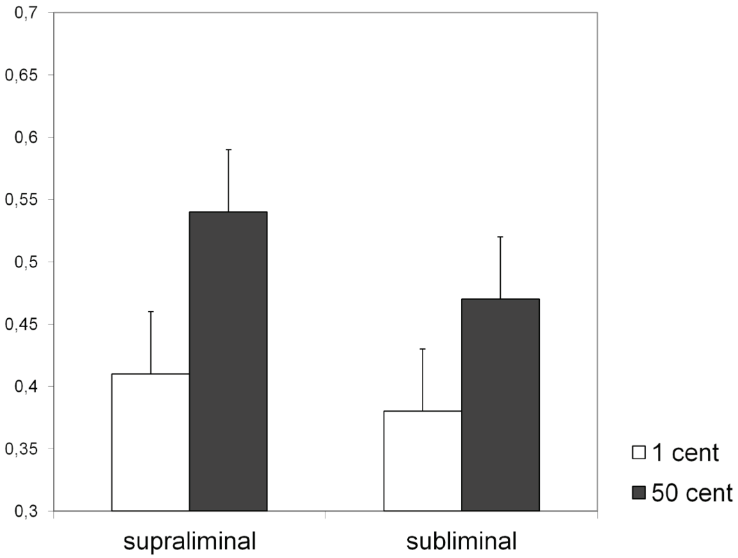

Figure 5.2. Proportion of correct trials as a function of reward value and reward presentation duration. Error bars represent the standard error of the mean.

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 5.1, 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.

Method

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 €).

Design and procedure

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

The procedure resembled the one described in Experiment 5.1 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.

Results and discussion

To test the effects of supraliminally versus 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, $F(1, 33) = 3.16$, $p = .09$, $\eta_p^2 = .09$, 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, $F(1, 33) = 12.65$, $p = .001$, $\eta_p^2 = .28$. 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 Figure 5.3.

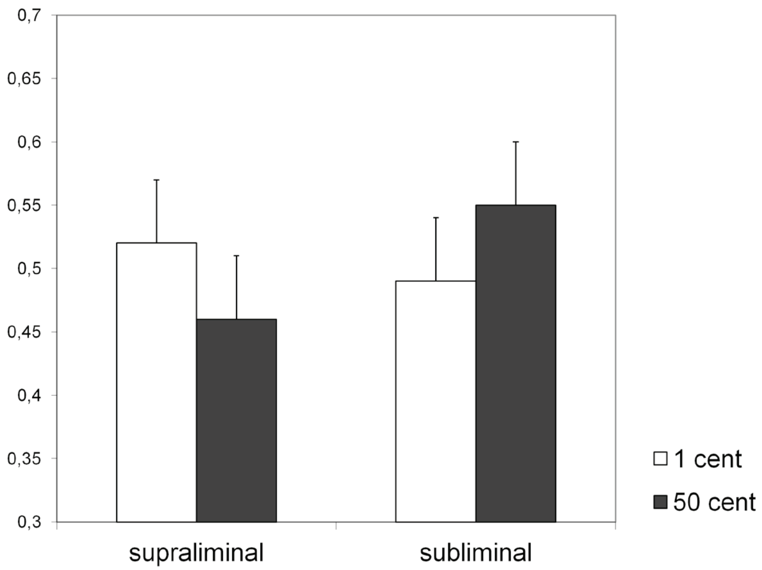

Figure 5.3. Proportion of correct trials as a function of reward value and reward presentation duration. Error bars represent the standard error of the mean.

Simple effects analyses revealed that performance increased in response to high rewards compared to low rewards when presented subliminally, $F(1, 33) = 5.28$, $p = .03$, $\eta_p^2 = .14$, thus replicating the findings of the first experiment. Relevant to the present hypothesis, however, for supraliminally presented rewards the opposite was found, $F(1, 33) = 3.29$, $p = .08$, $\eta_p^2 = .09$. High rewards led to worse performance than low rewards.

The results of Experiment 5.2 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.

The findings from Experiment 5.2 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 5.1, 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.

General discussion

Two experiments investigated the effects of consciously and unconsciously perceived rewards on performance in an active maintenance task. In Experiment 5.1, 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, 2010), 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 5.2, 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, 2009). However, we believe that the experimental setup in Experiment 5.1 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 5.2. 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; Niewenhuis, Riddinckhof, 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 5.2 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 down-regulate 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.

Can a 50 cents reward really choke working memory maintenance process?
A commentary by Manuel Vidal[1] and Matteo Mossio[2]
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Short overview

In the paper "Boosting or choking - How conscious and unconscious reward processing modulate the active maintenance of goal-relevant information" (Zedelius et al., 2011; *this chapter* [italics added]), the authors have compared in two different experiments the influence of subliminal and supraliminal reward presentation on participants' motivation to perform a verbal memorization task. The memorization task consisted in remembering a list of 5 words displayed successively, followed by an active maintenance phase during which 6 interfering distracters were displayed successively. The interesting and original contribution of this paper in the growing literature on motivation was to assess the influence of reward in the two different stages of the memorization task. The reward could be either presented before the storage phase (experiment 1) or just after (experiment 2), resulting in the interaction with both the storage and maintenance processes or only with the latter.

When the reward was presented at the beginning of the trial (experiment 1), recall performance improved significantly of about 32% and 24% for respectively supraliminal and subliminal presentation of 50 cents coins (estimated values from plot reading). In contrast, when the reward was presented after the storage phase (experiment 2), a differential effect was observed according to the awareness of the reward presentation. While supraliminal presentation led to an impairment of performance (12% decrease but not significant), subliminal presentation led to a significant performance increase of 13%.

On the basis of these results, the two central claims of this paper are: first, subliminal motivation with high reward improves mostly the maintenance process that takes place after the encoding stage and second, when presented supraliminally high rewards will impair the maintenance process contrarily to low rewards. The authors explain this latter finding in terms of both divided attentional resources (processing the reward cue while maintaining the word list) and emotional reaction to high rewards that would trouble the participant.

Questioning the choking effect

Although the striking finding that high rewards presented consciously after the word list memorization result in choking the maintenance process instead of boosting it could be of potential importance, several methodological issues and debatable interpretations seem to cast some doubts on its strength.

Concerning methodology, let's first consider the statistical analysis of the results. Despite the large number of participants (34 in experiment 2 as compared to the 26 of experiment 1), this claim is based on a difference that is not statistically significant (p=0.08). Furthermore, the authors chose to analyse the individual average proportion of correct trials through an all-or-nothing measure (accurate recalling of the entire 5 words list), in which forgetting one word or all of them penalized equally. In experiment 2, this probably resulted in the amplification of otherwise small or even absent disturbing effects of the high reward presented supraliminally. A finer computation of the performance scores (e.g. proportion of words recalled correctly for each trial, ranging from 0 to 100% at increments of 20%, like in Gilbert & Fiez, 2004) would have been suitable: how would the results look like? Taken together, these remarks suggest that the effect of a high reward being rather small, the assessment of the results would require collecting more data.

Let's now consider the general method per se. A first issue is the fact that the method used did not ensure that the participants were actually looking at the distracters during the delay period. In fact, closing the eyes would maximize the monetary gain. Moreover, in the second experiment half of the trials where tested with a maintenance phase shortened to 100ms after the reward presentation (therefore we presume without displaying distracters). This would introduce randomness, and thus prevent the participants from missing the reward indication. Unfortunately, no results or statistical analysis about this manipulation are provided. On the one hand, one would expect the main effect to be highly significant, with much improved performance once this delay is reduced to 100ms and no distracter is presented. Pooling together the results of this factor incidentally leads to a much higher baseline performance for this experiment and makes it difficult to compare with the first one.

On the other hand, in the specific case of supraliminal presentation, the second order interaction of this factor with the reward value would provide interesting insights on the choking effect. Showing that this interaction was not significant (meaning that for both delays there is a similar reduction of performance) would further support the author's interpretation concerning the disturbing effect of supraliminal reward. The disruption of the maintenance would indeed occur very shortly after the presentation of the 50 cents coin. Otherwise, it would be evidence against their central claim.

A distinct set of critical remarks concerns the interpretation of the results. The authors conclude that the subliminal boosting effect observed for high rewards stems mostly from the enhancement of the active maintenance process and not from the enhancement of the storage process. Yet, although subliminal presentation of high rewards after the word list storage does boost performance (13% increase), when presented before the boost substantially stronger (24% increase). Therefore these results indicate that the cognitive boost is already at work during the encoding phase, otherwise the same level of performance would have been observed. In fact, one could argue that the maintenance process starts during the presentation of word of the list. Throughout the encoding phase participants have to actively maintain the words presented previously and increase the list with each additional word, without getting disturbed. Therefore, consistently with the reported results, it is perfectly reasonable to expect a boosting of performance already during the storage of the word list.

The authors' explanation for the choking of the maintenance process when conscious high rewards are at stake is twofold. On the one hand, the conscious processing of the 50 cents coin presented visually would divide the attentional resources, otherwise fully engaged in the maintenance of the word list during the distracters presentation. This effect would result in an abrupt disruption of the active maintenance process, leading to a drop in performance for supraliminal presentation of the reward. On the other hand, the emotional reaction to a high reward (here 50 cents) would be more disturbing than for a low reward, resulting in a differential effect for high and low rewards. We would like to challenge both of these arguments.

Let's first consider the attentional resources involved in this task and the differences between both experiments. In terms of cognitive resources engaged when processing additional information irrelevant to the memorization task, one could wonder why should the processing of the coin interfere with the active maintenance of the list more than the processing of distracters. The results from the first experiment proved that the participants were are able to deal with distracters, therefore one could consider that in terms of attentional resources, the conscious processing of the reward shouldn't cost more than that of distracters. In addition, the authors quote dual-task literature to support the idea that a single-channel cognitive constraint could be responsible for the disruption (Pashler & Johnston, 1998). Actually, this book chapter concerns the refractory period theory observed when processing two successive stimuli, which indicates that it is the processing of the second stimulation (here the coin presentation) that would be slowed down. There is no mention of a disruptive function of ongoing maintenance. Moreover, as pointed out earlier, one could consider that during the encoding phase there is already an undergoing maintenance process. Accordingly, if the presentation of a supraliminal high reward "requires inhibition to return to the ongoing task" in order to release the attentional resources, then it should also have interfered with the encoding of the list of words in the first experiment. Indeed, why would ignoring a word require more attentional resources than adding it to the memorized list?

Nonetheless, should conscious processing of the reward presumably reduce or disrupt the engaged attentional resources, it would have equally impaired the processing of the 1 cent and 50 cents coins. Again, knowing that this effect is not statistically different, one might argue that the small difference reported is just below noise level and thus the disruption is equivalent for both reward values. In order to assess this issue, the authors could have measured the baseline performance where no reward is presented, as this would indicate the real impact of the supraliminal presentation of a 1 cent and 50 cents coin. In fact it might be that the handicap introduced when presenting the reward after the encoding phase is just due to the additional processing of a new kind of distracter.

Let's now focus on the emotional reaction to a high reward (here 50 cents) that would presumably be more disturbing than that to a low reward. On the one hand, the authors claim that the monetary gain was not high enough to disturb the cognitive process during the whole duration of the task (as reported in Mobbs et al., 2009), otherwise supraliminal high reward wouldn't have boosted the performance in the first experiment. On the other hand, however, they claim that the emotional reactions to the same reward can disrupt the ongoing maintenance process occurring after encoding. In order to support this disruption, the authors quote among others a very relevant study of Gilbert & Fiez (2004) who used a similar memorization task. This neuroimagery work links the ventral frontal cortex (VFC) activity with the emotional reaction to the presentation of rewards. The proposed mechanism is an activation of VLC in response to the reward, followed by a progressive deactivation so to fulfil the maintenance task with minimal emotional disturbance. Nevertheless, in their study they failed to report a significant increase of activity for reward vs. no-reward trials, which they explain by the fact that the reward presentation epoch was to short (6s as compared to the 0.3s in the present study) and that "increases in activation may have been obscured by decreases in activation that occurred with the onset of a memory load". Therefore it seems that the activation and deactivation of VLC acts in a relatively long time-scale, which is consistent with the rather long durations of the ventral pallidum activation/deactivation cycle and skin conductance response reported in (Pessiglione et al., 2007). Keeping in mind the fact that the encoding phase already requires an active maintenance after the first word, additional evidence should be provided to explain why the slow VLC deactivation would be fast enough for the words memorization in experiment 1, allowing to boost the recall, but not in experiment 2. In conclusion, we find the emotional reaction interpretation of the surprising reversal observed for 50 cents coin dubious. We would rather believe that the choking effect on the recall performance largely depends on the methodological choices, to which we have addressed some critical remarks.

Conclusions

In conclusion, the authors' idea of assessing the influence of subliminal and supraliminal reward during the maintenance process of a word memorization task is certainly interesting. However, the reinforcement observed for subliminal reward presentation could result, as the authors claim, not from the active maintenance phase alone, but rather from an enhancement of both storage and maintenance. As to the impairment of performance for supraliminal presentation of a high reward only, we have formulated some critical remarks, which challenge this finding. In fact, we believe that further work should be done to strengthen the validity of these results by addressing the methodological issues raised above and revising the interpretations accordingly.

How conscious processing of rewards impairs active maintenance performance - A reply by Claire M. Zedelius, Harm Veling, & Henk Aarts

We have shown that relatively high monetary rewards affect active maintenance performance, even when the rewards are processed unconsciously. Specifically, we found that both supraliminally and subliminally presented coins of 50 cents compared to 1 cent had the capacity to boost performance when presented at the beginning of a maintenance task (Experiment 1). Importantly, when rewards were presented when participants were already involved in the maintenance process, subliminal high rewards again boosted performance, but supraliminal high rewards led to a decrease in performance (Experiment 2). In a commentary on these experiments, Vidal and Mossio question the reported performance decrease and our interpretation of it as an instance of choking. In the following, we will explain why our data show that a relatively high reward of 50 cents can choke active maintenance, and elaborate further on methodological and theoretical implications.

According to Vidal and Mossio, the relative decrease for supraliminal 50 compared to 1 cent trials is questionable as it was marginally significant (p = .08). They argue that *conscious* processing of any reward during maintenance, independent of the value, is sufficient to disrupt active maintenance. This disruption may have obscured the performance boost that is usually found for high rewards. However, this alternative explanation cannot account for the present results. Most importantly, comparing the two 1 cent reward conditions, we find no difference in performance, $F(1, 33) = 1.48$, p = .23. This is inconsistent with the argument that perception of any consciously processed reward disrupts active maintenance. Comparing the two 50 cents reward conditions, we find that performance is significantly worse when it is presented supraliminally compared to subliminally, $F(1, 33) = 15.60$, $p < .001$, $\eta_p^2 = .32$. Thus, our data show that it is the value of the coin that modulates the performance: Unconscious processing of high rewards enhances performance, and conscious processing of high rewards impairs performance by distracting attention and disrupting the ongoing maintenance process.

In light of this finding, we agree with Videl and Massio that it is interesting to further elaborate on the mechanisms underlying the boosting and disrupting effects of rewards. By presenting the rewards after the encoding phase (Experiment 2), we showed that rewards have the capacity to affect the active maintenance of information, and not only encoding of the information. This does not imply, however, that the rewards could not have any influence during the encoding phase. As Vidal and Massio point out, the maintenance process for each word is already started during the presentation of the following words. It is therefore indeed reasonable to expect a performance boost already during the encoding phase—which we observed for conscious as well as unconscious rewards.

With regard to the mechanisms enabling the disrupting effects of conscious rewards, several issues were discussed. A first issue concerned the timing of the interference by conscious rewards. In our studies, we demonstrate that the effects of conscious rewards depend crucially on whether or not one is already actively engaged in the maintenance process. When presented at the beginning of the task, high rewards, though potentially distracting as a result of reflecting on it, did not interfere with the subsequent maintenance. We proposed that, at this stage, attention could be re-focused on the task before the target words appeared. In contrast, when rewards were presented during the maintenance phase, conscious perception of a high reward was detrimental. Although attention could again be re-focused on the task, at this stage the target words were no longer externally accessible and a word that was removed from active working memory could not easily be regained. It is in this sense that our data simulate a dual task interference phenomenon—an issue that has been examined on perceptual cognitive and behavioral level (e.g., Johnson & Proctor, 2004; Pashler and Johnson, 1998).

Based on the obtained data, we believe it is the conscious (reflective) processing of the reward itself which *immediately* caused the interference. As Vidal and Mossio propose, this argument can be further supported by comparing the trials with a longer delay with short delay trials (Experiment 2). If the choking effect were due to influences disturbing performance later in the delay period, we should find a reward × delay interaction in the supraliminal condition. This interaction was absent ($F < 1$), indicating that performance was indeed affected instantly by conscious processing of high rewards.

Furthermore, Vidal and Mossio questioned the proposed neural mechanism of the choking effect of high conscious rewards. Since our data do not include neuroanatomical measures, we can only speculate based on previous studies (Gilbert & Fiez, 2004; Pochon et al., 2002). These studies provide evidence that activation in the ventral frontal cortex (VFC) evoked by the affective motivational processing of rewards possibly interferes with cognitive performance. We reasoned that VFC activation resulting from the presentation of a reward should be detrimental for performance when it takes place during the task. Vidal and Mossio question this explanation. Referring to the above mentioned studies, they argue that the activation and deactivation of the VFC appear to act in a relatively long time-scale and thus cannot be responsible for our findings. Although studies show that the magnitude of a reward can be (cortically) processed within milliseconds (e.g., Yeung & Sanfey, 2004), neuroimaging techniques which are employed to locate different aspects of reward processing are of course not suited to provide accurate information about the actual time-scale of these processes in the brain. Given the methodological challenges of fMRI research on this topic, we agree that the existing studies are not yet conclusive.

As a final note, to assess the effects on performance we analyzed the proportion of trials in which all words were recalled correctly. Vidal and Mossio criticized this all-or-nothing analysis by stating that it probably resulted in the amplification of the effects. Whether or not such amplification may have occurred, it is important to realize that the rewards could only be obtained by complete correct recall of the given information (a common situation in daily life). Consequently, after forgetting one word, there was no benefit for participants in maintaining the others. Hence, the proportion of all words recalled correctly is the most informative indication of the participants' efforts to gain the rewards. Note that this procedure is different from that of Gilbert and Fiez (2004) where participants received rewards for any word that was correctly recalled.

In sum, in our recent studies, we showed that conscious and unconscious rewards affect the active maintenance of goal-relevant information differently. In this critical examination of the underlying mechanisms, we clarify that the conscious processing of a reward of relatively high value has a unique effect on performance in that it causes interference with an ongoing active maintenance process.

Chapter 6

All that glitters is not gold— Success and failure in behavioral regulation toward consciously and unconsciously perceived monetary cues

Previous research has shown that both consciously and unconsciously perceived monetary rewards lead to enhanced performance on cognitive and physical tasks. The present research investigates whether the value of unconscious (but not conscious) money-cues boosts task performance even when they are not rewards but just stimuli. Experiment 6.1 showed that unconsciously, but not consciously perceived high vs. low value coins indeed led to improved performance on a working memory task even when the coins did not serve as rewards. Experiment 6.2 qualified this finding by showing that only people who were currently in need for money were prone to enhanced performance through unconsciously perceived monetary non-rewards. These experiments reveal the powerful influence of money on human behavior by showing that (1) need-relevant incentive value cues in the environment are able to unconsciously boost performance, and (2) conscious awareness causes people to spontaneously regulate non-instrumental motivated responses.

This chapter is based on Zedelius, C. M., Veling, H., & Aarts, H. (in press). I was unaware and I needed the Money! Success and failure in behavioral regulation toward consciously and unconsciously perceived monetary cues. *Social Cognition*.

Money is a strong motivator that readily makes people work harder when they can earn it for good performance (Ahuvia, 2008; Lea & Webley, 2006). Interestingly, following previous social cognition research on unconscious goal pursuit (Bargh & Chartrand, 1999; Custers & Aarts, 2010; Förster, Liberman, & Friedman, 2007), recent work shows that monetary rewards boost task performance even when the rewards are perceived outside of conscious awareness (Bijleveld, Custers, & Aarts, 2009; 2010; Capa, Bustin, Cleeremans, & Hansenne, 2011; Pessiglione et al., 2007). Consciously and unconsciously processed rewards thus seem to affect task performance in a similar way.

The present study explored conditions under which conscious and unconscious money-cues differ in boosting human performance. Specifically, given the powerful influence of money on human behavior, we tested whether unconscious money-cues boost performance even in situations where money has high subjective incentive value, but is merely a stimulus and not used as a reward. We further tested whether this performance boost is down-regulated once people become conscious of non-rewarding incentive money-cues. Examining the regulatory effects of conscious versus unconscious perception on human performance is important, as it adds to the understanding of whether and when consciousness may have an advantage over the unconscious in adapting behavior to the situation at hand (Baumeister, Masicampo, & Vohs, 2011; Dijksterhuis & Aarts, 2010).

In modern society, money is omnipresent. People receive money for work, pay it as fees, or spend it on food and other items. Exposure to money can also occur incidentally and without much conscious thought, such as when one observes other people exchange money. Thus, whether money is a reward or not is determined by the social context (Rozycki, 1973; Zelizer, 1989). Yet, the incentive value (i.e., the motivational "pull", Dickinson & Baleine, 1995) of money is subjective and depends strongly on personal needs (Berridge, Robinson, & Aldridge, 2009; Lebreton et al., 2009). For instance, money should be a stronger incentive for a person who is broke than for somebody who has just received salary (Aarts, Gollwitzer, & Hassin, 2004; Brandstätter & Brandstätter, 1996). Because incentive cues may spontaneously elicit effortful responses aimed at obtaining these cues (Gupta & Aron, 2011), the perception of money-cues may lead to conflict in performance contexts where money is not a reward but at the same time has high personal incentive value. Because increasing performance in such situations is a waste of effort, it is important not to respond to the money's incentive value. We propose that this is difficult, however, when money is perceived unconsciously and motivational responses are triggered outside of awareness. Conscious perception may enable people to regulate their responses and invest effort more efficiently.

The role of consciousness in modulating behavior has previously been studied mainly by instructing participants to consciously set task goals and work on tasks related to reasoning, decision making, planning, and action control (Aarts, in press; Baumeister et al., 2011; Gollwitzer & Sheeran, 2006). Whereas this research paints the picture that conscious processes lead to flexible and strategic behavior, it does not exclude the possibility that adaptive behavior also occurs unconsciously, that is, when task goals are activated without awareness (Custers & Aarts, 2010; Lau, 2009). Furthermore, this previous research does not directly address how conscious and unconscious perception of reward-cues affects performance and whether the two routes of perception allow for the same flexible regulation of motivated behavior.

In an attempt to explore this issue, research has started to test the effects of conscious and unconscious monetary rewards on performance within a single experimental task. This research shows that both consciously (supraliminally) and unconsciously (subliminally) presented coins of high (50 cents) compared to low value (1 cents) prior to task engagement boost performance on cognitive and physical tasks (Bijleveld et al., 2010; Capa et al., 2011; Pessiglione et al., 2007). These effects are assumed to originate from a subcortical reward network that assesses the rewarding value of stimuli independent of conscious awareness (Phillips, Walton, & Jhou, 2007; Salamone et al., 2009) and projects to prefrontal cortical areas that support working memory and action control processes (Aston-Jones, & Cohen, 2005). This way, monetary rewards can boost working memory performance outside of conscious awareness (Bijleveld, Custers, & Aarts, 2012-b). Thus far, however, studies examining the effects of consciously and unconsciously perceived money-cues on performance have mainly relied on the situation in which money was presented as a reward that could be earned through good performance. In the present research, we examine whether the same effects can occur for non-rewarding monetary cues. Moreover, we test whether these effects differ for conscious and unconscious processing as a function of the personal incentive value of money.

Research suggests that the incentive value of stimuli is assessed independent of their externally determined function as rewards (Berridge et al., 2009; Lebreton et al., 2009; Peters & Büchel, 2010). In addition, there is evidence that the mere perception of incentive cues has direct behavioral consequences. For example, studies show that incentive cues, such as water for thirsty participants, spontaneously elicit effortful responses aimed at obtaining these incentives (Gupta & Aron, 2011; Veling & Aarts, 2011). However, this effort boost may not necessarily produce overt behavior. Because people are generally inclined to prevent unwarranted expenses of effort (Brehm & Self, 1989; Gendolla, Wright, & Richter, 2012; Hull, 1943; Kool, McGuire, Rosen,

& Botvinick, 2010), they should be motivated to regulate effortful responses to high value money-cues in situations where money is not a reward. In fact people appear competent in regulating their reactions to money-cues, either by devaluing money or by inhibiting their initial reaction to money (Delgado, Gillis, & Phelps, 2008; Staudinger, Erk, Abler, & Walter 2009; Staudinger, Erk, & Walter, 2011). However, participants in these studies were always aware of the money-cues and the potential influence they might have on them. We argue that such regulation fails when money-cues are perceived outside of awareness.

There is evidence that people indeed have difficulties with regulating reactions toward unconscious stimuli (Dehaene et al., 2003; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001; Morsella 2005; Morsella, Gray, Krieger, & Bargh, 2009; Stephan et al., 2002). Unconsciously (i.e. subliminally) presented cues can influence people's emotional reactions, impressions, judgments, choices, and their behavior. Interestingly, these effects are hard to control even when participants are warned of this subliminal influence (Murphy & Zajonc, 1993; Rotteveel, de Groot, Geutskens, & Phaf, 2001; Winkielman, Zajonc, & Schwarz, 1997). In order to counteract such influences, people need a clear opportunity to implement their regulatory efforts (Bargh, 1992; Wegener & Petty, 1997). Naturally, this opportunity is rather limited when people are unaware of, or unable to identify a particular stimulus.

The present research

Accordingly, in two experiments we tested the hypothesis that, when people perceive non-rewarding money-cues that have high incentive value, unconscious perception will lead to a boost in performance, whereas conscious perception enables people to effectively regulate performance to these cues. In the first experiment we aim to provide an initial test for the idea that consciously and unconsciously perceived high value money-cues affect performance differently in a situation where money is always an incentive, but not always a reward. For this purpose, we recruited subjects that were all in current need for money, and tested performance on a cognitive (working memory) task, during which participants were presented subliminally or supraliminally with coins of low (1 cent) or high (50 cents) value. We expected that unconsciously, but not consciously perceived high compared to low value coins enhance performance, thus representing an instance of regulation failure. We also included a control condition (between-subjects) in which the coins did serve as rewards. In this condition, we expected increased performance for both consciously and unconsciously perceived rewards. This control condition was included to show that our task and procedures replicate previous work when money serves as a reward, and that the expected differential effects of conscious and unconscious non-rewarding money-cues can indeed be attributed to the fact that the cues are not rewards.

In the second experiment, we tested the hypothesis that failure to regulate motivational responses to unconscious monetary non-rewards results from the money's high personal incentive value. To this end, we again presented coins as non-rewards, and we now assessed whether participants were in current need for money or not. Thus, we exploited the general notion that a higher current need lead people to more strongly represent need relevant stimuli as an incentive (Kringelbach et al., 2003). Based on the idea that a person's current need for money modulates the subjective incentive value of money-cues (Brandstätter, & Brandstätter, 1996), we expected increased performance after perception of unconscious (but not conscious) high vs. low value money-cues only for people currently in need for money. For people not in need for money, performance was expected to be the same for consciously and unconsciously perceived rewards.

Experiment 6.1

Participants and design

Participants were 71 psychology undergraduates (57 female) with a mean age of 21.3 years (*SD* = 3.02). Only participants were recruited who wanted to participate for money, and hence were in current need for it. Accordingly, they all received 6 € for their participation in the present, as well as another, unrelated experiment. Note that the money given in exchange for participation in this study was a flat rate and unrelated to the money presented during the experimental task. The design was a 2 (coin value: 1 cent vs. 50 cent) x 2 (exposure: supraliminal vs. subliminal) x 2 (instructions: reward vs. non-reward) mixed design with coin value and exposure as within-participants factors and reward instructions as between-participants factor.

Procedure

The experiment consisted of a visual delayed match to sample task (Lencz et al., 2003) in which participants were asked to maintain a visual target stimulus in memory over a short delay period. Participants were instructed to do their best on this task. Thus, accurate maintenance represents effortful performance. Participants learned that on every trial a coin (1 cent or 50 cents) would be presented on the screen, and that the coin would sometimes be shown very quickly and would thus be difficult to perceive.

In the reward condition, participants were told these coins were rewards they could gain for correct responses. In the non-reward condition, participants were told that the presented coins were no rewards. The alleged explanation for the presence of the coins in this condition was that they were presented to keep the experimental setup similar to previous experiments on rewards and performance.

Each trial started with a 1 or 50 cents coin presented for 17 ms (subliminal) or 300 ms (supraliminal). The coins were preceded by a mask for 1000 ms and followed by a post mask for 600 ms minus the duration of the coin (for a subliminality check of this procedure, Bijleveld et al., 2009). After the coin-priming episode, participants were presented with a target stimulus consisting of squares built up of a random constellation of 9 x 9 black and white pixels. The target stimulus was presented for 500 ms. Next, 6 distracters (8 randomly arranged black and grey pixels) appeared for 250 ms with blank screens of 500 ms in between. After the delay period, two test stimuli appeared, of which one was identical to the target and the other deviated from the target by 7 randomly selected pixels. Participants were asked to indicate with a button press which test stimulus was identical to the target. Finally, accuracy feedback was shown. The task consisted of 64 randomly presented trials (16 for each value by exposure combination). The proportion of correct trials served as the dependent variable.

Results and discussion

We subjected the proportion of correct trials on the working memory task to an ANOVA according to the design. This yielded a marginally significant main effect of coin value, $F(1, 69) = 3.34$, $p = .07$, $\eta_p^2 = .07$. Notably, this effect was qualified by the predicted three-way interaction of coin value × exposure × instructions, $F(1, 69) = 6.55$, $p = .02$, $\eta_p^2 = .09$ (see Figure 6.1). In the reward condition, performance increased in response to high compared to low value coins, $F(1, 69) = 6.18$, $p = .02$, $\eta_p^2 = .07$. There was no interaction of value × exposure, $F < 1$. This result is a direct replication of earlier findings and shows that consciously and unconsciously perceived money-cues equally improve performance when presented as rewards for a subsequent maintenance task (see Zedelius, Veling, & Aarts, 2011-b, Chapter 5).

Importantly, in the non-reward condition, we found the predicted interaction of coin value × exposure, $F(1, 69) = 7.18$, $p = .009$, $\eta_p^2 = .09$. For subliminally presented coins, performance was significantly improved for high compared to low value coins, $F(1, 69) = 4.33$, $p = .04$, $\eta_p^2 = .06$. This confirms our novel prediction that unconsciously perceived high value money-cues improve performance even when it is clear that they are not rewards. In contrast, for supraliminally presented coins, a marginally significant performance decrease for high compared to low value coins was found, $F(1, 69) = 3.40$, $p = .07$, $\eta_p^2 = .05$. Thus, if anything, consciously perceived high value coins led to a drop in performance. These findings support the hypotheses that unconscious non-rewarding money-cues boost performance, but that conscious awareness of these cues causes people to down-regulate their motivated responses.

Experiment 6.2

Experiment 6.2 was designed to test the hypothesis that the performance boost through unconscious monetary non-rewards in Experiment 6.1 was caused by the subjective incentive value of the money. Therefore, we examined effects of the different kinds of money-cues among participants that differed in their current need for money. We expected to replicate the findings of the non-reward condition in Experiment 6.1 for students with a high current need for money. For students with no current need for money, performance was expected to be unaffected by the coins, regardless whether they were perceived consciously or unconsciously.

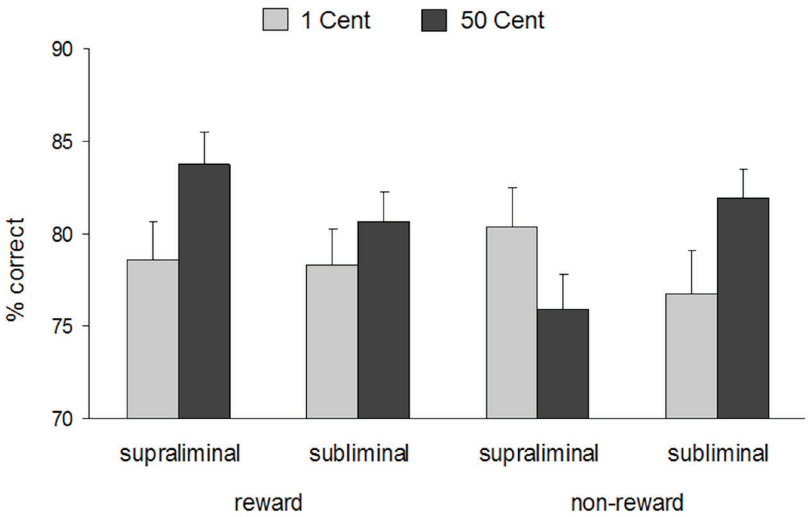

Figure 6.1. Results of Experiment 6.1. Mean and standard error of the percentage of correct trials as a function of coin value, exposure, and instructions. Error bars represent standart errors.

Method

Need for money pre-study

In order to distinguish participants with a current need for money from students with no current need for money, we asked participants to choose to receive money or course credits for their participation in Experiment 6.2. Course credits are part of the curricular requirements students have to fulfill during the bachelor program. In order to test whether this choice is indeed indicative of participants' current need for money, a pre-study was conducted among an independent sample of 66 psychology students. Students could chose to participate for money (a flat rate of 6 € for 45 minutes of participation) or for credits in an unrelated experiment. 37 students chose to participate for money and 29 for credits. At the end, participants indicated their current need for money on a 7-point scale ranging from 1 (not at all in need for money) to 7 (very much in need for money). An ANOVA confirmed that the need for money was indeed higher for students participating for money (M = 5.43, SD = 1.46) than for students participating for course credits (M = 4.45, SD = 2.06), $F(1, 64) = 5.14$, $p = .03$, $\eta_p^2 = .07$. Note that these findings also indicate that, in general, our participants in Experiment 6.1 had a current need for money.

Participants and design

Participants in Experiment 6.2 were 57 undergraduate psychology students (41 female) with an average age of 21.42 years (SD = 2.93). The design was a 2 (coin value: 1 cent vs. 50 cents) x 2 (exposure: supraliminal vs. subliminal) x 2 (current need for money: yes vs. no) mixed design with value and exposure as within-participants factors and current need for money as a quasi-experimental factor. 32 students chose to participate for money and 25 for course credits. Students choosing to participate for money received the same flat rate, the amount of which was unrelated to the coins displayed in the task. Students choosing to participate for credits received the fixed amount of one credit, also independent of performance.

Procedure

The experimental task was the same as in Experiment 6.1. In this experiment, however, all participants were instructed that the coins displayed during the task were no rewards. After the experimental task, we assessed the participants' current need for money using the same scale as in the pre-study. Finally, participants were thanked for their participation and dismissed.

Results and discussion

First, an ANOVA confirmed that students who participated for money reported a higher current need for money (M = 5.50, SD = 1.19) compared to those participating for credits (M = 4.64, SD = 1.89), $F(1, 55) = 4.40$, $p = .04$, $\eta_p^2 = .07$.

Next, we subjected the proportion of correct trials on the working memory task to an ANOVA according to the design. There were no main effects of coin value, $F(1, 55) = 0.58$, $p = .45$ or current need for money, $F(1, 55) = 0.65$, $p = .42$, and no interaction of coin value × current need for money, $F(1, 55) = 1.11$, $p = .30$. However, we did find the expected three way interaction of coin value × exposure × current need for money, $F(1, 55) = 6.42$, $p = .01$, $\eta_p^2 = .10$.

To gain more insight into this interaction and test our specific hypothesis that unconsciously perceived non-rewards would only affect performance for students currently in need for money, we conducted separate contrast analyses for the two levels

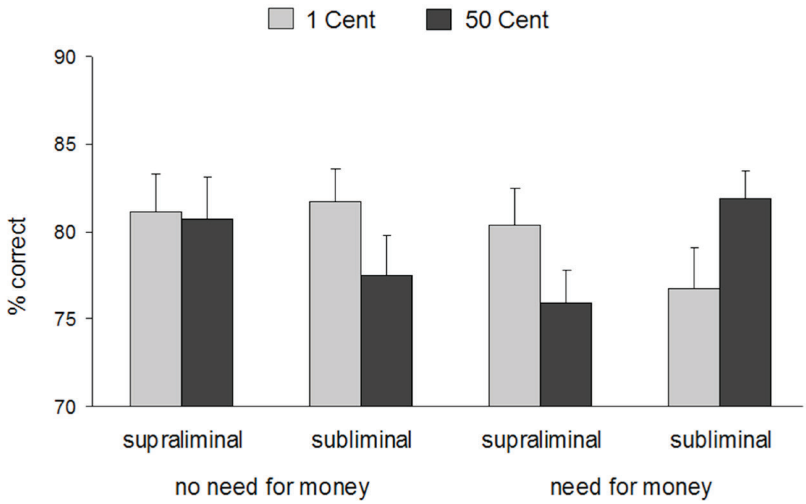

Figure 6.2. Results of Experiment 6.2. Mean and standard error of the percentage of correct trials as a function of coin value, exposure, and current need for money. Error bars represent standart errors.

of current need for money. First, for students currently in need for money, we found a significant interaction of coin value × exposure, $F(1, 55) = 7.54$, $p = .008$, $\eta_p^2 = .12$. This interaction indicated a performance increase in response to subliminally presented high compared to low value coins, $F(1, 55) = 5.32$, $p = .03$, $\eta_p^2 = .09$, and a marginally significant performance decrease in response to supraliminally presented high compared to low value coins, $F(1, 55) = 3.04$, $p = .09$, $\eta_p^2 = .05$ (see Figure 6.2). These results mirror the pattern of results found in the non-reward condition in Experiment 6.1, where all participants were in need for money. In contrast, no significant effects were found for students who were currently not in need for money, all Fs < 2.68. Thus, the findings from this experiment confirm our hypothesis that unconsciously perceived non-rewards affect performance only when they are perceived as having high personal incentive value.

General discussion

In the present work we explored performance responses toward (incentive) money-cues as a function of conscious awareness. Replicating earlier work (Capa et al., 2011; Zedelius, Veling, & Aarts, 2011-b, Chapter 5), both consciously and unconsciously perceived high vs. low value coins serving as rewards enhanced performance on a working memory task. Moreover, and going beyond replication, when money did not function as a reward, unconsciously perceived high vs. low value money-cues still increased performance. Importantly, Experiment 6.2 revealed that non-rewarding money-cues only affected performance when people were in current need for money, and the money-cues thus had high personal incentive value. Finally, when money-cues were no rewards and were processed consciously, the value of the coins did not increase performance, even when the money had high personal incentive value.

The performance boost by unconscious incentive money-cues can be understood to arise from a subcortical reward network that assesses the value of stimuli independent of conscious awareness (Phillips et al., 2007; Salamone et al., 2009) and subsequently projects to prefrontal cortical areas that support the execution of working memory tasks (Aston-Jones & Cohen, 2005). Importantly, the present research suggests that this reward network can be activated by incentive cues even when these are not actually rewards, as long as they are relevant to a person's current needs. One intriguing implication of this finding is that it might be possible to increase people's cognitive performance in everyday life contexts (e.g., at work or in schools) by presenting subtle environmental cues that carry incentive value (cf. Capa, Cleeremans, Bustin, Bouquet, & Hansenne, 2011). Future research may reveal whether other kinds of non-rewarding incentive cues similarly boost performance, or whether the effect is specific to money-cues, which are often used as performance rewards.

Furthermore, the present study adds to the understanding of whether and when consciousness may have an advantage over the unconscious in adapting behavior to the situation at hand (Baumeister, et al., 2011; Dijksterhuis & Aarts, 2010). Consciousness perception of environmental stimuli is considered dependent on the activation strength of these stimuli (Dehaene et al., 2006). This suggests that both supraliminal and subliminal money-cues do initially boost effort mobilization (Bijleveld et al., 2009; Pessiglione et al., 2007). However, through their prolonged presentation, the supraliminal money-cues eventually reach consciousness, and at this stage effort mobilization is down-regulated. The finding that participants with high need for money actually showed a trend towards decreased performance for conscious high vs. low value non-rewards suggests that they did become motivated by the high value coins, but actively adjusted their performance level in the opposite direction by inhibiting their effort in response to non-rewards. The resulting trend towards "overregulation" converges well with research showing that inhibition of pre-potent responses decreases their activation level below baseline (e.g., Aron, 2007; Veling & Aarts, 2011). Thus, an important contribution of the present research lies in suggesting a crucial role of consciousness in down-regulating spontaneously evoked effort mobilization toward incentive money-cues.

Remarkably, participants regulated their responses to conscious non-rewards without any explicit instructions to do so. Thus, whereas previous work on the role of consciousness in adapting behavior often instructs subjects to strategically process information or to alter their behavior, our findings suggest that participants spontaneously adopted a strategy that seems fairly adequate in dealing with motivated responses to consciously perceived money-cues. Although we did not examine the exact mechanism as to how people arrive at such a strategy, the general gist of our findings converges well with research showing that people avoid wasting limited resources when they have the opportunity (Bijleveld et al., 2012-a; Gendolla et al., 2012).

Our findings bear similarities with previous work revealing that needs (e.g., thirst) modulate the way people react to unconscious stimuli (Karremans et al., 2006; Strahan, et al., 2002; Veltkamp, Aarts, & Custers, 2008). For instance, subliminal primes related to drinking behavior increased subsequent consumption only when participants were thirsty (Strahan et al., 2002). The present study extends this earlier work by providing two important new insights. First, in previous work participants were given the opportunity to drink water after the subliminal exposure to drinking-related concepts. In this case, the primes caused thirsty participants to drink more fluid as a means to reduce their need. Here we show that subliminal cues that are relevant for people's personal needs can instigate motivational processes that boost effortful performance, even though the performance is not instrumental in satisfying the need. Accordingly, whereas previous research demonstrates that subliminal incentive cues motivate instrumental behavior, our findings illustrate that subliminal incentive cues can also motivate non-instrumental behavior—a case of unconscious unintended motivational effects.

Second, previous work on priming and needs has not directly tested the role of consciousness in eliciting effects on motivated behavior, possibly because conscious and unconscious priming often lead to parallel effects (e.g., Aarts, Custers, & Wegner, 2005; Chartrand & Bargh, 1996; Veling, Ruys & Aarts, 2012). The present work shows that when incentive cues cause a non-instrumental motivational boost of effort, conscious perception of these cues causes a down-regulation of this boost, preventing non-instrumental expenses of effort. Future work involving direct comparisons between conscious and unconscious priming manipulations may further establish the unique and perhaps crucial role of consciousness in effort regulation and motivated behavior.

To conclude, the present studies show that people who are in need for money work harder when unconsciously exposed to monetary non-rewards. Yet, these people also manage to regulate these immediate reactions when allowed to consciously attend to money-cues. Thus, while consciousness may not be needed to become motivated to work for monetary rewards, conscious awareness appears to play an essential role for regulating one's eagerness to work for money when it is not a reward.

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Summary in Dutch

Nederlandstalige Samenvatting

De effecten van beloningen op menselijke prestatie zijn een wederkerend thema in de psychologie. In het vroege onderzoek naar de effecten van beloningen domineerde de op het behaviorisme gebaseerde zichtwijze van een een-op-een-relatie tussen beloningswaarde en prestatie (Skinner, 1953; Thorndike, 1932). Met andere woorden, men nam aan dat het vooruitzicht op een hogere beloning altijd tot betere prestatie zou leiden. Maar dit bleek vaak niet zo te zijn. Later onderzoek richtte zich daarom voornamelijk op de cognitieve mechanismen die de relatie tussen beloningswaarde en prestatie mediëren, zoals complexe beslissingen en gedragsstrategieën voor het behalen van beloningen. Het huidige onderzoek brengt wederom een nieuwe nuance aan door expliciet in te gaan op de rol van bewustzijn in het behalen van beloningen. Dit onderzoek sluit aan bij een bredere vraag naar de rol van bewustzijn in het reguleren van doelgericht menselijk gedrag meer algemeen. Hoewel contra-intuïtief, is er de laatste decennia steeds meer onderzoek dat suggereert dat veel van ons complexe doelgerichte gedrag op processen berust die onbewust verlopen, en dat bewustzijn van deze processen vaak pas achteraf van pas komt.

En rol voor bewustzijn?

Uit het oogpunt van onderzoek naar de complexe beslissingen en gedragsstrategieën die verbonden zijn aan het nastreven en behalen van beloningen lijkt het bewuste waarnemen van een beloning in eerste instantie wellicht essentieel. Er zijn echter aanwijzingen dat dit niet altijd zo is. Allereerste evidentie leverde een studie van Pessiglione en colleaga's (2007). In deze studie konden proefpersonen beloningen verdienen door telkens zo hard mogelijk in een handgreep te knijpen. Elke keer voordat de proefpersonen in de handgreep gingen knijpen kregen zij eerst een muntje te zien, dat aangaf hoeveel zij voor de volgende keer knijpen maximaal konden verdienen. De muntjes waren van relatief lage (1 Britse Penny) of hoge (1 Britse Pond) waarde. Hoe harder een proefpersoon kneep hoe groter het percentage van het getoonde bedrag hij of zij zou verdienen. Het bijzondere aan dit experiment was dat de muntjes niet altijd bewust waarneembaar waren. Dat wil zeggen, soms werden de muntjes lang genoeg gepresenteerd (bijv. 300 milliseconden; oftewel supraliminaal) om ze bewust waar te kunnen nemen, maar soms werden de muntjes maar enkele milliseconden (subliminaal) getoond, en waren ze (volgens rapportage van de proefpersonen) niet bewust zichtbaar. De resultaten van de studie lieten zien dat hogere beloningen tot betere prestatie leiden, ongeacht of zij bewust of onbewust worden waargenomen. Deze studie liet voor het eerst zien dat bewustzijn van de waarde van een beloning niet nodig is om instrumentele prestatie uit te lokken, en markeerde het beginpunt voor een reeks onderzoeken naar de effecten van bewust en onbewust waargenomen beloningen (zie bv. Bijleveld, Custers, & Aarts, 2009; Capa, Bustin, Cleeremans, & Hansenne, 2011), waaronder ook het onderzoek in deze dissertatie.

Hoe kunnen de opmerkelijke resultaten van deze studie worden verklaard? Volgens neurowetenschappelijk onderzoek speelt hierbij het zogenaamde "beloningssysteem", een subcorticale breinstructuur die met name het ventrale striatum omvat, een belangrijke rol. Het beloningssysteem is gespecialiseerd in het snel en efficiënt detecteren en evalueren van diverse, potentieel belonende stimuli in de omgeving (Lebreton, Jorge, Michel, Thirion, & Pessiglione, 2009; Montague & Berns, 2002; Seymour & McClure, 2008). Het speelt verder ook een belangrijke rol voor het voortbrengen van instrumenteel gedrag om beloningen te verkrijgen. Het systeem levert namelijk input aan hogere corticale gebieden, die wederom essentieel betrokken zijn bij het ondersteunen van complex, moeizaam en doelgericht gedrag (Liljeholm & O'Doherty, 2012; Salamone, Correa, Farrar, Nunes, & Pardo, 2009; Schmidt, Lebreton, Cléry-Melin, Daunizeau, & Pessiglione, 2012).

Aangezien subcorticale structuren zoals het beloningssysteem onafhankelijk functioneren van hogere gebieden die met bewustzijn worden geassocieerd (Knutson, Delgado, & Phillips, 2008; Schultz et al., 1995), is het niet verrassend dat zelfs onbewust waargenomen beloningen instrumenteel gedrag kunnen verbeteren, zoals de studie van Pessiglione en collega's (2007) aangetoond heeft. Dit hoeft echter niet te betekenen dat de bewuste waarneming van een beloning *niets* meer toevoegt aan ons instrumentele gedrag. In de studie van Pessiglione en collega's hadden proefpersonen maar één relatief simpele taak, zo hard mogelijk in een handgreep knijpen. De meest adequate respons op hogere beloningen was dus *altijd* om simpelweg meer kracht en moeite toe te passen. Maar er zijn in het leven veel situaties waar het *niet* gerechtvaardigd is om voor een hogere beloning simpelweg meer inspanning te leveren, bijvoorbeeld omdat de beloning niet—of niet meteen—bereikbaar is, of omdat de situatie om een meer strategische aanpak vraagt. Zouden bewust en onbewust waargenomen beloningen ook in dit soort situaties altijd tot dezelfde effecten leiden? Of voegen bewustzijn van een beloning en het vermogen om over de beloningswaarde te reflecteren iets unieks toe in het reguleren van complex doelgericht gedrag? Deze vraag staat centraal in het onderzoek in dit proefschrift, en wordt in de verschillende hoofdstukken vanuit verschillende gezichtspunten onderzocht.

Empirische evidentie

Hoofdstuk 1 geeft een beknopte inleiding in het onderwerp, waarna Hoofdstuk 2 een meer uitvoerige overzicht geeft van de huidige stand van zaken in onderzoek naar de overeenkomsten en verschillen tussen de effecten van bewust en onbewust waargenomen beloningen op processen zoals besluitvorming, taak preparatie, en taak executie. De overige, empirische hoofdstukken gaan dieper in op specifieke onderzoeksvragen. De algemene aanpak daarbij is gebaseerd op de procedure van Pessiglione en collaga's (2007), waarbij proefpersonen telkens supraliminaal en subliminaal aan relatief hoge (bv. 50 cent) en lage (bv. 1 cent) beloningen blootgesteld worden, die zij kunnen verdienen door een goede prestatie te leveren op een daaropvolgende taak. Deze algemene procedure wordt steeds aangevuld of aangepast door systematische veranderingen in de beloningscontext aan te brengen, die het mogelijk maken specifiekere vragen te onderzoeken.

Hoofdstuk 3 onderzoekt de vraag hoe bewust en onbewust waargenomen beloningen voor *toekomstige* prestatie *onmiddellijke* prestatie beïnvloeden. Het idee achter dit hoofdstuk was dat in ieder geval één manier waarop beloningen prestatie verbeteren in verbeterde taak preparatie ligt. Er is vaak aangetoond dat preparatie al begint voordat men alle informatie heeft die nodig is om een taak uit te voeren (Miller, 1987; Min & Herrmann, 2007). Onze verwachting was daarom dat een beloning al een effect op taak preparatie heeft zodra de beloningswaarde verwerkt wordt, zelfs als de beloning pas voor latere prestatie bereikbaar is. Hogere beloningen voor latere prestatie zouden daarom niet alleen latere, maar ook al onmiddellijke, niet beloonde prestatie verbeteren. Om deze hypothese te toetsen voerden wij een experiment uit waarbij proefpersonen telkens twee opeenvolgende tonen te horen kregen, met de instructie om telkens zo snel mogelijk aan te geven of het een hoge of een lage toon was. Voor elk tweetal tonen werd, supraliminaal of subliminaal, een muntje van hoge of lage waarde getoond. Het bijzondere was dat de beloningen te verkrijgen waren door snel en correct op elke *tweede* toon te reageren. Reacties op elke eerste toon waren irrelevant voor het behalen van beloningen. Desondanks vonden wij, conform de hypothese, dat hogere beloningen niet alleen reacties op de tweede, maar ook op de eerste toon versnelden, en dit ongeacht of de beloningen bewust of onbewust werden waargenomen. Wij vonden echter ook een belangrijk verschil tussen bewuste en onbewuste beloningen. Dit verschil lag in de mate waarin de proefpersonen hun reacties strategisch aanpasten. Alleen bewust waargenomen beloningen leidden namelijk tot een strategische afweging tussen snelheid en accuratesse. Dit betekent dat proefpersonen voor hoge bewuste beloningen niet alleen sneller reageerden, maar dat dit ten koste ging van een lagere accuratesse, een bevinding die consistent is met eerder onderzoek (Bijleveld, Custers, & Aarts, 2010). Opmerkelijk was dat deze strategie al optrad bij de eerste, niet beloonde toon. Dit resultaat geeft aan dat bewustzijn van een beloning al tijdens de preparatie voor een latere taak tot strategisch handelen aanzet.

Hoofdstuk 4 gaat nog een stap verder door niet alleen te kijken naar de effecten van beloningen die niet *direct* bereikbaar zijn, maar juist de effecten te onderzoeken van volledig onbereikbare beloningen. Vanuit een standpunt van efficiëntie zou men verwachten dat mensen zich niet inspannen als er niets te halen valt. En inderdaad is er veel onderzoek dat laat zien dat mensen bij het streven naar beloningen bedachtzame berekeningen maken op basis van beloningswaarde en de kans dat een beloning ook bereikbaar is (Brehm & Self, 1989; Wright, 2008). Echter, een dergelijke berekening vereist een integratieproces, waarbij informatie over de beloningswaarde gecombineerd wordt met andere bronnen van informatie over de bereikbaarheid van een beloning. Onze vraag was of dit integratieproces voor zowel bewust als onbewust waargenomen beloningen op dezelfde manier zou functioneren. Het wordt vaak gesteld dat bewustzijn een bijzondere rol heeft in informatie integratie (Baars, 2002; Dehaene & Naccache, 2001; Kouider & Dehaene, 2007). Het zou daarom kunnen zijn dat onbewuste verwerking van een beloning tot verminderde integratie leid, wat ertoe zou leiden dat mensen inefficiënt met hun inspanning omgaan.

Om dit te onderzoeken hebben wij de bovengenoemde procedure dusdanig aangepast dat de beloningen die proefpersonen te zien kregen soms wel en soms niet bereikbaar waren. In een eerste experiment werd dit in dezelfde taakcontext gevarieerd. Dat wil zeggen, voor elk muntje dat gepresenteerd werden kregen de proefpersonen de concrete instructie dat dit muntje of bereikbaar, of juist onbereikbaar was. Vervolgens kregen proefpersonen een werkgeheugentaak, waarbij zij snel aangeboden series woorden in hun werkgeheugen moesten houden om deze na enkele seconden te herhalen. Om bij deze taak *efficiënt* inspanning te leveren, dat wil zeggen alleen wanneer een beloning bereikbaar én de moeite waard was, was het dus nodig om op voor elke mogelijke beloning die op het spel stond informatie over beloningswaarde en bereikbaarheid met elkaar te integreren. De resultaten voor bewuste beloningen lieten zien dat deze integratie plaatsvond. Hoge versus lage beloningen leidden dus tot verbeterde prestatie, maar alleen als deze bereikbaar waren. Voor onbereikbare beloningen was de prestatie algemeen laag ongeacht de beloningswaarde. Voor onbewuste beloningen vonden wij echter een ander patroon; Ten eerste leidden hoge beloningen tot betere prestatie wanneer deze onbereikbaar waren— een verspilling van moeite dus. Verder vonden wij dat onbewuste bereikbare beloningen algemeen tot goede prestatie leidden, ongeacht of zij van hoge of lage waarde waren. Het bleek dus dat proefpersonen, wanneer zij zich niet bewust waren van een beloning, hun inspanning of op de beloningswaarde baseerden, of op het feit dat de beloning bereikbaar was, maar niet op een combinatie van beide.

Om uit te zoeken of dit inderdaad een gevolg was van onvoldoende integratie van informatie, en niet te wijten was aan andere factoren, voerden wij een tweede experiment uit. De procedure leek op die van het eerste experiment, op één belangrijk verschil na. In dit experiment varieerde de bereikbaarheid van beloningen niet binnen de taak maar tussen proefpersonen. Beloningen waren dus voor een persoon of altijd bereikbaar, of altijd onbereikbaar. In deze opzet was het dus niet meer nodig om op trial basis, dus voor elke beloning die getoond werd, informatie over waarde en bereikbaarheid te integreren. En in dit experiment vonden wij dan ook dat zowel bewust als onbewust waargenomen beloningen tot efficiënte prestatie leidden. Samengenomen spreken de studies in dit hoofdstuk er dus voor dat bewustzijn van een beloning weliswaar niet nodig is om mensen te motiveren om te presteren, maar dat het inderdaad een belangrijke rol speelt bij het integreren van verschillende bronnen van informatie die relevant zijn voor het efficiënte nastreven van beloningen.

Op grond van de hierboven besproken studies mag de indruk ontstaan dat bewuste, vergeleken met onbewuste verwerking van beloningen vooral voordelen heeft. Dit hoeft niet perse zo te zijn. Hoofdstuk 5 belicht een situatie waar bewuste verwerking nadelig is voor het behalen van beloningen. Omdat mensen zo gedreven zijn in het behalen van beloningen kunnen beloningen sterk de aandacht trekken en beloningsgerelateerde gedachtes oproepen. Tijdens een beloonde taak kan dit soort afleiding ironisch genoeg juist interfereren van de taak zelf, en dus tot slechtere prestatie leiden (e.g., Beilock, 2007). In dit hoofdstuk wilden wij onderzoeken of deze interferentie specifiek is voor bewust waargenomen beloningen, of ook optreedt wanneer een beloning buiten bewustzijn wordt verwerkt. Hiervoor voerden wij twee experimenten uit. In beide experimenten kregen proefpersonen dezelfde verbale werkgeheugentaak als in hoofdstuk 4, waarbij zij series van woorden over een korte periode in hun werkgeheugen moesten houden. Voor elke reeks woorden was er wederom een hoge of lage beloning te verdienen, die supraliminaal of subliminaal gepresenteerd werd. Het belangrijke verschil tussen de twee experimenten was dat de beloningen of vóór de te onthouden woorden werden getoond (Experiment 5.1) op een moment waar de proefpersonen nog niet bezig waren met de taak, of vlak ná de woorden, en dus op een moment waar het cruciaal was om de aandacht bij de taak te houden (Experiment 5.2). In Experiment 5.1 vonden we dat zowel bewust als onbewust waargenomen hoge (vergeleken met lage) beloningen tot verbeterde prestatie leidden. In Experiment 5.2 daarentegen, vonden wij dat alleen onbewuste hoge (versus lage) beloningen prestatie verbeterden, terwijl bewust waargenomen hoge beloningen prestatie verslechterden. Dit hoofdstuk laat dus zien dat bewustzijn geenszins alleen voordelen heeft, of functioneel is voor effectief doelgericht gedrag, zeker in contexten waar geen strategische afwegingen vereist zijn.

Effecten van waarde

De eerste hoofdstukken van deze dissertatie behandelen allemaal situaties waar mensen met beloningen geconfronteerd worden. In het leven worden we echter ook vaak geconfronteerd met waardevolle en begeerlijke dingen die geen beloningen voorstellen. Geld bijvoorbeeld is weliswaar iets waar vaak prestatie aan gekoppeld is, maar we bevinden ons ook vaak in situaties waar we zomaar aan geld blootgesteld zijn zonder dat het door iets te verkrijgen is. Dit roept een belangrijke vraag op in het licht van dit dissertatie onderzoek; Zijn de hierboven besproken effecten van beloningen inderdaad effecten van beloningen, of zijn zij puur gedreven door blootstelling aan stimuli die geassocieerd zijn met bepaalde *waardes*? Met andere woorden, reageren mensen op dezelfde manier op bewust en onbewust waargenomen geldstimuli wanneer deze geen beloningen signaleren? Deze vraag werd in Hoofdstuk 6 behandeld.

Of geld als beloning ingezet wordt of niet is meestal een objectief feit. Echter, onderzoek heeft laten zien dat de *subjectieve* belonende waarde van stimuli veel meer afhangt van momentane persoonlijke behoeftes (Berridge, Robinson, & Aldridge, 2009; Lebreton et al., 2009). Geld heeft bijvoorbeeld een grotere subjectieve waarde voor iemand die bijna blut is dan voor iemand die net zijn salaris heeft gekregen. Onderzoek heeft verder laten zien dat het waarnemen van stimuli die als persoonlijk belonend worden ervaren spontaan inspanning oproept (Gupta & Aron, 2011; Veling & Aarts, 2011). Gezien deze achtergrond verwachtten we dat geld zelfs tot betere prestatie zou kunnen leiden wanneer het niet als beloning wordt ingezet, althans voor personen met een momentane behoefte aan geld. De vraag was echter in hoeverre mensen deze tendentie zouden kunnen reguleren wanneer zij weten dat het begeerde geld niet objectief een beloning voorstelt. Bewustzijn wordt vaak verondersteld bij te dragen aan het flexibele reguleren en controleren van gedrag (Baars, 2002; Dehaene et al., 2006). Daarom verwachtten we dat bewustzijn van een beloning kan helpen om motivationeel gedrag in respons op geldstimuli te reguleren.

Om dit te onderzoeken hebben wij twee experimenten uitgevoerd. De procedure leek op die uit de experimenten uit de eerdere hoofdstukken. Proefpersonen werden dus wederom subliminaal en supraliminaal aan muntjes van hoge en lage waarde blootgesteld, en kregen na elk muntje een werkgeheugentaak. Deze keer was de taak een visuele taak waarbij proefpersonen complexe plaatjes (bestaand uit willekeurige verdeelde zwarte en witte pixels) moesten onthouden. In Experiment 6.1 maakten wij een expliciete vergelijking tussen condities waar geld wel of niet als beloning diende. Proefpersonen kregen dus de concrete instructies dat de getoonde muntjes ofwel beloningen voorstelden, of gewoonweg (irrelevante) stimuli waren. In de beloningsconditie repliceerden wij de resultaten van eerdere experimenten. Muntjes van hoge waarde leidden dus tot verbeterde prestatie ongeacht of zij bewust of onbewust werden waargenomen. In de geen-beloningsconditie vonden wij een ander patroon. Hier leidden muntjes van hogere waarde niet tot betere prestatie wanneer zij bewust werden waargenomen. Als er al een effect was dan een lichte trend in de tegenovergestelde richting; muntjes van hogere waarde leken de prestatie juist te verminderen. Interessant genoeg leidden onbewust waargenomen muntjes van hoge waarde wel weer tot verbeterde prestatie. Deze resultaten ondersteunden dus onze verwachtingen dat het waarnemen van hoge waarde automatisch motiveert om beter te presteren, en dat bewustzijn van de stimulus nodig is om deze tendentie te reguleren.

Experiment 6.2 gaat dieper in op de rol van persoonlijke behoeftes in deze effecten. Het experiment was in wezen een replicatie van de geen-beloningsconditie in Experiment 6.1, met als toevoeging een meting van de momentane behoeftes van de proefpersonen voor geld. De resultaten voor proefpersonen met hoge behoefte aan geld leken op die van Experiment 6.1. Voor proefpersonen zonder behoefte aan geld, daarentegen, vonden wij geen effecten van de waarde van de muntjes op prestatie. Dit duidt dus aan dat de motivationele effecten van waardevolle stimuli die geen beloningen zijn gedreven worden door persoonlijke behoeftes, die de subjectieve representatie van de stimuli beïnvloeden.

Conclusie

Al met al laat de empirische evidentie die ik in dit proefschrift presenteer zien dat bewustzijn wel degelijk een rol speelt in de effecten van beloningen op menselijke prestatie. Hoewel bewustzijn niet nodig is voor het nastreven en behalen van beloningen, bevordert het toch andere, vaak strategische processen die helpen om flexibeler op beloningen en de beloningscontext te reageren. Dit kan helpen om moeite te sparen voor beloningen die niet, of nog niet, bereikbaar zijn, of om het eigen gedrag te reguleren wanneer men geconfronteerd word met iets dat waardevol is en bij de eigen behoeftes aansluit, maar dat simpelweg geen beloning voorstelt in de momentane context. Bewustzijn kan echter ook in de weg staan, bijvoorbeeld wanneer bewuste gedachtes en reflectie over beloningsinformatie afleiden van de taak die instrumenteel is voor het verkrijgen van de begeerde beloning. Deze resultaten zijn niet alleen relevant voor het begrijpen van processen die direct te maken hebben met het behalen van beloningen, zij spreken ook voor het belang van bewustzijn voor het reguleren van doelgericht menselijk gedrag in het algemeen.

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Curriculum Vitae

Claire Marie Zedelius was born on May 4th, 1984 in Viersen, Germany. She grew up between forests and lakes in Nettetal in the lower Rhine region. This is also where she attended the Werner-Jaeger Gymnasium, from which she graduated in 2003. In September 2003, she enrolled at Radboud University Nijmegen, where she obtained her Bachelor's degree in social psychology in 2006 and graduated (cum laude) from the Behavioral Science Research Master's program in 2008. In October 2008, Claire began a PhD project at Utrecht University, in which she examined the role of conscious awareness in human reward pursuit. This research resulted in the present dissertation. Since November 2012, Claire works as a postdoctoral researcher at the University of California, Santa Barbara.

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