The Unconscious and Conscious Foundations of Human Reward Pursuit

De onbewuste en bewuste fundamenten van het menselijk streven naar beloningen
(met een samenvatting in het Nederlands)

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Chapter 1

Introduction, overview, and implications

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Humans are by nature reward-seeking animals, and they often find themselves in a position to choose between various actions that all lead to attractive outcomes. For example, people can choose to walk to the fridge to get food, to go to the store to buy a book, or to do a job that earns them money. At the same time, the prospect of rewards is widely used to encourage people to do certain things (e.g., things that are not attractive in themselves) or to stimulate them to invest more effort and increase their performance. For example, teachers encourage children to exert effort by giving out stickers, managers stimulate employees by paying salaries, and governments promote pro-environmental choices by offering tax credits. So, people often have to engage in some decision-making process about reward pursuit. That is, they have to resolve which reward is valuable to them at a given point in time, and they have to establish how much effort should be invested to attain it. The present dissertation deals with the question of how people make these reward-related decisions.

Within the field of psychology, this is an important question. While most work in this area considers the decision-making process that underlies the pursuit of rewards to be the result of a conscious and deliberate calculation, research on the neural and cognitive underpinnings of reward pursuit suggests that this process may also operate unconsciously. Moreover, there are theoretical reasons to expect that reward pursuit may lead to different behavioral outcomes (such as related to task performance) when it occurs unconsciously compared to when it occurs consciously. So, gaining insight in how reward pursuit occurs via unconscious and conscious processes—and gaining insight in the circumstances under which these have different effects—is important from a theoretical and practical point of view. That is, examining and understanding the unconscious and conscious foundations of reward pursuit may improve our ability to predict how rewards affect human behavior.

In the remaining of this chapter, I will provide a brief historical overview of the scientific study of reward pursuit in psychology, describing how the field evolved into its current shape. Next, I will argue and discuss in more detail why reward pursuit might well operate unconsciously. Then, I will describe the research that constitutes the meat of the present dissertation. Based on these studies, I will then briefly discuss the current dissertation's theoretical framework, which explains how reward pursuit occurs via unconscious and conscious processes and how these may have different consequences for human behavior. Finally, I will outline the broader implications of this new theoretical framework.

The science of reward pursuit

The study of reward, often considered to be the study of how behavior is instigated and intensified, has fascinated philosophers and other thinkers since ancient times (Aristotle, n.d./1976). The empirical study of this process can be traced back at least to the early behaviorists, who started to address the effects of rewards in the first half of the 20th century. Generally using (hungry) animals as their subjects, these researchers began to describe behavior in terms of the natural rewards, such as food, that could be attained by performing actions. Based on their findings, they proposed that rewarding outcomes strengthen the links between stimuli and specific behaviors. In response to a light flash (a stimulus), for example, rats were found to press a lever in their cage (a behavior) more often and more vigorously after this has previously yielded them food (Skinner, 1938). This notion of *behavior reinforcement* has been widely applied. Even today, it is still used to teach marine mammals to perform stunts during shows.

Yet, the idea that rewards merely glue stimuli and responses together was challenged by findings from further animal research. In one study (Breland & Breland, 1961), for example, pigs were trained—via reinforcement with food—to deposit large wooden coins into a container. While the pigs were initially successful in carrying out this task, something interesting happened after a couple of weeks: the pigs started to treat the coins as if they were food, dropping them in the dirt and digging them around with their snouts. By contrast to the notion of behavior reinforcement, this study demonstrated that the stimuli that are associated with rewards (e.g., coins) can start to function as rewards by themselves. Studies like this, of which the results could not be explained by principles of behavior reinforcement, led to the development of *incentive learning models* (e.g., Bindra, 1978; Bolles, 1972). These models propose that rewards do not forge rigid stimulus–response links, but that they establish *incentive cues*—i.e., cues that predict the occurrence of rewards. Importantly, such incentive cues may by themselves drive and intensify behavior to attain the associated reward. Thus, these models could explain that even objects that are not directly consumable—such as money, in humans—can acquire reward value and can trigger reward-directed behavior and increase performance.

Starting with the cognitive revolution of the 1950s (Neisser, 1976; Miller, 2003), psychologists increasingly became interested in the mental processes underlying incentive learning and human performance, which were often implicitly or explicitly assumed to be accompanied by consciousness (e.g., Baddeley & Hitch, 1974; Norman & Shallice, 1986). They theorized that incentive cues lead animals to *expect* the associated outcomes, perhaps conditional on the expense of some effort. In the special case of humans, this implied that people should be able to represent desirable outcomes in their minds. These mental representations of desired outcomes, often termed *goals*, are thought to lie at the basis of goal-directed behavior. Especially in social psychology (Higgins, 2011), this idea gradually gave rise to elaborate theories that specify how people determine what outcomes to pursue (*goal setting*) and how they do so (*goal striving*) (Aarts & Elliot, 2011; Bargh, Gollwitzer, & Oettingen, 2010). Broadly, there are three approaches that these theories have taken. First, *expectancy-value theories* propose that people engage in actions based on the value of that action's outcome and whether they expect that action to actually cause the outcome (Ajzen & Fishbein, 1980; Atkinson, 1964; Eccles & Wigfield, 2002; Feather, 1982; Heckhausen, 1991). Second, *motivational intensity theory* describes how people pursue rewards by investing effort on tasks, incorporating the important idea that people cannot afford to waste effort (Brehm & Self, 1989; Gendolla, Wright, & Richter, 2011; Wright, 2008). Third, *self-determination theory* provides a broad framework for understanding how people fulfill their needs and desires via intrinsically and extrinsically motivated choices (Deci & Ryan, 1985). Perhaps as an inheritance from the cognitive revolution, these contemporary approaches have in common that they consider humans to be deliberate decision makers, who make conscious choices about the rewards that they pursue.

Unconscious processes in reward pursuit

The idea that people make conscious decisions about reward pursuit is appealing and in line with our introspections. After all, the pursuit of rewards is often accompanied by conscious awareness of the reward. Yet, there is research that suggests that the pursuit of rewards can also occur outside awareness.

First, psychological research has shown that the processes that could well play a role in reward pursuit—estimating a rewarding outcome's value, maintaining it in working memory, recruiting effort to attain it—can operate *unconsciously* (Custers & Aarts, 2010; Hassin, Uleman, & Bargh, 2005). That is, the process itself and the content relevant to the process remain outside awareness (Dijksterhuis & Aarts, 2010). Along with other research on the unconscious processes that cause and shape experiences and behavior (e.g., Bargh, 2007; Wegner, 2002), this research has challenged the traditional idea that the unconscious is relatively stupid and simple. By contrast to what was previously thought, psychological work from the past decades thus suggests that decisions about rewards are strongly supported by unconscious processes.

A second reason for why one could expect that reward pursuit may unfold outside awareness comes from research on how reward pursuit is implemented in the brain. That is, when people process or anticipate a reward, the value of the reward is known to be mirrored by activity in the striatum, a brain structure that lies deep in the brain, below the cortex (Delgado, 2007), and is thought to play a key role in the recruitment of effort (Assadi, Yücel, & Pantelis, 2009; Salamone, Correa, Farrar, Nunes, & Pardo, 2009; Wightman & Robinson, 2002). Interestingly, as the striatum is an ancient brain structure that evolved long before our ancestors developed consciousness, it is probably not associated with conscious awareness (Bargh & Morsella, 2008). This suggests that people have a sense of the value of a reward before they are consciously aware of it.

It is important to note that the striatum is strongly connected to the rest of the brain, particularly to the prefrontal cortex (PFC; Knutson, Delgado, & Phillips, 2008). Unlike the striatum, the PFC has arisen relatively late in human evolution. Accordingly, the PFC is thought to play an important role in producing conscious thought and awareness of information, and in making (strategic) deliberate decisions (e.g., Baars, 2002; Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Lamme, 2006), including those which pertain to rewards. Yet, the wiring of the brain suggests that the PFC gradually becomes involved in reward pursuit *after* the striatum, when reward pursuit is already well under way (Haber & Knutson, 2009). And even if the PFC gets involved in reward pursuit, this does not necessarily mean that people are consciously aware of the reward. Specifically, a recent line of research suggests that the PFC can be activated by stimuli that remain outside awareness (e.g., van Gaal, Ridderinkhof, Scholte, & Lamme, 2010). So, if conscious processes play a role in reward pursuit at all, these processes are preceded and prepared by unconscious processes. In any case, the role of consciousness in reward pursuit is probably smaller than commonly assumed. It is indeed well possible that certain aspects of reward pursuit can be carried out outside awareness.

But what aspects are these? In other words: how do unconscious and conscious processes play a role in the decisions people make about rewards? Do they have different consequences? If so, under what conditions? This is where the present dissertation comes in.

Overview of the present dissertation: Unconscious and conscious processes in reward pursuit

One of the first findings that indicated that rewards could unconsciously and consciously affect performance comes from a study on monetary reward cues and the recruitment of physical effort. Specifically, this experiment revealed that high-value (but not low-value) reward cues could cause people to exert more force during an effortful physical task, even when these rewards were subliminally presented (Pessiglione et al., 2007). Based on this demonstration, we started to explore how unconscious and conscious reward pursuit occurred under different conditions, such as varying effort requirements. In addition, we started to explore whether unconscious and conscious rewards always have similar outcomes, or whether there also might be differences.

Effort requirements and reward value can be combined unconsciously

The study described above raises the intriguing possibility that this effort recruitment effect—that is independent of conscious awareness and relied on rudimentary brain structures—is the result of an unconscious weighing process, that takes into account not only the value of the reward but also the amount of required effort. To test this possibility, we conducted an experiment in which participants were exposed to monetary rewards (i.e., coins of high vs. low value) that they could earn by holding a series of digits on their mind for a couple of seconds, and then correctly reporting them back. During this working-memory task, which was either fairly easy (3 digits) or moderately difficult (5 digits), the dilation of participants' pupils was recorded. This measure, that is known to be linked to activation of the sympathetic nervous system, served as an indication of how much mental effort was recruited to attain the reward that was at stake (Kahneman, 1973). Replicating previous work (Pessiglione et al., 2007), findings indeed indicated that people expended more effort for higher-value rewards, regardless of whether these were consciously perceived. Importantly, however, this occurred only when reward attainment required the expense of a significant amount of effort, i.e., only when people had to maintain 5 digits (Bijleveld, Custers, & Aarts, 2009; Chapter 3). So, as it turned out, people combine rewards with effort requirements, and they can rely on an unconscious weighing process to do so.

In three follow-up experiments, this finding was studied in more detail. In these experiments, participants were again exposed to coins that they could earn, in this case by carrying out a physical effort task in which they were required to quickly tap a key on a computer keyboard. To gain further insight in the process by which people integrate rewards and effort requirements, effort requirements were manipulated in several ways. These experiments supported the more specific idea that whenever more physical effort is demanded, people become more sensitive specifically to rewards that are high (vs. lower) in value, via a process that is not dependent on conscious awareness of the reward. Importantly, these studies showed that people become more sensitive to unconsciously presented rewards when they detect *any* bodily effort requirements, even if these requirements are unrelated to the specific reward that is at stake (Bijleveld, Custers, & Aarts, submitted; Chapter 4).

So far, the studies largely suggested that unconscious and conscious reward pursuit unfolds in the same way, and have the same consequences for performance. However, our research also revealed that there are circumstances under which unconscious and conscious processes have *different* effects. Specifically, in one of our studies (Chapter 4, Experiment 3), conscious processes prevented people from taking into account irrelevant effort requirements—i.e., effort requirements that were unrelated to the reward that was at stake. This finding suggests that there are specific functions tied to conscious reward pursuit that have additional merit for attaining rewards while at the same time conserving effort (Baars, 2002; Dehaene et al., 2006; Schooler, 2002).

Task strategies can be changed only consciously

To gain insight in the specific functions of conscious processes in reward pursuit, further experiments were conducted. These experiments were designed to test the hypothesis that when people become conscious of a reward that is at stake, they may formulate or change strategies in the service of adaptively attaining this reward (Dehaene et al., 2006).

In two studies, this hypothesis was examined in a context in which people were able to choose their own strategies for attaining rewards. In a task in which they could earn money by quickly and accurately solving mathematical equations, people could choose to prioritize accuracy (leading to a greater chance at a smaller reward), or on speed (leading to a smaller chance at a greater reward). In line with what was expected, findings indicated that unconscious processes simply led to the facilitation of performance (i.e., people were faster at the same level of accuracy), but that conscious processes induced people to also change their speed–accuracy-related strategies (Bijleveld, Custers, & Aarts, 2010; Chapter 5). This finding is in line with the idea that conscious processes lead people to change their task strategies in such a way that they think this helps them to attain the reward.

A follow-up study examined the idea that people's conscious strategies may sometimes backfire—and hurt instead of help performance (DeCaro & Beilock, 2010). This counterintuitive outcome was hypothesized to occur in tasks in which valuable rewards induce people to consciously concentrate on the task that leads to reward attainment, as increased concentration can ironically increase the extent by which people process distracting information. One of these tasks is the *Attentional Blink* task, a task in which people have to detect two targets among a rapidly changing stream of distractors (Olivers & Nieuwenhuis, 2006). To test this idea, we conducted a study in which people could earn money by doing an Attentional Blink task. In line with our hypothesis, unconscious processes initiated by rewards facilitated performance, but the subsequent conscious processes that were induced by the same rewards thwarted this initial facilitation (Bijleveld, Custers, & Aarts, 2011a; Chapter 6; for related ideas, see Gable & Harmon-Jones, 2010).

Taken together, the data that are presented in this dissertation suggest that reward pursuit is shaped by successive unconscious and conscious processes. First, people can rely on unconscious processes to recruit effort, and that this occurs via a weighing mechanism that takes into account the momentary demands of the situation. While this unconscious process is adaptive in that it facilitates reward attainment and conserves effort, it is also relatively simple. This simplicity may sometimes lead to suboptimal outcomes, e.g., when effort requirements are irrelevant for attaining the reward that is at stake. Second, when people become conscious of a reward that can be earned, they may not just recruit more effort but they can also change or formulate task strategies in order to attain the reward. This may be helpful in some cases, but it can also hurt performance, e.g., when people choose the wrong strategy to attain the reward.

Building on the data reported in this dissertation and on other recent research (Bargh & Morsella, 2008; Berridge, 2003; Camerer, Loewenstein, & Prelec, 2005; Capa, Bustin, Cleeremans, & Hansenne, 2011; Childress et al., 2008; Haber & Knutson, 2009; Pessiglione et al., 2007; Zedelius, Veling, & Aarts, 2011), a framework for understanding how unconscious and conscious processes successively shape reward pursuit is presented in Chapter 2 (Bijleveld, Custers, & Aarts, in press). The ideas expressed in this framework, finally, are taken outside the laboratory and onto the tennis court. That is, Chapter 7 (Bijleveld, Custers, & Aarts, 2011b) reveals that real-life reward cues—in this case, the trophies that are sometimes displayed near the tennis court during finals of professional tournaments—affects performance of tennis players as can be predicted from the ideas that are described in and supported by the present dissertation.

For further details of the theory and of the studies that were described above, the interested reader can turn to Chapters 2–7. It should be noted that each chapter in this dissertation, except for the present one, is based on an article that has also been published in or submitted to a scientific journal. As such, the chapters can be read independently and in any desired order. In the remaining of the current chapter, I address a few broader implications of the current dissertation as a whole. To learn about more detailed implications, I encourage the interested reader to read the individual chapters, especially Chapter 2.

Implications

The present dissertation reveals how subsequent unconscious and conscious processes shape reward pursuit (see Chapter 2). Accordingly, it challenges the traditional idea that human motivation to pursue rewards or goals is based on conscious calculations about the *value*, the *expectancy*, and the *demands* of outcomes (Eccles & Wigfield, 2002). Specifically, it suggests that it is not always necessary to take such models as a starting point. Instead, in order to paint a more accurate picture of how people pursue rewards, it proved useful to address the unconscious processes that presumably make use of rudimentary brain structures. Importantly, these unconscious processes not only serve as an input for conscious deliberation (Camerer et al., 2005), they may also affect behavior more directly. The research and theory that is laid out in the present dissertation incorporated and further developed this idea. Thus, by contrast to traditional expectancy–value models, the present dissertation highlights the importance of unconscious processes in reward pursuit.

An important finding from the experiments that are reported in this dissertation is that, via unconscious processes, rewards facilitated performance across various mental and physical tasks. This finding is especially striking as many of the tasks on which facilitation occurred are thought to require conscious awareness. For example, to accurately solve a complex mathematical equation, one needs to be consciously instructed about what the task is, and one needs to be consciously aware of the mathematical operands and operators (but see Ric & Muller, in press). Yet, even on such tasks, performance can still be facilitated via unconscious, reward-instigated processes. This finding lends novel support for the recent idea that conscious and deliberate processes are affected and perhaps even shaped by the unconscious processes that precede them (Hassin et al., 2005).

Furthermore, the present dissertation has implications for the modern idea that the pursuit of rewards and goals can occur in the absence of conscious awareness (Bargh, 2006; Bargh, Gollwitzer,

& Oettingen, 2010; Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001; Custers & Aarts, 2005, 2010; Dijksterhuis & Aarts, 2010). Research that supports this proposal has often taken the approach of systematically testing whether key aspects of goal-directed action (e.g., keeping a rewarding outcome active in mind) require conscious awareness. This endeavor often raised the controversial suggestion that conscious processes make no unique contribution to goal pursuit, as these key qualities of goal-directed behavior proved *not* to rely on awareness (Bargh, Gollwitzer, et al., 2010). Yet, most of these studies exclusively focused on unconscious processes, and direct comparisons to their conscious counterparts are relatively rare (for examples, see Bargh, Gollwitzer, et al., 2001, Experiment 2; Custers & Aarts, 2005, Experiment 4; Mc Culloch, Ferguson, Kawada, & Bargh, 2008, Experiments 2-3; Parks-Stamm, Oettingen, & Gollwitzer, 2010, Experiment 1). And even if such control conditions were included, these are problematic, as unconscious and conscious activation of goals is usually induced via procedures that are by nature very different (e.g., overt instructions vs. priming). In this dissertation, a methodological solution for this problem is proposed—i.e., presenting the same reward information so that it can be consciously perceived (supraliminally) or not (subliminally). Using this approach, unconscious processes can be compared with their exact conscious equivalents, leading to more specific ideas of the qualities and the limitations of each. Thus, the present dissertation not only shows how conscious processes contribute to the pursuit of goals, it also provides a new means of specifically targeting these processes.

Theories of consciousness have addressed related issues, aiming to specify how cognition and behavior are affected when people become consciously aware of certain stimuli, such as rewards

(Baars, 2002; Dehaene & Naccache, 2001; Kouider & Dehaene, 2007; Lamme, 2006). While these theories have not yet reached agreement, they have converged on the idea that consciousness is involved in *integration*—or, the coordination of processes that would otherwise operate independently (Seth, 2009). This process has been proposed to make use of a widespread frontal-parietal brain network that 'broadcasts' information to various other brain structures (Baars, 2002; Dehaene et al., 2006). The behavioral effects of such integrative functions have often been examined in semantic priming tasks. These have generally shown that subliminal stimuli are less 'integrated': although they can be semantically processed (*bottom-up*), they cannot affect how people strategically deal with tasks (*top-down*) (e.g., Naccache, Blandin, & Dehaene, 2002; Van den Bussche, Segers, & Reynvoet, 2008).

Still, it seems to be the case that some types of integration may occur without consciousness and without engaging this widespread brain network (Morsella, 2005). For that reason, the nature and the behavioral consequences of consciousness are currently quite unclear (Dehaene & Naccache, 2001). As the present dissertation studies how consciousness has a role in reward-directed action, it develops and tests new and specific ideas with regard to this issue. That is, chapter 4 shows that effort requirements and rewards can be unconsciously integrated in a basic manner (see also Mudrik, Breska, Lamy, & Deouell, 2011, for integration of visual information), but that when people become consciously aware of the reward, they take into account effort requirements more strategically, i.e., only when they are relevant. Along similar lines, chapters 5 and 6 show how conscious awareness of rewards can promote the coordination of task strategies that involve making tradeoffs between speed and accuracy and the deployment of attention, respectively (see Naccache et al., 2002). So, while the behavioral effects of ‘integration’ were previously mainly examined in terms of how people semantically process information, the present dissertation reveals what it means in terms of reward-directed action.

Taken together, the present dissertation has important implications for the field of human motivation to pursue rewards, as it provides a framework for understanding how unconscious and conscious processes together shape reward pursuit. Furthermore, it describes a useful method for disentangling and studying these processes. In addition, the present dissertation has implications for the scientific study of consciousness, as it provides a new way of understanding the behavioral consequences of being consciously aware of stimuli—stimuli that signal rewards, in this case. This dissertation has thus has led to several new insights. But perhaps more importantly, it may inspire future research that is rewarding to conduct.

Chapter 2

Human reward pursuit: From rudimentary to higher-level functions

Abstract: Human reward pursuit is often found to be governed by conscious assessments of expected value and required effort. Yet, research also indicates that rewards are initially valuated and processed outside awareness, using rudimentary brain structures. Building on both findings, we propose a new framework for understanding human performance in the service of attaining rewards. In essence, we suggest that people initially process rewards unconsciously, which can boost effort and facilitate performance. Subsequently, people may process rewards more fully, which allows them to make strategic decisions based on task conditions, and to consciously reflect on rewards. Intriguingly, these specific processes associated with full reward processing can cause initial vs. full reward processing to have different effects on performance. In the present article, we address recent research that supports this framework. Finally, we discuss how the present framework may lead to a refined yet broadly applicable understanding of the human pursuit of rewards.

This chapter is based on: Bijleveld, E., Custers, R., & Aarts, H. (in press). Human reward pursuit: From rudimentary to higher-level functions. *Current Directions in Psychological Science*.

Human reward pursuit: From rudimentary to higher-level functions

Human beings are regularly confronted with the opportunity to attain rewards for which they need to work. In psychology, such reward pursuit is often conceptualized and examined in terms of people's assessments of *expected value* (Eccles & Wigfield, 2002; Feather, 1982). When determining which reward to pursue and how much effort to invest, people are assumed to weigh the *value* of a reward with its *expectancy* (e.g., whether it can be attained) and its *demands* (e.g., how much effort is required). This analysis underlying performance is often thought to require consciousness, as it relies on higher-level functions such as value learning and information integration. Recent findings, however, indicate that many of these functions may also operate outside awareness (Custers & Aarts, 2010; Hassin, Bargh, Engell, & McCulloch, 2009; Olson & Fazio, 2001). In line with these discoveries, we propose that rewards receive *initial processing* in the service of performance outside awareness, and then receive *full processing* when they are consciously perceived. In this article, we address how these two stages shape reward pursuit.

The idea that stimuli initially receive basic, pre-conscious processing is not new (Bargh, 2006). For example, unconsciously perceived stimuli have been shown to impact performance on tasks that require semantic processing (e.g., Dehaene et al., 2006). Along similar lines, fearful stimuli are thought to prompt action before they enter conscious awareness via an initial, quick route (that relies on subcortical brain structures), only to be processed more fully via a slower but more thorough route (that relies on both subcortical and cortical brain structures) (LeDoux, 1996). In line with these demonstrations, we propose a new framework that focuses on the human pursuit of rewards and specifies how performance in the service of rewards is supported by subsequent unconscious and conscious processes. Summarized in Table 1, our framework draws from research from neuroscience and psychology, specifying how and when these unconscious vs. conscious processes have distinct behavioral consequences.

In essence, we propose that people first process rewards in rudimentary, subcortical brain structures—most notably, the striatum. Whereas this initial process can serve as a source of information for further deliberation (Camerer, Loewenstein, & Prelec, 2005), we propose that it can also facilitate task performance directly, as it can prompt the recruitment of effort in the service of reward attainment. Notably, this initial process can operate in the absence of conscious awareness of the reward. Subsequent to this initial valuation, rewards may be processed more fully—i.e., also engaging higher-level cognitive functions located in the cortex. Only when such full processing takes place, people are consciously aware of the reward. This allows them to change the strategies they employ to attain the reward, and to reflect on its meaning. This process, which is specific to full reward processing, may distinctly affect behavior above and beyond the mere recruitment of more effort.

We will now proceed to further characterize the qualities of initial and full reward processing. Then, we discuss a series of recent studies that employed a novel monetary reward priming paradigm to analyze and compare the effects of initial vs. full reward processing, providing evidence for the present framework. Finally, we describe how our framework may broadly contribute to our understanding of human choice behavior and performance.

Initial reward processing

To understand the neural underpinnings of reward pursuit, researchers have examined the brain structures that are engaged when people invest effort to attain rewards. It has often been shown that when people initially establish the value of rewards, they rely on subcortical brain structures that are part of the dopamine system. One of these structures in particular, the striatum (which encompasses the nucleus accumbens), reliably mirrors the reward value of stimuli in the environment, such as related to food, sex, drugs, and money (Delgado, 2007). Thought to have arisen early in evolution, the striatum is generally not considered to be associated with consciousness (e.g., Dehaene et al., 2006; but see Merker, 2007). In line with this idea, a study among cocaine users showed that reward-related stimuli (i.e., pictures related to cocaine) engaged the striatum, even though these were presented at low intensity, too briefly to be consciously reportable (Childress et al., 2008). This finding indicates that initial reward valuations make use of rudimentary brain functions and that they require only little perceptual input of the reward to take place—at least, less than is needed for the reward to be consciously detectable.

Nevertheless, such initial valuations have important implications for people's behavior, in that they can directly boost the expense of effort to attain rewards. In a first experiment (Pessiglione et al., 2007), participants could earn rewards by performing an effortful task. On each trial, participants first saw the reward at stake, a high-value vs. a low-value British coin, which they could earn by squeezing forcefully into a handgrip: the harder they squeezed, the greater the proportion of the coin they received. Importantly, the duration of the coins was varied so that they could either be processed only initially

	Required intensity of reward	Phenomenological experience of reward	Functionality and potentially involved brain structures	Behavioral outcomes
Initial reward processing	Low	Reward is not consciously experienced	Rudimentary (VS and its immediate outputs)	Facilitation of performance
Full reward processing	High	Reward is consciously experienced	Rudimentary (VS and its immediate outputs) + Higher-level (MPFC, ACC, DLPFC)	Facilitation of performance + task strategies and reflections

Table 1. Framework for understanding how human reward pursuit occurs via rudimentary and higher-level functions, and how this affects performance on tasks. VS = Ventral Striatum; MPFC = Medial Prefrontal Cortex; ACC = Anterior Cingulate Cortex; DLPFC = Dorsolateral Prefrontal Cortex.

(17 or 50 milliseconds), or fully (300 ms). Strikingly, it was found that even at the shorter durations—which did not allow for conscious perception of the coins—people still squeezed harder when the coins were of higher value. In line with the study on cocaine users addressed above (Childress et al., 2008), the brain areas that were associated with this behavior were subcortical, and rudimentary in nature. Importantly, initial reward valuation processes can thus directly facilitate performance on tasks (Table 1)—in this case, it increased crude physical force.

A further study addressed the possibility that people do not reflexively invest effort upon initial processing of a reward cue, but only when they face a task in which the expense of effort is in fact required (Bijleveld, Custers, & Aarts, 2009). If such were true, it would suggest that people can unconsciously integrate information about effort requirements and reward value, which is in line with research showing that animals indeed carry out such integrations in rudimentary brain structures (i.e., the striatum; Phillips, Walton, & Jhou, 2007). Using the same monetary reward priming paradigm as previous work (Pessiglione et al., 2007), Bijleveld and colleagues (2009) tested this idea by rewarding people for doing a non-demanding or a demanding task (i.e., they had to retain either 3 or 5 digits). During this task, pupil dilation was recorded as an unobtrusive measure of effort. As expected, findings indicated that rewards—also when they were processed only initially—boosted mental effort specifically when it was required, i.e., only when people faced a demanding task (Figure 1). Thus, even on a rudimentary level, people are capable of adaptively responding to reward cues: they take into account not only the value of the reward at stake, but also the effort requirements of the current situation. This conclusion is in line with the idea that people have a profound tendency to spend effort only when they need to, conserving it when they can (Brehm & Self, 1989; Gendolla, Wright, & Richter, 2011; Hull, 1943; Kool, McGuire, Rosen, & Botvinick, 2010).

Full reward processing

Rewards may also be processed more fully. In terms of the brain structures that are engaged, this implies that reward processing may involve higher-level cognitive functions located in the frontal cortex, after the rudimentary structures have processed the reward. Most notably, these likely include the medial prefrontal cortex (involved in integrating multiple signals in the brain to make strategic decisions), the anterior cingulate cortex (involved in executive control over behavior, among other functions), and the dorsal prefrontal cortex (involved in actively maintaining reward information over time) (Haber & Knutson, 2009). Thus, the structure and function of the brain suggests that rudimentary and higher-level functions are successively engaged, while only the latter are associated with conscious awareness of the reward that is at stake (Berridge, 2003).

The engagement of the cortex in the service of reward pursuit likely has important implications for behavior. While the recruitment of effort may already be under way (due to initial reward processing), these higher-level functions are known to be involved in controlling and coordinating brain processes that would otherwise operate independently (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006), thereby allowing people to initiate a more advanced mode of reward pursuit (Wallis & Kennerley, 2010). This idea resonates with theories of reward pursuit that propose that people consciously reflect on a reward's expectancy, its value, and any information they have about task demands before they take a strategic decision about

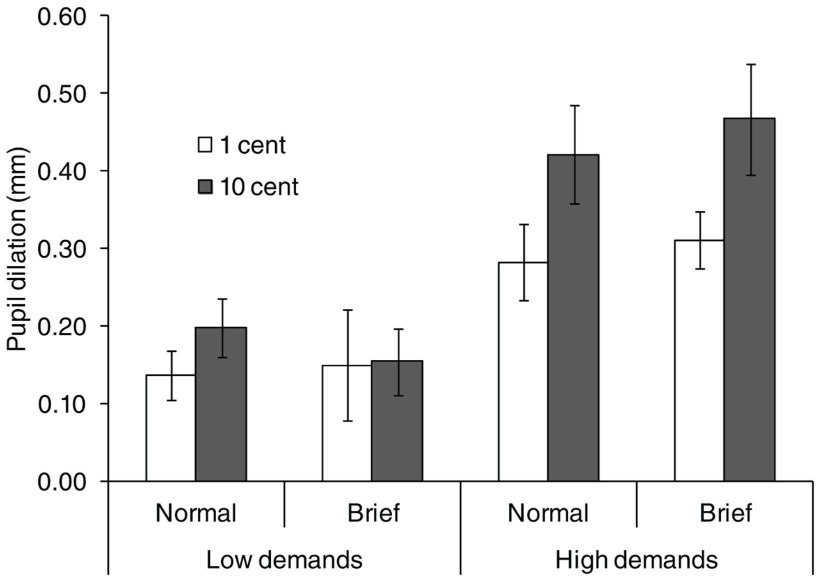

Figure 1. Pupil dilation (mm)—a measure of mental effort—as a function of reward value (1 cent or 10 cent), how the reward was presented (normally or briefly), and the demands of the task (low or high). Even when they process rewards only initially (due to brief presentation, in this case) people exert mental effort during reward pursuit in an adaptive way—i.e., only when effort is actually required to attain the reward. The figure is taken from Bijleveld et al. (2009).

how to attain it (e.g., Brehm & Self, 1989; Eccles & Wigfield, 2002). Building and extending on this work, we propose that full processing of a reward allows people to make strategic decisions about attaining this reward (Dehaene et al., 2006), above and beyond the mere recruitment of effort. Moreover, full processing allows people to reflect on the reward at stake (Schooler, 2002). As we will address below, these specific features of full reward processing can cause the outcomes of initial vs. full reward processing to diverge.

When consequences of initial and full reward processing diverge

In many tasks, performance is mainly determined by the recruitment of effort (e.g., squeezing a handgrip, recalling a series of digits). As strategic considerations play only a minor role in such tasks, the specific processes that are instigated by full reward processing do not necessarily change performance. This idea is corroborated by the research addressed above, in which rewards led to similar outcomes regardless of whether they were processed fully or only initially. In other tasks or circumstances, however, people may choose between multiple strategies that might increase their chance at attaining the reward (e.g., people may choose an eager vs. a cautious strategy). As full reward processing may enable people to make such strategic choices, these task situations may foster differences between initial vs. full reward processing.

In a study designed to test this idea (Bijleveld, Custers, & Aarts, 2010), people could earn money by quickly and accurately solving a mathematical equation. In doing this demanding task, they could decide whether to focus on speed or accuracy of performance—in other words, they could choose between an eager vs. a cautious strategy. When rewards were processed only initially, people did not change such strategies (that is, while people were faster for higher rewards, this did not reduce accuracy). When rewards were fully processed, however, people strategically prioritized accuracy over speed, in order to be sure to attain the reward. Full reward processing thus permits people to make strategic choices of which they think it serves reward attainment.

People do not always make the right choice, though. Some task situations are known to evoke strategies in people that *hurt* instead of help performance. For example, people often feel that concentrating on a task that requires attention helps them to perform well, but this strategy may backfire on tasks such as the Attentional Blink (Olivers & Nieuwenhuis, 2006), in which two target stimuli have to be detected in a quickly-changing stream of distracters. In a study, people were rewarded for accurately detecting the targets of these task, which is challenging. While initially processed rewards boosted performance, this performance increment disappeared when the same rewards were fully processed (Bijleveld, Custers, & Aarts, 2011a). This finding supports the idea that full reward processing leads people to consciously choose a strategy—concentrating on the task, in this case—but that this strategic choice may backfire and hurt performance. Thus, although full reward processing may lead to the engagement of higher-level functions, this does not necessarily enhance the effectiveness of reward pursuit.

Aside from enabling the selection of specific task strategies in the service of reward attainment, full reward processing is associated with conscious awareness of the reward that is at stake. Accordingly, full reward processing may cause people to reflect on the meaning and the importance of this reward (Schooler, 2006). Importantly, recent research suggests that such reflections can affect performance as well. People who carried out a demanding working memory task *during* which they processed rewards fully performed *worse* on this task, while the same rewards boosted performance when they were processed only initially (Zedelius, Veling, & Aarts, 2011). This finding is in line with the idea that thinking about desired outcomes (e.g., attaining money) may distract attention away from the current task, and may thus hamper performance (Beilock, 2010; Bijleveld, Custers, & Aarts, 2011b).

The notion that fully (but not initially) processed rewards distract attention may be explained by the idea that fully processed rewards can put people in a conscious state of mind in which they deliberate or ruminate about how to deal with the present situation (e.g., “Is it worth the effort?”; “Can I really do it?”)—which can impede ongoing performance on demanding tasks (Gollwitzer, 1990; Kuhl, 1984). This theoretical perspective may be employed to further understand and examine the conditions under which full reward processing hurts performance. For example, some task contexts have the potential to be interpreted in terms of rewards (e.g., due to instructions), and may thus be more likely to be impacted by full reward processing (Koole & Jostmann, 2004; Richter, 2010). Furthermore, some people more than others are more likely to ruminate about desired outcomes (such as rewards), and may thus be more prone to the adverse effects of full reward processing (e.g., Kuhl, 1984). Drawing from this work, new predictions may be formulated about when and in whom the effects of full reward processing are most pronounced.

Conclusion and implications

The current framework suggests a new, more precise way of understanding how people act when they pursue rewards. Specifically, we reviewed research that converges on the idea that reward pursuit is shaped by the subsequent employment of rudimentary and higher-level functions, which distinctly affect behavior (Table 1). We suggested that initial reward processing may lead to simple facilitation of performance via the recruitment of effort. Accordingly, when task performance is mainly determined by effort, initial and full reward processing may have the same outcomes. However, in specific circumstances—i.e., when task strategies and/or conscious reflection on the reward affect performance—the outcomes of initial and full reward processing can diverge. As it turns out, full reward processing does not necessarily lead to better outcomes.

A key implication of our framework is that it is not necessary, or even desirable, to always assume that people make conscious assessments about expectancy and value when they pursue rewards (Camerer et al., 2005; Custers & Aarts, 2010). Instead, our analysis indicates that the rudimentary functions that underpin these assessments can also affect performance directly. While the studies described above mainly addressed decisions related to effort and performance, the ideas in principle extend to other types of decisions as well—such as decisions in negotiations, and decisions under risk. For example, initial processing of valuable rewards may increase risk-seeking choices (Knutson, Wimmer, Kuhnen, & Winkielman, 2008), whereas full processing may instead lead to risk-aversion (Bijleveld et al., 2010). The present framework thus generates new and specific hypotheses about when rudimentary and higher-level functions have similar vs. different consequences for decisions.

More broadly, the present framework may prove interesting to fields of research that have identified and studied the effects of administering rewards to increase people's motivation and performance. For example, when rewards can be earned on a task, these are often found to undermine motivation due to decreases in task enjoyment (Deci, Koestner, & Ryan, 1999; Murayama, Matsumoto, Izuma, & Matsumoto, 2010), a finding that carries important implications for educational and organizational practices.

As these effects stem from people's reflections on what is at stake (Deci et al., 1999), they likely occur due to full reward processing. Accordingly, the present framework raises the possibility that initial and full reward processing have different consequences for how people experience the tasks that they carry out in pursuit of rewards. Perhaps, when people process extrinsic rewards only initially, this may boost performance *without* compromising task enjoyment. Taken together, the present framework provides a new way of looking at important psychological phenomena, contributing to a precise but broadly applicable science of the effects of rewards on human motivation and performance.

Chapter 3

The unconscious eye opener: Pupil dilation reveals strategic recruitment of resources upon presentation of subliminal reward cues

This chapter is based on: Bijleveld, E., Custers, R., & Aarts, H. (2009). The unconscious eye-opener: Pupil size reveals strategic recruitment of resources upon presentation of subliminal reward cues. *Psychological Science, 20*, 1313-1315.

The unconscious eye opener: Pupil dilation reveals strategic recruitment of resources upon presentation of subliminal reward cues

Recent research suggests that reward cues, in the absence of awareness, can enhance people's investment of physical resources (Aarts, Custers, & Marien, 2008; Pessiglione et al., 2007). Pessiglione et al., for example, showed that participants spent more physical effort in a demanding force task when they could gain a high-value coin (a pound) than when they could gain a low-value coin (a penny), even when the coins were presented subliminally (i.e., below the threshold of awareness). One explanation for this intriguing finding is that subliminal reward information is processed strategically—that the costs (i.e., the required effort) and benefits (i.e., the value of the reward) of an action are weighed against each other. However, such a weighing process would require higher control functions (Cohen, Heller, & Ranganath, 2005) that are typically thought to operate only on information available to consciousness (Baars, 2002). Another explanation is that the prime directly boosts resources. From this perspective, the effects of subliminal rewards can be explained in terms of low-level, reflex-like responses to primes (Bargh, 2006). Here, we challenge this perspective by examining the interaction of reward value and task demands. We aim to show that resources are not directly recruited in reaction to high-reward cues, but instead are recruited strategically only when the task requires it, and regardless of whether or not the cues enter conscious awareness.

In a computerized experiment, we employed an on-line, physiological index: pupil dilation. Because the pupil dilates with sympathetic activity and constricts with parasympathetic activity (Steinhauer, Siegle, Condray, & Pless, 2004), pupil size is an accurate and unobtrusive measure of the resources invested in a task. Ruling out potential alternative explanations, such as anxiety, research demonstrates that pupil dilation increases when tasks require more resources, either because of variations within or between tasks (Kahneman, 1973) or because of individual differences in, for example, cognitive ability (Ahern & Beatty, 1979). These findings demonstrate that the amount of resources individuals need to mobilize for a task can be reliably indexed by changes in their pupil size.

If subliminal reward cues input into the strategic processes involved in resource recruitment, the effects of rewards on pupil dilation should occur when the task is demanding (here, recall of five digits), but not when the task is undemanding (recall of three digits), as undemanding tasks can be completed routinely and do not require many resources. It is important to note that this interactive effect of reward and demand on recruitment of resources is expected to occur regardless of whether the reward is processed consciously or nonconsciously.

Method

Fifteen participants (mean age = 21 years) performed a digit-retention task in which they could earn a coin (1 or 50 euro cents) presented on the computer screen by correctly recalling a subsequent series of digits. They were told that the coin would sometimes be "difficult to perceive." Accordingly, in half of the trials, the coin was presented supraliminally (i.e., was consciously perceivable); in the other half, the coin was presented subliminally (Pessiglione et al., 2007). The number of random digits to be recalled also varied (three vs. five). If participants responded correctly (mean accuracy = 96.9%)

on the digit task, they received the coin.

Each trial in the digit-retention task featured a fixation cross (4,000 ms), followed by a premask (400 ms), the coin stimulus (17[1] or 300 ms), and a postmask (583 or 300 ms; total duration of the masks and coin was always 1,000 ms). Next, participants saw another cross (2,000 ms), after which the number of upcoming digits was announced (e.g., "3 digits"; 2,000 ms). Then, another fixation cross was shown, and after 3,000 ms the digits were presented aurally (1 per second). After 4,000 ms (retention interval), a sound cued participants to verbally report the digits. Subsequently, feedback about performance on the trial (incorrect or correct, 1 or 50 cents; 2,000 ms), and the cumulative earnings (1,500 ms) were displayed.

During 48 trials (6 for each condition of the 2 × 2 × 2 within-subjects design), pupil size was recorded using a Tobii 1750 infrared eye tracker sampling at 50 Hz (Tobii Technology, Falls Church, VA). In the pilot[2] and the experiment, raw pupil data were corrected for artifacts and filtered (Kuchinke, Võ, Hofmann, & Jacobs, 2007). Task-evoked pupillary responses were calculated to index the amount of resources recruited in each condition (Beatty & Lucero-Wagoner, 2000). Average pupil size in the 1,000 ms preceding the trial served as a baseline.

1 Subliminality was tested in a separate signal detection task with different participants. After inspection of the coin pictures, 15 participants were presented with 24 coins, in the same manner as in the 17-ms-duration condition. After each postmask, they were asked to indicate the value of the coin (1 or 50 cents). Participants performed no better than chance in discriminating between the coins, P = .51, $t(14) = 0.425$, $p_{rep} = .62$.

2 We conducted a pilot study to validate pupil dilation as a measure of resource deployment within our specific digit-retention task. Fifteen participants (who did not take part in the main study) merely retained three or five digits. Peak pupil dilation was greater in the five-digit condition (M = 0.48 mm) than in the three-digit condition (M = 0.18 mm), t(14) = 3.84, prep = .99. If retaining five digits requires more resources than retaining three digits, then pupil size should have declined more slowly in the 4-s retention interval in the former condition. Indeed, during the retention interval, pupil size declined with time, but this decline was significantly slower in the five-digit condition, r(199) = −.87, than in the three-digit condition, r(199) = −.95, prep of the difference > .99 (Meng, Rosenthal, & Rubin, 1992). These results validate the idea that pupil dilation reliably indexes the amount of mental resources deployed in our task.

Results

Pupil responses were submitted to a 2 (reward) × 2 (reward-presentation duration) × 2 (number of digits) repeated measures analysis of variance, which revealed that the mean increment in pupil diameter was greater in the five-digit (0.37 mm) than in the three-digit (0.16 mm) condition, $F(1, 14) = 29.56$, $p_{rep} > .99$, $\eta_p^2 = .68$. Mean pupil dilation also proved greater in the high-reward (0.31 mm) than in the low-reward (0.22 mm) condition, $F(1, 14) = 6.85$, $p_{rep} = .95$, $\eta_p^2 = .33$. Crucially, a Reward × Number of Digits interaction was found,

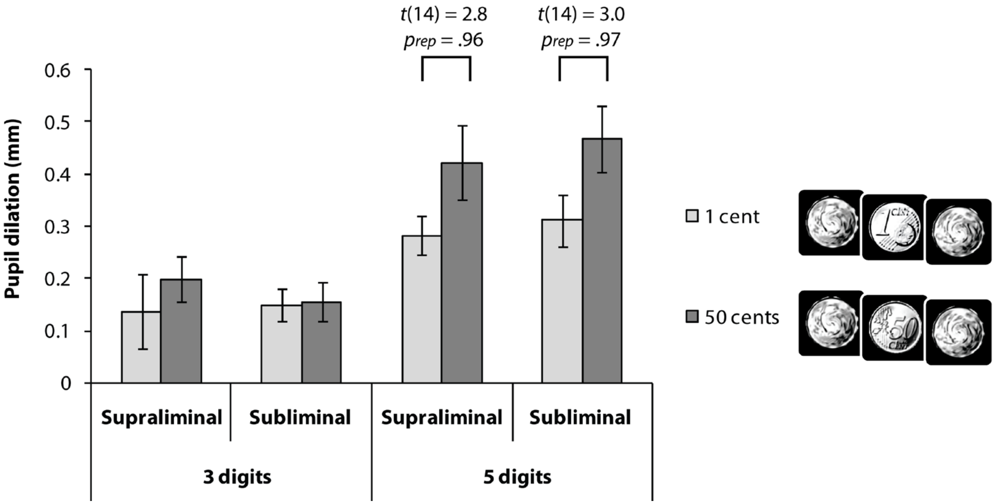

Figure 1. Maximum increase in pupil diameter as a function of level of reward (1 vs. 50 euro cents), presentation of the reward display (supraliminal vs. subliminal), and number of digits (three vs. five). Error bars represent standard errors of the mean. Significant differences between corresponding high- and low-reward conditions are marked (other paired t's < 1). On the right, the sequence of premasks, coins, and postmask are depicted for high and low rewards.

$F(1, 14) = 4.74$, $p_{rep} = .92$, $\eta_p^2 = .25$, indicating that the effect of reward was present in the five-digit, but not the three-digit, condition. This effect was not qualified by a three-way interaction, nor were there any effects of reward-stimulus duration, all F's < 1; thus, subliminal and supraliminal rewards affected pupil size in the same way (see Figure 1).

Discussion

Pupil-dilation data indicated that valuable (compared with nonvaluable) rewards led to recruitment of more resources, but only when obtaining the reward required considerable mental effort. This pattern was identical for supraliminal and subliminal reward cues. This indicates that awareness of a reward is not a necessary condition for strategic resource recruitment to take place. These findings are in line with recent research suggesting that the unconscious has flexible and adaptive capabilities (Hassin, Uleman, & Bargh, 2005; Wilson, 2002). More generally, whereas analyses of costs (required effort) and benefits (value of rewards) are usually thought to require consciousness, our findings suggest that such strategic processes can occur outside of awareness—and these processes show in the eyes.

Chapter 4

How adaptive is human reward processing? Effort requirements modulate unconscious reward responses

Abstract: When pursuing rewards, humans have to weigh the value of potential rewards against the amount of effort that is required. Although previous research has generally conceptualized this process as a deliberate calculation, recent work suggests that rudimentary mechanisms—that operate without conscious intervention—may play an important role as well. In the present research, we develop and test a novel perspective on the nature of such unconscious reward processing. In essence, we propose that whenever effort is required of the body, people respond more strongly to rewards that are higher (vs. lower) in value, as indicated by a greater difference in expended effort for high-value vs. lower-value rewards. Using a reward priming paradigm that allows us to dissect responses to reward cues into conscious and unconscious components, we show that this unconscious mechanism operates when effort requirements are anticipated (Experiment 1), when they are currently experienced (Experiment 2), and even when they are not instrumentally related to the reward that is at stake (Experiment 3). It is concluded that humans rely on a simple but adaptive mechanism to unconsciously conserve effort during reward pursuit. This mechanism is dissociated from more advanced processes that are initiated due to consciously perceived rewards. We discuss these findings in the context of decision making, motivation, and consciousness.

This chapter is based on: Bijleveld, E., Custers, R., & Aarts, H. (revised and resubmitted). How adaptive is human reward processing? Effort requirements modulate unconscious reward responses. *Journal of Experimental Psychology: General*.

How adaptive is human reward processing? Effort requirements modulate unconscious reward responses

As a consequence of their adaptation to the environment, animals can effectively execute behaviors to attain rewards. Humans are no exception to this, as they are well-equipped to pursue rewards like food, drink, and money. While the activities that are instrumental to reward attainment (e.g., grasping, running, or even thinking) may vary widely in nature, these have in common that all have at least some energetic costs. In other words, it takes effort to attain rewards—which is why people weigh the value of rewards against the amount of effort that is required to attain them. Such weighing seems to be an intricate process that involves the careful, conscious integration of multiple features of the environment. But is consciousness indeed a necessary condition for this functionality to operate? In a series of experiments, the present research explores this question.

Although research has generally characterized the integration of rewards and effort requirements as deliberate calculations, we propose that the underlying mechanisms can be very rudimentary. This idea is based on research showing that the same functionality can also be observed in nonhuman animals (e.g., rats; van den Bos, van der Harst, Jonkman, Schilders, & Spruijt, 2006), and on research showing that some of the brain structures that are central to this functionality are evolutionary very old, operating independently of consciousness (Delgado, 2007; Salamone, Correa, Farrar, Nunes, & Pardo, 2009). Such research raises the intriguing suggestion that people may be able to integrate reward information and effort requirements without conscious awareness.

The current work addresses this possibility, by testing a novel perspective on the (un)conscious nature of the human response to rewards. In essence, we propose that whenever effort requirements are detected by the body, people become more sensitive to the value of rewards, in that they invest effort especially when valuable (vs. less-valuable) rewards are at stake. Accordingly, this unconscious mechanism operates in line with the basic idea that when more effort is required, only valuable rewards can compensate for this. Subsequent to such simple but adaptive processing, rewards sometimes permeate into conscious awareness. In that case, they additionally prompt *reward decisions* (Bijleveld, Custers, & Aarts, 2010). In line with work on conscious motivation (Brehm & Self, 1989), we propose that such reward decisions serve the conservation of effort based on advanced calculations, by adjusting and overruling unconscious modulations of reward sensitivity.

If this perspective is true, it would challenge the traditional assumption that strategic behavior is exclusively caused by conscious and deliberate decisions. Instead, it would suggest that people are able to integrate cues from the environment and from the body (reward value, effort requirements) in an unconscious manner, resulting in the adaptive regulation of effort output—even though this occurs via a relatively simple mechanism. At the same time, we delineate a specific role for consciousness. Taken together, by bridging the field of motivation and recent work on conscious vs. unconscious processing, the current research aims to have implications for our general understanding of how people act on rewards.

In the past century, psychology has devoted ample attention to effects of rewards on human behavior, often addressing reward effects on task performance. Not surprisingly, research has generally confirmed the basic idea that the higher a reward is valuated, the more effort is invested into attaining it (see Bargh, Gollwitzer, & Oettingen, 2010, for a review).

In typical experiments addressing this issue, humans anticipate a reward (e.g., due to reward cues or reward instructions) that is contingent on their performance on some subsequent task. In line with lay beliefs, it is generally found that, via effort, the anticipation of a reward enhances performance in a wide variety of domains—such as related to physical exertion (Treadway, Buckholtz, Schwartzman, Lambert, & Zald, 2009), cognitive control (Krebs, Boehler, & Woldorff, 2010; Veling & Aarts, 2010; Watanabe, 2007), creativity (Eisenberger & Aselage, 2009; Glucksberg, 1962), and attention (Engelmann & Pessoa, 2007; Kiss, Driver, & Eimer, 2009). Although there are exceptions (e.g., Ariely, Gneezy, Loewenstein, & Mazar, 2009; Beilock, 2010), rewards appear to have a widespread, facilitatory influence on human functioning (Bonner & Sprinkle, 2002; Camerer & Hogarth, 1999).

Recent research in cognitive neuroscience pointed out that reward valuations are correlated with neural activity in the striatum. This subcortical structure mirrors the reward value of all kinds of stimuli, including money that can be earned (Bjork & Hommer, 2007); also, it outputs to many other brain structures, including those which support goal-directed action (Aston-Jones & Cohen, 2005; Delgado, 2007; Knutson, Delgado, & Phillips, 2008). Importantly, the striatum is thought to have developed early in human evolution, and it has the same general structure and function across vertebrates. This idea provoked the suggestion that basic responses to rewards may not need conscious awareness, which is a faculty that is thought to have arisen relatively recently (e.g., Donald, 2001).

Pessiglione and colleagues (2007) tested this idea using a novel reward priming paradigm. In an experiment, people were exposed to coins (of high vs. low value), part of which they could earn by squeezing into a handgrip; the harder they squeezed, the greater the proportion of the coin they received. It was not surprising that people squeezed harder when the coin was more valuable. Sometimes, however, coins were presented very briefly, so that they could not be consciously perceived (i.e., they were subliminally presented). Remarkably, even in this case, people worked harder when a more valuable coin was at stake, leading to the intriguing discovery that rewards do not need to be consciously perceived to trigger the recruitment of effort (for replications, see Bijleveld, Custers, & Aarts, 2009, 2010, 2011a; Capa, Bustin, Cleeremans, & Hansenne, 2011; Schmidt, Palminteri, Lafargue, & Pessiglione, 2010; Zedelius, Veling, & Aarts, 2011).

Adaptive reward pursuit: with and without conscious awareness?

However, and like all other species that have successfully adapted to their environment, humans need to spend effort strategically—or, in other words, only when this is functional for attaining valuable rewards. Indeed, research on conscious motivation has identified various ways in which people integrate reward value and effort requirements in order to conserve effort while still attaining valuable rewards. In short, extensive evidence supports the ideas that people (a) are unlikely to spend more effort than warranted by the reward, and (b) are unlikely to spend more effort than necessary given the effort requirements of the task that leads to reward attainment (Brehm & Self, 1989; Gendolla, Wright, & Richter, 2011; Wright, 2008). For example, such conscious processes induce people to withhold effort for rewards that are consciously judged to be not sufficiently valuable, given the amount of effort that is required to attain them (Eubanks, Wright, & Williams, 2002). But does basic integration of reward value and effort requirements already take place on an unconscious level? This central question remains.

One possibility is that rewards, upon perception, directly and unconsciously prompt the recruitment of effort. When the reward enters consciousness, then, effort may be further regulated after deliberate cost-benefit analyses, which are based on conscious information about the effort requirements, but also about the reward's value. Although this idea seems in line with research on the regulation, channeling, and control of initial reactions (e.g., Epley, Keysar, Van Boven, & Gilovich, 2004; Gilbert, Pelham, & Krull, 1988; Strack & Deutsch, 2004), such a mechanism would be inefficient in that it would frequently lead to the unconscious, superfluous recruitment of effort.

A second possibility is that a basic integration of reward information and effort requirements may already take place without conscious awareness. Indeed, research has shown that people have several ways in which they keep track of the amount of effort that they currently expend, not necessarily with the aid of conscious awareness (Marcora, 2009). This idea raises the possibility that the human reward response is modulated to fit the current requirements of the situation. More specifically, people may differentiate more strongly between rewards of different value whenever more effort is required (Bijleveld et al., 2009). Such a modulatory mechanism would lead people to respond to rewards most strongly when this is likely to be most necessary—i.e., when the organism detects (not necessarily with conscious awareness) that the current situation demands effort. Conversely, in situations that feel less demanding, people would respond equally strongly to rewards that are high vs. lower in value. This makes sense, as in this case, rewards are generally easier to get, making their value less relevant.

Currently, the evidence for the existence of such an unconscious, modulatory mechanism is circumstantial at best. Suggestive evidence comes from a previous study (Bijleveld et al., 2009), in which people were rewarded for successfully maintaining and reporting back digit strings, that were either short (3) or long (5). Similar to the work on reward priming addressed above (Pessiglione et al., 2007), participants were first exposed to coins that they earned by correctly reporting the digits. As revealed by pupil dilation, which is a physiological measure of mental effort, high-value subliminal rewards prompted more effort only on the relatively difficult trials, i.e., on the trials in which digit strings were long (Bijleveld et al., 2009). While this finding shows that effort requirements and rewards were integrated, this study provided no direct evidence for that this actually happened on an unconscious level. As an alternative explanation, it might be the case that a reward response was unconsciously initiated but was later consciously inhibited after it had turned out that only little effort was required for attaining the reward.

Research from other fields is consistent with the possibility that the integration of effort requirements and reward may take place unconsciously, and that it may rely on current bodily feedback of much effort is required. For example, animals that have limited conscious experience and limited higher-cognitive capabilities still effectively integrate effort requirements and rewards (van den Bos et al., 2006).

This suggests that conscious deliberation may not be necessary for modulations of the reward response to take place. This idea would be in line with recent neuroscientific work that shows that such basic modulations may be mediated by dopamine levels in the ventral striatum (Salamone et al., 2009), and may thus be rudimentary and independent of conscious awareness. More generally, other research is consistent with the idea that the demands that are imposed on the body input to various aspects of information processing (Preston & Wegner, 2009). For example, such demands have been shown to inform various judgments (Jostmann, Lakens, & Schubert, 2009; Proffitt, 2006). Similarly, effort requirements have been found to serve as a marker for which actions are one's own and which are not (Preston & Wegner, 2007). Often explained from theories of embodied cognition (Barsalou, 1999; Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005), these studies suggest that effort requirements are an important source of information. By extension, this research fits well the idea that unconscious, reward-related processes may depend on current bodily information about effort requirements. The main aim of the present work is to test this novel hypothesis.

While previous work on motivation has often assumed that consciousness is crucial for weighing pros and cons of actions (Bargh et al., 2010), the research addressed above thus suggests otherwise. Yet, this is not to say that consciousness has no function at all in the human response to rewards. Recent research showed that when rewards permeate into conscious awareness, they trigger *reward decisions*, over and above the basic recruitment of additional effort (Bijleveld et al., 2010). Indeed, several lines of research suggest that only consciously perceived stimuli gain access to a widespread frontal-parietal brain network that is involved in 'broadcasting' information (e.g., about rewards) throughout the brain, providing higher-level functionality involved in the deliberate control of behavior (Baars, 2002; Dehaene & Naccache, 2001). While we do not yet know whether and how such higher-level functions contribute to the integration of reward value and effort requirements, it is likely that they serve calculations about reward pursuit that go beyond unconscious modulations of reward sensitivity. For example, most current theories of (conscious) reward-directed behavior suggest that people not just weigh in effort requirements that are currently demanded of their body, but that they rely on specific predictions of how much effort is required for the course of action that leads to reward attainment (Eccles & Wigfield, 2002; Gendolla, Wright, & Richter, 2011). As these advanced calculations about value and effort requirements likely require higher-level brain functions (e.g., parts of the frontal-parietal network mentioned above; Haber & Knutson, 2009), these may well be associated with conscious awareness (Bijleveld et al., 2010).

In line with this work, we propose that consciousness aids the conservation of effort even more extensively, in that only on the basis of consciously perceived rewards, people make advanced calculations about expected value and effort requirements. In so doing, they take into account not just current bodily effort requirements, but rather the effort requirements that pertain to the specific course of action that leads to reward attainment. However, this does not necessarily mean that unconscious reward responses vs. conscious reward decisions lead to different outcomes. In fact, it may often be the case that current bodily effort requirements (which affect unconscious responses) overlap with the effort requirements that serve reward attainment (which affect conscious decisions). For that reason, unconscious modulations and advanced calculations may have similar effects. Specifically, as long as effort requirements are relevant for reward attainment, these effort requirements should make people become more sensitive also to the value of consciously perceived rewards (Brehm & Self, 1989; Gendolla et al., 2011; Wright, 2008).

In sum, based on the line of reasoning addressed above, our main hypothesis is that whenever they sense that more effort is required of their body, people respond more strongly to high-value (vs. lower-value) rewards that are perceived without conscious awareness. In addition, we hypothesize that whenever more effort is required, people also respond more strongly to high-value (vs. lower-value) rewards that are consciously perceived—at least, as long as these effort requirements are relevant for attaining the reward that is at stake.

The present research

A new reward priming paradigm was developed in order to test our hypotheses. We designed the paradigm to meet two key requirements. First, it should directly measure effort, undiluted by cognitive task strategies and thoughts. We accommodate for this by using a finger tapping task in which the expense of effort directly translates into motor performance. Second, it should allow us to dissect unconscious reward responses from conscious reward decisions. For that reason, we used a reward priming procedure similar to previous research, in which people are exposed to a coin that they can earn by successfully performing a task—finger tapping, in this case. The coins were either of high or of low value (10 cent vs. 1 cent), and were presented in such a way that they could be consciously perceived, or not (supraliminal vs. subliminal). As a dependent measure of effort we recorded finger tapping speed, in a similar way as previous research on effort in rodents and humans

(Salamone, Cousins, McCullough, Carriero, & Berkowitz, 1994; Treadway et al., 2009). While the supraliminal but not the subliminal coins can be processed with conscious awareness, this procedure has proven useful for dissociating between unconscious and conscious aspects of reward processing (Bijleveld et al., 2010).

Importantly, to investigate how effort requirements affect unconscious and conscious reward processing, we manipulated effort requirements in several ways across three experiments. In Experiment 1, we test the basic idea that people differentiate more strongly between rewards of different value when they are explicitly instructed that an upcoming task requires a lot vs. a little effort. In this experiment, we manipulate effort requirements such that participants have to complete the same finger tapping task in a short vs. a long time window (high vs. low required effort, respectively). This experiment served to test our basic hypothesis, to replicate previous research in a different paradigm, and to test whether we could effectively dissociate between unconscious and conscious reward-induced processes. While the design of Experiment 1 allowed participants to anticipate task demands on beforehand, participants were able to experience effort requirements only *during* action in Experiment 2. This allowed us to test the idea that the unconscious modulation of the reward response may also be based on current, momentary feedback about required effort. Finally, in Experiment 3, we removed the instrumental relation between required effort and reward attainment, by manipulating effort requirements via a secondary, reward-irrelevant task. As this procedure defeats all conscious reasons to integrate reward value with effort requirements (i.e., they have nothing to do with each other), finding reward sensitivity to be modulated at the unconscious level would constitute strong evidence for the idea that this basic integration is independent of conscious deliberation. In addition, this procedure allowed us to test the idea that when effort requirements are irrelevant for attaining the reward at stake, these no longer affect conscious reward decisions.

Experiment 1

Method

Participants and design. Thirty-five students (19 women, 16 men; mean age = 20.7) were recruited to participate. Participants were compensated with the money they earned during the experiment. The study used a 2(Reward Value: 1 cent vs. 10 cent) x 2(Reward Presentation: Supraliminal vs. Subliminal) x 2(Effort Requirements: Low vs. High) within-subjects design. Participants completed 96 trials in total, 12 repetitions per condition. The Effort Requirements factor was manipulated by blocks. As such, participants completed 4 blocks in which effort requirements were low and 4 blocks in which effort requirements were high, in alternating order. The type of the first block (low demands vs. high demands) was counterbalanced across subjects.

Procedure. Participants worked individually on the task in cubicles. They learned that, on each trial, they would see a coin (1 cent or 10 cent; the Reward Value factor), which they could earn by tapping the G-key on the keyboard 25 times within a specified time limit. At times, so they were instructed, the coin would be 'difficult to perceive'. Accordingly, on half of the trials, the coin was presented subliminally (the Reward Presentation factor). In low-requirement blocks, participants received the coin if they tapped 25 times within 10 seconds. In high-requirement blocks, people had only 3.5

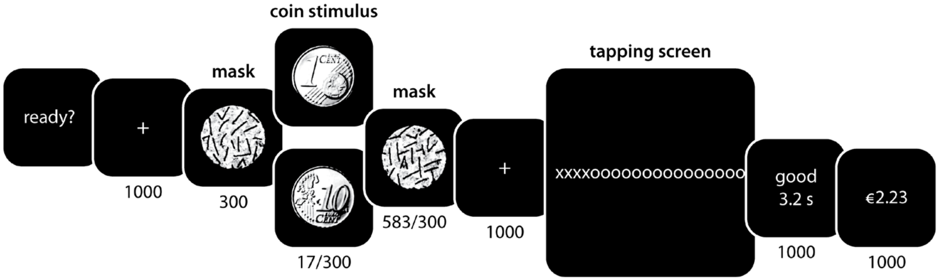

Figure 1. The course of a trial (Experiment 1). Numbers represent presentation durations in milliseconds (ms). A duration of 17 ms corresponds to the duration of one frame on a 60 Hz monitor. In all conditions, the duration of the coin and the masks added up to 900 ms.

seconds to complete 25 taps. Before the experimental trials started, participants completed 8 practice trials. At the beginning of each block, participants were clearly informed of the upcoming block's time criterion (i.e., whether the block would be a low-requirement or a high-requirement block).

Trials. The sequence of events in a trial is depicted in Figure 1. Each trial started when the participant pressed the A-key (for left-handed people: the L-key). To ensure that participants tapped only with one hand, they were required to hold the key throughout the trial. Next, they saw a fixation cross. Then, participants saw a coin, masked in such a way that it was consciously perceptible or not (see Figure 1). After another fixation cross appeared, the tapping part of the trial started. Specifically, people saw a row of 25 open circles (O), which indicated that they had to start tapping. With each tap, one of the open circles became a cross (X), starting from the left. This way, participants could keep track of their progress; when there were no open circles left, this indicated that participants were finished tapping. Next, participants received feedback on their performance (whether they met the criterion, and how fast they tapped). When their tapping time was below the set criterion (10 or 3.5 seconds), the value of the reward was added to their cumulative earnings, which were shown at the final screen of the trial. Then, a new trial started.

The experiment was programmed such that participants had to hold the A-key (for left-handed people: the L-key) throughout the trial, to ensure that tapping could only be performed with one hand. Based on the well-supported idea that faster tapping consumes more effort (e.g., Treadway et al., 2009), we operationalized effort expense as the time in which participants tapped 25 times.

Subliminality of coins. Subliminality of the stimuli was confirmed in a separate signal detection task with 30 different participants. On each trial, participants saw a coin (1 cent vs. 10 cent), presented in the same way as in the experiment (17 ms vs. 300 ms; in between masks). After each of the 80 coins, participants indicated the value of the coin. When coins were presented for 17 ms, detection accuracy did not deviate from chance, M = 51.1%, $t(29) = 0.68$, $p = .502$. When coins were presented for 300 ms, however, participants could accurately report their value, M = 99.3%, $t(29) = 209.2$, $p < .0001$.

Results

We analyzed tapping times as a function of Reward Value, Reward Presentation, and Effort Requirements. Trials that deviated more than 3 standard deviations from the mean of the high-demand

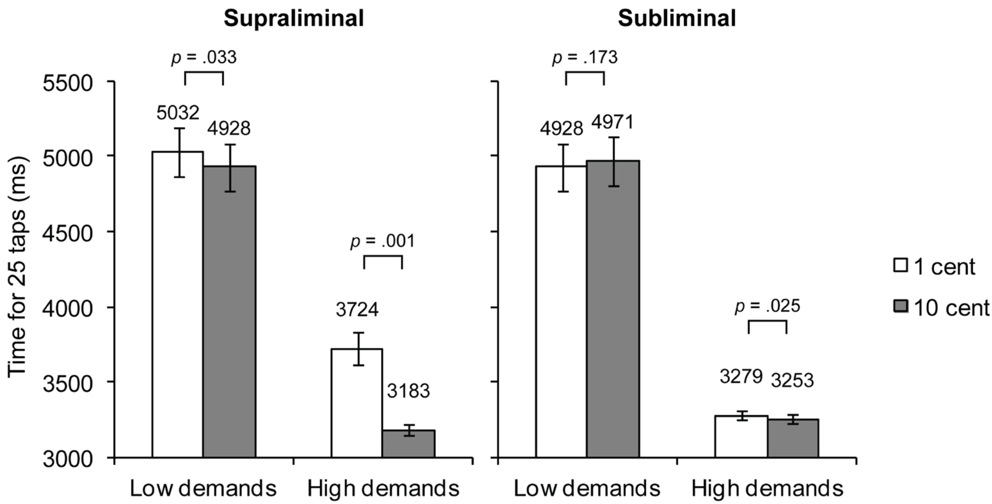

Figure 2. Results of Experiment 1. Mean tapping time (ms) for 25 taps is depicted as a function of Reward Value, Reward Presentation, and Effort Requirements. Error bars represent within-subjects standard errors around the mean (following the method suggested by Cousineau, 2005).

or the low-demand condition were deleted, which resulted in the exclusion of 1.3% of trials. Mean tapping times were submitted to repeated-measures ANOVA according to the design (Figure 2). This yielded a main effect of Reward Value, $F(1, 34) = 13.5$, $p = .001$, $\eta^2_p = .29$, revealing that participants tapped faster when more was at stake. Also, there was a main effect of Reward Presentation, $F(1, 34) = 8.0$, $p = .008$, $\eta^2_p = .19$, indicating that participants tapped faster when coins were presented subliminally. Moreover, there was a main effect of Effort Requirements, $F(1, 34) = 104.2$, $p < .001$, $\eta^2_p = .75$, indicating that participants were faster when effort requirements were high. As predicted, these effects were qualified by the Reward Value x Effort Requirements interaction, $F(1, 34) = 14.8$, $p < .001$, $\eta^2_p = .30$. In line with expectations, this interaction indicated that people responded more strongly to rewards when effort requirements were high, compared to when they were low (Figure 2). However, this interaction was qualified by the Reward Value x Reward Presentation x Effort Requirements three-way interaction, $F(1, 34) = 8.3$, $p = .007$, $\eta^2_p = .20$. To interpret this interaction and to specifically test our hypotheses, we tested whether the Reward Value x Effort Requirements interaction existed in both the supraliminal and the subliminal condition. Crucially, this was the case. Though the interaction was stronger for the supraliminal coins, $F(1, 34) = 12.16$, $p = .001$, $\eta^2_p = .26$, it was also present for the subliminal coins, $F(1, 34) = 4.4$, $p = .044$, $\eta^2_p = .11$. Thus, these data support the idea that modulations of reward sensitivity by effort requirements are not dependent on conscious awareness.

Discussion

Experiment 1 showed that participants differentiated more strongly between high-value and lower-value rewards in the face of a more demanding task. Importantly, in line with expectations, we found this to be the case for both supraliminally and subliminally presented rewards. This finding thus points to the existence of an unconscious mechanism that serves the adaptive allocation of effort. While previous work on this mechanism was limited to physiological evidence (Bijleveld et al., 2009), we replicated this previous work using a different measure, supporting the validity of our finger tapping paradigm.

Although higher effort requirements made people more sensitive to both supraliminal and subliminal rewards, this modulation was stronger for supraliminal rewards. Inspection of the pattern of means suggested that this difference in strength was primarily driven by the fact that people spent particularly little effort after having consciously perceived a low-value reward under conditions of high effort requirements (Figure 2). In our view, this finding is in line with the idea that, via conscious reward decisions, people control the expense of effort based on advanced calculations about reward pursuit. If the expected value is particularly low and people have to expend a lot of effort to attain it, the value of the reward cannot compensate for the effort that is required to attain it. Due to conscious deliberations about this tradeoff, people are indeed known to invest very little effort in such cases (Brehm & Self, 1989; Gendolla et al., 2011).

While the idea that conscious reward decisions involve more advanced calculations about expected value and effort requirements is more directly tested in Experiment 3, this particular difference between unconscious reward responses and conscious reward decisions fits well with previous experiments that used the same reward presentation paradigm as the present research (Bijleveld et al., 2010). In these experiments, people could choose between different task strategies to attain the reward that was at stake—specifically, they could decide to focus either on speed or on accuracy of performance. Findings indicated that after conscious perception of low-value rewards, people were fast but also very inaccurate, failing to attain the reward more often than in any other condition. Thus, this previous research also suggests that conscious perception of low-value rewards prompts the strategic decision to invest especially little effort.

Experiment 2

While Experiment 1 provides initial evidence for our hypotheses, a potential alternative explanation for the findings may lie in the fact that people could consciously anticipate the effort requirements of upcoming trials. One could argue that the experimental blocks constituted different contexts (i.e., a high-effort-requirements and a low-effort-requirements context), in which rewards evoked different responses to begin with. Indeed, it has often been shown that unconscious responses to stimuli may be contingent on the context they are presented in (Gawronski, Rydell, Vervliet, & De Houwer, 2010). For example, people who received successful exposure treatment for specific anxiety disorders (e.g., fear of spiders) may still relapse when they are faced with a fear-inducing stimulus (e.g., a spider) in a context in which their fearful responses used to occur (Bouton, 1993). Another example is provided by research on prejudice, that shows that spontaneous responses to Black faces are different when these are presented against the backdrop of a church vs. a street corner (Wittenbrink, Judd, & Park, 2001). Following a similar rationale, one might explain the results from Experiment 1 as an effect of the experimental contexts of low vs. high effort requirements. These contexts, as were manipulated by blocks in Experiment 1, may have pre-defined people's responses to rewards of different value. If such were true, it would mean that people may not truly respond to momentary effort requirements, but rather configure their responses to rewards well in advance, and in a rather static way.

To exclude this possibility, we aimed to replicate Experiment 1 with one major modification. Specifically, effort requirements were manipulated such that they could be assessed only during action (i.e., during tapping), and no longer in anticipation of the task. In this task, participants were required to move a coin stimulus from the left to the right of the screen by repeatedly tapping the keyboard. When they did this within a fixed time limit (3.5 seconds), they received the coin. On some trials, however, the coin would move somewhat faster in response to keyboard taps, compared to other trials. The difference between trials of different effort requirements being only slight, this manipulation of effort requirements was much more subtle than the manipulation used in Experiment 1. More importantly, this procedure denied participants the opportunity to predict the demands of trials on beforehand.

Method

Participants and design. Forty-nine students (21 men, 28 women; mean age 20.8) were recruited to participate. Participants were compensated with the money they earned during the experiment. The tapping task used a 2(Reward Value: 1 cent vs. 10 cent) x 2(Reward Presentation: Supraliminal vs. Subliminal) x 3(Effort Requirements: Low vs. Medium vs. High) within-subjects design, comprising 96 trials in total, 8 repetitions per condition. Trials were presented in two blocks of equal length.

Procedure. Participants learned that on each trial, they would see a green square that quickly moved from the left to the right of the screen. Although this was not mentioned to the participants, the green square always had the same speed; it moved from the left to the right edge of the screen in 3.5. seconds. At the same time as the green square, a coin appeared too. Participants could move this coin rightwards by repeatedly tapping the G-key on the keyboard. When the coin reached the right edge of the screen before the green square, so they learned, participants would earn the coin, that was worth either 10 cent or 1 cent. Reward Presentation (i.e., coin visibility) was manipulated in a similar way as in Experiment 1. On supraliminal trials, the coin was visible throughout the tapping part of the trial. On subliminal trials, the coin was briefly (17 ms) presented in between rapidly alternating masks (the same sequence as in Experiment 1), once every 300 ms.

Critically, on low-required-effort trials, participants had to tap 21 times within 3.5 seconds to keep up with the green square; on medium-required-effort trials, 23 times; and on high-required-effort trials, 25 times (thus aligning with the high-required-effort condition of Experiment 1). No mention of these variations was made to participants. Hence, they could only detect effort requirements in an on-line fashion.

Trials. The sequence of events in a trial is depicted in Figure 3. Each trial started with a black screen, after participants had pressed the A-key (for left-handed participants: the L-key). Next, a fixation cross appeared, followed by the tapping part of the trial. Specifically,

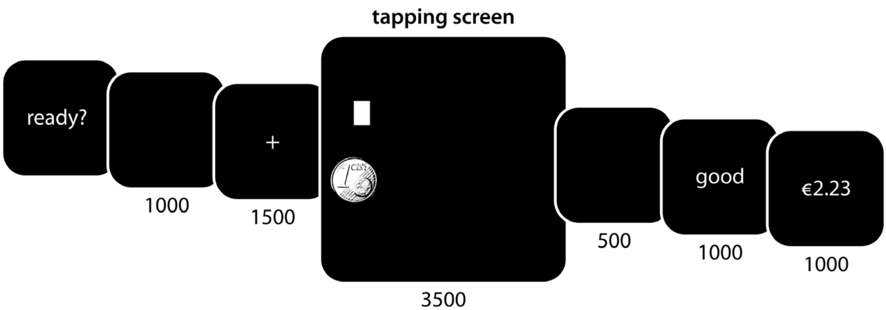

Figure 3. The course of a trial (Experiment 2). Numbers represent presentation durations in milliseconds.

a coin and a green square appeared at the left edge of the screen. The square moved by itself from the left to the right, whereas participants had to move the coin by repeatedly tapping the G-key. After 3.5 seconds, when the green square had reached the right part of the screen, participants received feedback about their performance (i.e., whether they succeeded in keeping up with the square, which required 21 vs. 23 vs. 25 taps in 3.5 seconds, depending on the effort requirements manipulation). Finally, the participants' cumulative earnings were displayed. After a one-second inter-trial interval, a new trial started. While tapping time was kept constant in this experiment (i.e., unlike in Experiment 1, participants tapped for 3.5 s on every trial), effort was operationalized as the proportion of trials on which participants met the reward-attainment criterion.

Results

As tapping time was kept constant over conditions in Experiment 2, performance was operationalized as the proportion of trials on which participants met the demands of the task, and thus attained the reward (Figure 4). These proportions were submitted to ANOVA according to the design. This analyses revealed a main effect of Reward Value, $F(1, 48) = 30.6$, $p < .001$, $\eta^2_p = .39$, revealing that participants performed better when 10 cent (vs. 1 cent) was at stake. Also, there was a main effect of Reward Presentation, $F(1, 48) = 8.3$, $p = .006$, $\eta^2_p = .15$, indicating that participants performed better when coins were presented subliminally. The main effect of Effort Requirements was also significant, $F(2, 96) = 46.7$, $p < .001$, $\eta^2_p = .49$, revealing that participants more often met the criterion when it was lower. Replicating Experiment 1, these effects were qualified by the Reward Value x Effort Requirements interaction, $F(2, 96) = 13.7$,

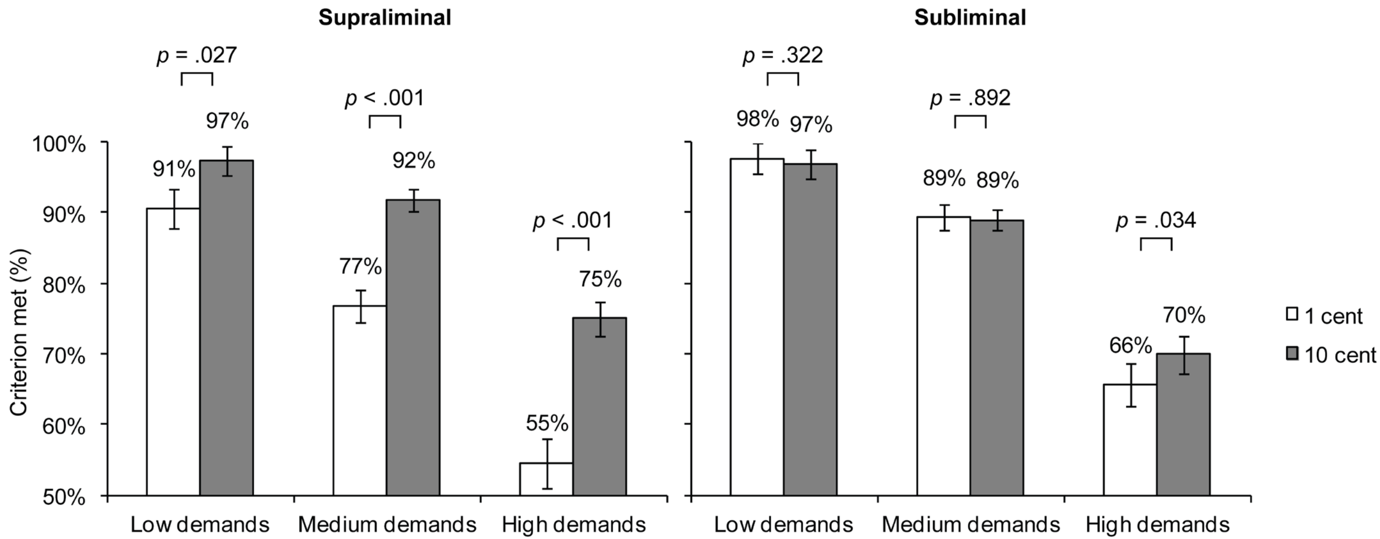

Figure 4. Results of Experiment 2. The proportion of trials in which the criterion was met is depicted as a function of Reward Value, Reward Presentation, and Effort Requirements. Error bars represent within-subjects standard errors around the mean (Cousineau, 2005).

$p < .001$, $\eta^2_p = .22$, that suggested that people respond stronger to rewards as a function of increasing levels of effort requirements. To confirm this idea, we tested whether the linear contrast of Effort Requirements interacted with Reward Value. This appeared to be the case, $F(1, 48) = 35.7$, $p < .001$, $\eta^2_p = .43$. As in Experiment 1, these effects were qualified by a marginally significant Reward Value x Reward Presentation x Effort Requirements three-way interaction, $F(2, 96) = 2.9$, $p = .060$, $\eta^2_p = .06$. Therefore, we examined whether the Effort Requirements x Reward Value interaction existed in both the supraliminal and subliminal conditions. Crucially, in line with our hypotheses, it was again present in the supraliminal condition, $F(1, 48) = 17.9$, $p < .001$, $\eta^2_p = .27$, but also in the subliminal condition, $F(1, 48) = 5.5$, $p = .024$, $\eta^2_p = .10$.

Discussion

Although people could assess effort requirements only during action in Experiment 2, people still responded more strongly to supraliminal *and* subliminal high-value rewards when more effort was required, which was in line with expectations. This finding reveals that unconscious modulations of reward sensitivity respond to momentary information about effort requirements (e.g., via visual feedback about their progress), and thus are presumably not caused by the experimental context. As such, Experiment 2 further characterizes unconscious reward processing as adaptive—that is, unconscious reward responses facilitate the attainment of valuable rewards while being attuned to the current demands of the situation. In addition, in line with the idea that conscious reward decisions control the expense of effort in line with more advanced calculations about expected value and effort requirements, we again observed that this modulation was stronger for the supraliminal coins.

Experiment 3

In the previous experiments, and in line with most previous work on rewards and performance, the expense of effort was instrumentally and causally related to reward attainment. In other words, the tasks (and the instructions) were designed such that manipulations of required effort always pertained to a specific reward. At least in the domain of how people consciously pursue rewards, this way of addressing reward effects seems realistic and ecologically valid (Eccles & Wigfield, 2002; Feather, 1982). For the present purposes, however, it leaves open the possibility that this causal instrumentality—as induced by conscious instructions—prepares people for the integration of rewards and effort requirements, as a part of the specific set of strategies that is evoked by the task and the related instructions (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006). Accordingly, one might argue that the unconscious modulations that were identified in Experiments 1–2 were created by the experimental setting, and are thus a specific consequence of the task rather than a basic human tendency.

To exclude the latter possibility, we designed Experiment 3. Pushing our manipulations of effort requirements one step further, we manipulated effort requirements to be *unrelated* to the reward outcome of the tapping task (cf. Preston & Wegner, 2007). Specifically, participants were required to forcefully squeeze a handgrip with their non-dominant hand vs. to merely hold the handgrip. Importantly, the effort requirements imposed by this manipulation were not instrumentally related to the reward that was at stake. By contrast, they could earn rewards with the finger tapping task that they completed concurrently, with their dominant hand.

If Experiment 3 would show that effort requirements make people more sensitive to unconscious rewards—even though they are unrelated to reward attainment in this experiment—this would support the idea that the modulatory mechanism is fundamental to the human reward response, and is not just an effect that is specific to clearly defined laboratory situations. This idea would be in line with findings showing that these modulations are mediated by rudimentary brain structures (Berridge, 2003; Salamone et al., 2009), and that they constitute a basic tendency that has widespread implications for research on motivation.

It is less probable, however, that these reward-unrelated effort requirements also affect people's conscious reward decisions. As was addressed in the introduction, most contemporary theories of motivated action suggest that people make reward decisions based on advanced calculations about the expected value and the effort requirements of the reward. In so doing, they rely on their estimates of how much effort is required for the *specific course of action* that leads to reward attainment (Eccles & Wigfield, 2002; Bargh et al., 2010). These deliberate calculations, which are thought to be served by higher-level brain functions (e.g., Dehaene et al., 2006), are thus unlikely to incorporate effort requirements that have no relation to the reward that is at stake. For that reason, we do not expect the irrelevant effort requirements of Experiment 3 to make people more sensitive to consciously perceivable rewards.

Method

Participants and design. Twenty participants (8 men, 12 women; mean age = 21.3) were recruited to participate. They were paid the amount of money they earned during the experiment, that was conducted in individual sessions. The study used a 2(Reward Value: 1 cent vs. 10 cent) x 2(Reward Presentation: Supraliminal vs. Subliminal) x 2(Task-Irrelevant Effort: Low vs. High) within-subjects design, comprising 80 trials in total, 10 repetitions per condition. The Task-Irrelevant Effort factor was manipulated by blocks. As such, participants completed 5 blocks in which effort requirements were low and 5 blocks in which effort requirements were high, in alternating order. The type of the first block (low task-irrelevant demands vs. high task-irrelevant demands) was counterbalanced across subjects.

Apparatus. Handgrips were custom made of foam isolation material and steel. To make sure participants followed the instructions, handgrips were connected to the computer, eliciting a digital signal when they were squeezed. Participants indicated that squeezing the handgrip was effortful, at least to a moderate extent.

Procedure. While the task context was strongly modified, the procedure of Experiment 3 was similar to Experiment 1. Specifically, in Experiment 3, effort requirements were not manipulated in the tapping task itself but via a secondary task that involved the handgrip. First, participants were familiarized with the handgrip by the experimenter, who made sure that they were able to adequately squeeze it. After participants had completed 5 practice trials, the experiment started. The time limit that participants had to meet to attain the reward was kept constant at 3.5 seconds.

Trials. The sequence of events in a trial is depicted in Figure 1. In order, participants saw a fixation cross, the masks and the coin, and another fixation cross. After that, they saw a row of 25 open circles (O), indicating to participants that they were to start tapping. With each tap, a circle turned into a cross (X), allowing participants to keep track of their progress. After tapping, they received feedback on their performance. Importantly, on high Task-Irrevant Effort blocks, participants squeezed the handgrip after the coin was presented. Instead, on low Task-Irrelevant Effort blocks, participants merely held the handgrip in their hand.

Results and discussion

We analyzed the time in which participants completed 25 taps, as a function of Reward Value, Reward Presentation, and Task-Irrelevant Effort. Trials that deviated more than 3 standard deviations from the participant mean were deleted, which resulted in the exclusion of 1.0% of trials. Mean tapping times were submitted to repeated-measures ANOVA according to the design (Figure 5). This yielded a main effect of Reward Value, $F(1, 19) = 29.1$, $p < .001$, $\eta^2_p = .61$, indicating that participants tapped faster when a more valuable reward was at stake. Moreover, the main effect of Task-Irrelevant Effort was significant, $F(1, 19) = 5.1$, $p = .036$, $\eta^2_p = .21$, indicating that participants generally tapped faster when they concurrently squeezed the handgrip. These effects were qualified by the Reward Value x Reward Presentation interaction, $F(1, 19) = 15.0$, $p = .001$, $\eta^2_p = .44$, that revealed that the effect of Reward Value was stronger on supraliminal trials. Importantly, these findings were qualified by the Reward Value x Reward Presentation x Task-Irrelevant Effort three-way interaction, $F(1, 19) = 4.4$, $p = .050$, $\eta^2_p = .19$. To interpret this interaction and to test the hypothesis that task-irrelevant effort only affects sensitivity to unconscious rewards, we analyzed the effects of Reward Value x Task-Irrelevant Effort separately for supraliminally vs. subliminally presented coins.

For supraliminal coins, there was a main effect of Reward Value, $F(1, 19) = 27.6$, $p < .001$, $\eta^2_p = .59$, indicating that people worked harder for more valuable coins, and a marginally significant main effect of

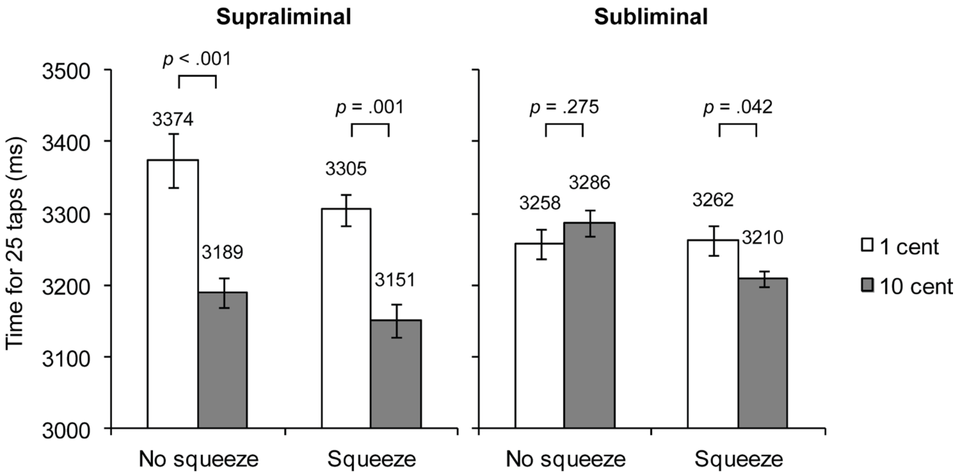

Figure 5. Results of Experiment 3. Mean tapping time (ms) for 25 taps is depicted as a function of Reward Value, Reward Presentation, and Task-Irrelevant Effort. Error bars represent within-subjects standard errors around the mean (Cousineau, 2005).

Task-Irrelevant Effort, $F(1, 19) = 3.8$, $p = .068$, $\eta^2_p = .17$, suggesting that people worked harder when they concurrently squeezed. As expected, these effects did not interact, $F < 1$, suggesting that sensitivity to consciously perceived rewards is independent of the amount of incidentally expended effort.

For subliminal coins, there was again a modest effect of Task-Irrelevant Effort, $F(1, 19) = 3.9$, $p = .063$, $\eta^2_p = .17$, revealing that people worked harder when they concurrently squeezed. Importantly, this effect was qualified by the Reward Value x Task-Irrelevant Effort interaction, $F(1, 19) = 6.3$, $p = .021$, $\eta^2_p = .25$, which revealed that only when people exerted task-irrelevant effort, people tapped faster for a high-value (vs. low value) coin, $F(1, 19) = 4.8$, $p = .042$, $\eta^2_p = .20$ (other simple effect, $F < 1.3$). As hypothesized, this finding demonstrates that incidentally expended effort makes people more sensitive to unconscious rewards.

Taken together, Experiment 3 revealed that even when effort requirements are not instrumental to attaining a specific reward (in this case, squeezing a handgrip), this still affects people's unconscious reward responses but not their conscious reward decisions. We discuss the implications of this finding in greater detail below.

General discussion

The current research was designed to test the prediction that unconscious reward responses are attuned to the current effort requirements that are imposed on the body. Across three experiments that employed a finger tapping paradigm, we found support for this idea. Our findings show that people act in line with the normative idea that the value of rewards becomes more important when rewards require more effort to attain. Thus, the main conclusion of the present work is that, albeit in a basic way, adaptive reward pursuit may take place without conscious awareness.

Importantly, we found evidence for this modulatory mechanism with various ways of manipulating effort requirements, across three experiments. In Experiment 1, people received overt instructions that the upcoming block would require little vs. much effort. Results indicated that people responded stronger to high-value rewards on blocks in which more effort was required. We replicated this pattern of results in Experiment 2, in which people could detect effort requirements only while they were carrying out the task. This finding lent support for the idea that reward responses are dynamically modulated by current information about effort requirements, and are not just pre-defined consequences of the effort-demanding context. We pushed the idea another step further in Experiment 3, by manipulating effort requirements such that they were unrelated to the reward that could be earned. During task performance, participants concurrently squeezed a handgrip with their other hand (or not), in order to test whether the bodily experience of effort is sufficient to make people more reward sensitive, on an unconscious level. This proved to be the case. Since people were given no conscious reasons to integrate effort requirements and rewards, Experiment 3 excluded the possibility that unconscious modulations were only observed because they were consciously prepared via the task instructions. Instead, this finding suggests that unconscious modulations are a basic human tendency which may well have ubiquitous implications for human cognition and behavior.

Additionally, the present work shows that in some situations, consciousness of rewards may adjust or even overrule the basic modulatory mechanism (Bargh & Morsella, 2008). Our findings were in line with research on conscious reward decisions, which are thought to be based on more advanced deliberations about the expected value of a reward and the effort requirements of the course of action that leads to its attainment (Eccles & Wigfield, 2002; Gendolla et al., 2011; Brehm & Self, 1989). Likely due to such more advanced deliberations, reward decisions led people to invest only little effort when the (conscious) expected value could not compensate for the effort requirements (Experiments 1–2; Bijleveld et al., 2010). Also due to advanced deliberations, reward decisions proved not to be affected by irrelevant effort requirements (Experiment 3). These findings can be well understood in terms of work on consciousness, that suggests that only consciously-perceived stimuli (such as rewards) are processed in higher-level brain structures (e.g., the prefrontal cortex) that serve the adaptive control of behavior even further than is already done by the rudimentary brain structures (e.g., the ventral striatum) they lie on top of (e.g., Baars, 2002; Dehaene et al., 2006).

This account of the specific role of consciousness in reward pursuit resonates well with the idea that the anticipation of events beyond the immediate future is an ability specific to humans (Gilbert & Wilson, 2007; Suddendorf, Addis, & Corballis, 2009), likely associated with conscious awareness. While the rudimentary mechanism may be very effective when it comes to rewards that are actually present in the environment (most animals act predominantly on these), conscious reward pursuit seems to also take into account the future. For example, investing only little effort when becoming conscious of a reward of low expected value may facilitate performance on subsequent, more fruitful tasks. Also, this idea is consistent with the findings from Experiment 3. In this experiment, task-irrelevant effort requirements were integrated with rewards on an unconscious level, but this integration was no longer present when coins were perceived with conscious awareness. Again, when it comes to rewards that are currently present in the environment, the rudimentary mechanism probably does a good job, as current effort requirements should in most cases pertain to rewards that are currently present. Conscious awareness, in turn, may aid in shielding reward pursuit from unwanted, irrelevant influences—again, this is an ability that is especially useful for the pursuit of rewards that are further away, either in time or in space. While this explanation is admittedly speculative, the present findings clearly show that when rewards permeate into consciousness, this triggers control processes that serve adaptive reward pursuit in an even more advanced way (see Bijleveld et al., 2010; Dehaene & Naccache, 2001).

Theoretical implications

On the surface, the current work seems to bear relation to the phenomenon of *effort discounting*. This phenomenon entails that when a certain course of action is anticipated to lead to effort requirements, this course of action is valued less (e.g., as reflected by reduced activity in the striatum; Botvinick, Huffstetler, & McGuire, 2009; Croxson, Walton, O'Reilly, Behrens, & Rushworth, 2009)—and, after repeated exposure, is avoided (Hull, 1943; Kurniawan et al., 2010). Thus, as does the present research, these studies address the integration of information about reward value and effort requirements. Nevertheless, the outcome of effort discounting (i.e., choosing effortful options *less* often) seems to be the opposite of the present findings, in which people recruited *more* effort in the face of higher demands. This apparent contrast was previously noted by Botvinick and Rosen (2008), who proposed that anticipated effort requirements not only induce people to avoid effortful choices, but also serve a second important function—i.e., to prepare the recruitment of effort in the face of actual demanding situations. The present work focuses on this second function, and is novel in showing that anticipations modulate the human reward response via a rudimentary mechanism, aiding adaptive effort recruitment. Taken together, the mechanism that is addressed by the current work is markedly different from effort discounting due to its distinct functionality.

Nevertheless, an interesting similarity between these two lines of research is that both have increasingly focused on the role of unconscious processes. For example, work on effort discounting has recently shown that people do not need to be aware of differences in effort requirements between choice options to still develop a preference for less-demanding options (Kool, McGuire, Rosen, & Botvinick, 2010). Also here, rudimentary mechanisms likely play a vital role. It should be noted, however, that that the avoidance of effortful choices is best accounted for by (implicit) learning processes, as people's aversion against effortful choices seems to develop over the course of time (see also Pessiglione et al., 2008). Instead, the current work addresses a mechanism that directly responds to momentary effort requirements. Though from different points of view, these recent developments raise the interesting question of how decisions are shaped by rudimentary processes. One could, for example, predict that unconscious integrations gain importance when conscious control processes are less available or less relevant (e.g., under load or under threat, see Hester & Garavan, 2005; Inzlicht, McKay, & Aronson, 2006; Ramirez & Beilock, 2011).

A related issue is raised by the finding that currently experienced effort requirements can modulate reward sensitivity through a low-level mechanism, even when effort requirements cannot be consciously anticipated (Experiment 2). Do these anticipations (Experiment 1), then, still make use of the same low-level mechanism? This issue may be understood and examined in the context of theories of embodied cognition (Barsalou, 1999, 2009; Niedenthal et al., 2005) that propose that our knowledge of the world is represented in *simulators*, i.e., neural structures that store sensory, motor, affective, and other bodily reactions. According to this idea, merely retrieving a concept (or merely anticipating an action) is thought to activate the simulators that are also involved in actual perceptual experiences with that object. In the context of the present work, one could well interpret anticipations of effort requirements as a *simulation* of actual effort requirements. Regardless of how the activation of this embodied representation occurs (i.e., whether via actual effort requirements or via anticipations; see Morewedge, Huh, & Vosgerau, 2010), the effects on reward sensitivity may well be the same. By drawing from such theory, it can thus be better understood why anticipations and actual effort have the same consequence. Consistent with the current data, one might speculate that not the anticipation or the actual effort per se, but the activation of this embodied, low-level representation of 'effort' is what makes people more reward sensitive on an unconscious level.

As the effects on reward sensitivity thus turn out to be easily triggered, they are likely to be ubiquitous, carrying implications for other fields of research. One of such fields pertains to self-regulation, an area that focuses on how people control their impulses towards rewards such as food. Although the initial behavioral response towards palatable food generally is to approach it (and then to eat it), people may rely on conscious control processes to resist this temptation (Fishbach & Shah, 2006; Muraven & Baumeister, 2000). Theories of impulse control have largely focused on the control side of this process (e.g., when people employ control processes most effectively), but the impulses themselves have received relatively little research attention, in spite of their clear predictive importance (Hofmann, Friese, & Strack, 2009; Veling & Aarts, 2011). The present work suggests that effort requirements (or perhaps more specifically, the activation of their bodily representation, Barsalou, 2009) may be an important moderator of the strength of impulses towards rewarding stimuli. After all, the rudimentary system that produces this response is not only aimed at approaching rewarding items, but also at conserving effort.

More generally, this rudimentary system is known to be implicated in many aspects of cognition and behavior, not just the ones that were discussed above. Accordingly, the consequences of the basic integration of effort requirements and rewards likely extend to various motivational cues, not just those related to money (and food). In spite of their diversity, many subfields of psychology include motivational factors, that are in turn often conceptualized in terms of rewards and demands. Thus, it is well possible that the rudimentary motivational system that we have addressed supports functions, for example, related to the pursuit of goals (Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001; Custers & Aarts, 2010), the experience of free will (Preston & Wegner, 2007), perceptual judgments (Balcetis & Dunning, 2006; Proffitt, 2006), risk taking (Knutson, Wimmer, Kuhnen, & Winkielman, 2008), social behavior (Santamaria & Rosenbaum, 2011), and judgments of value (Higgins, 2006; Kruger, Wirtz, Van Boven, & Altermatt, 2004). While future research should examine whether and how effort requirements affect these domains, the present work implies that effort requirements need to be studied along with rewards—and that in their integration, unconscious processes may well play a lead role.

Chapter 5

Unconscious reward cues increase invested effort, but do not change speed–accuracy tradeoffs

Abstract: While both conscious and unconscious reward cues enhance effort to work on a task, previous research also suggests that conscious rewards may additionally affect speed-accuracy tradeoffs. Based on this idea, two experiments explored whether reward cues that are presented above (supraliminal) or below (subliminal) the threshold of conscious awareness affect such tradeoffs differently. In a speed-accuracy paradigm, participants had to solve an arithmetic problem to attain a supraliminally or subliminally presented high-value or low-value coin. Subliminal high (vs. low) rewards made participants more eager (i.e., faster, but equally accurate). In contrast, supraliminal high (vs. low) rewards caused participants to become more cautious (i.e., slower, but more accurate). However, the effects of supraliminal rewards mimicked those of subliminal rewards when the tendency to make speed-accuracy tradeoffs was reduced. These findings suggest that reward cues initially boost effort regardless of whether or not people are aware of them, but affect speed-accuracy tradeoffs only when the reward information is accessible to consciousness.

This chapter is based on: Bijleveld, E., Custers, R., & Aarts, H. (2010). Unconscious reward cues increase invested effort, but do not change speed–accuracy tradeoffs. *Cognition, 115,* 330-335. doi:10.1016/j.cognition.2009.12.012

Unconscious reward cues increase invested effort, but do not change speed-accuracy tradeoffs

When valuable rewards are at stake, humans and other animals increase the amount of effort they expend. In the real world as well as in the lab, this effort is in some cases translated into speed, for example when athletes compete in a race or when our processing capabilities are quantified as the amount of time we need to perform a certain action (Knutson, Taylor, Kaufman, Peterson, & Glover, 2005; Tremblay & Schultz, 2000). In other cases, additional effort translates into increased accuracy, for example when people play a game of darts or when researchers are interested in tapping participants' precision in solving logical or mathematical problems in response to rewards (Kahneman & Peavler, 1969; Wieth & Burns, 2006). More often than not, however, humans have to make tradeoffs between speed and accuracy, focusing more on either speed (becoming eager) or accuracy (becoming cautious) to maximize reward outcomes (Gold & Shadlen, 2002; Swanson & Briggs, 1969). In this paper, we address the impact of rewards of which we are conscious or not on the speed-accuracy tradeoffs people make. Recent research suggests that humans exert effort in response to cues signaling rewards, even if these cues are perceived outside of conscious awareness (Bijleveld, Custers, & Aarts, 2009; Pessiglione et al., 2007). However, whereas conscious reward cues may change speed-accuracy tradeoffs, whether such tradeoffs are also adjusted in response to unconscious reward information is as yet an unresolved question. We report two experiments to shed more light on this intriguing issue.

The conscious considerations that are involved in speed-accuracy trade-offs in the face of rewards are well-documented. Within the field of decision making under uncertainty, it has repeatedly been shown that when higher rewards (gains) are at stake, people are more reluctant to take risk. Research has shown that people tend to prefer sure gains over bets, even when the bet has a higher expected value than the sure gain (Kahneman & Tversky, 1979; Tversky & Kahneman, 1981). This phenomenon is more pronounced when rewards at stake are more valuable, rendering people even more risk-averse (Rabin & Thaler, 2001). Considered a product of human development (Higgins, 1989), strategic concerns for securing rewards are known to change the speed-accuracy tradeoff, as such concerns cause people to take decisions only when they are sure they will be accurate (see e.g., Förster, Higgins, & Bianco, 2003). Hence, people generally raise their standards in terms of accuracy but sacrifice speed in order to secure valuable rewards.

Whereas previous research focused on rewards of which people are conscious, it has recently been demonstrated that people also respond to unconscious reward information. That is, by boosting the effort that is invested in a task, reward cues facilitate cognitive and physical processes, regardless of whether these cues are presented above (supraliminal) or below (subliminal) the threshold of conscious awareness. Specifically, Pessiglione et al. (2007) showed people a coin that they could earn if they squeezed firmly into a handgrip. Whether coins were presented supraliminally or subliminally, people squeezed harder when a high (vs. low) reward was at stake. Recently, subliminal effects of reward information have been demonstrated to be dependent on the task-demanding context (Bijleveld et al., 2009). Specifically, high (50 cents coin) compared to low (1 cent coin) rewards increased participants' effort in a high-demanding task (retaining five digits), but not in a low-demanding task (retaining 3 digits).

Taken together, rewards seem to govern human cognition and behavior via two processes. First, valuable reward cues – whether conscious or nonconscious – increase effort in demanding tasks, facilitating mental and physical processes to gain the reward. Second, conscious but not unconscious reward cues likely influence the trade-off between speed and accuracy, in that standards for accuracy are raised to secure more valuable rewards, inducing people to sacrifice speed. Indeed, neuroscientific work on speed-accuracy tradeoffs suggests that the effort people invest in tasks is independent of the accuracy standards that are used (Carpenter, 2004; Ratcliff & Smith, 2004). Furthermore, the idea that conscious (but not unconscious) rewards affect the tradeoff between speed and accuracy is consistent with the notion that only information carried by supraliminal stimuli is capable of changing trade-offs in tasks (see e.g., Baars, 2002; Dehaene & Naccache, 2001).

In this study, then, we test the hypothesis that rewards enhance invested effort regardless of whether people are conscious of them, whereas rewards influence speed-accuracy tradeoffs only when they are available to consciousness. To test this hypothesis, we used a paradigm that enabled us to distinguish between increased effort and shifted accuracy standards. Specifically, after presentation of a reward cue (high value vs. low value coins presented supraliminally vs. subliminally), participants performed a demanding task that required them to solve a mathematical problem. Comparing effects between low and high rewards allows us to determine the role of conscious and unconscious input in the speed-accuracy tradeoff process. Importantly, on each trial the reward declined with time and only accurate responses were rewarded. In this demanding context, high (vs. low) rewards initially increase effort (with no shift in accuracy standards), thus inducing faster responses. Therefore, unconscious high (vs. low) rewards are expected to speed-up responses without changing accuracy. However, because standards for accuracy are expected to raise when high (vs. low) rewards are consciously perceived, people should display increased accuracy at the cost of speed. Experiment 1 provides an initial test of this idea. Experiment 2 examined whether unconscious as well as conscious valuable rewards can speed up responses without changing accuracy by reducing the tendency for making speed-accuracy tradeoffs.

Experiment 1

Method

Participants and design. 29 undergraduates took part in this study, completing 56 trials, 14 repetitions per condition of the 2(reward: 50 cents vs. 1 cent) x 2(presentation: supraliminal vs. subliminal) within-subjects design. Participants received the money they earned in the experiment.

Procedure. Participants worked in individual sessions on a computer. They learned that on each trial they were to see a coin (50 cents or 1 cent), which they could earn by correctly solving a mathematical problem. The amount of money they received for a certain trial – provided they were accurate – was contingent on their speed: the faster they were, the more they got. They learned that, at times, the coin would be 'difficult to perceive'. Accordingly, on half of the trials, the coin was presented subliminally.

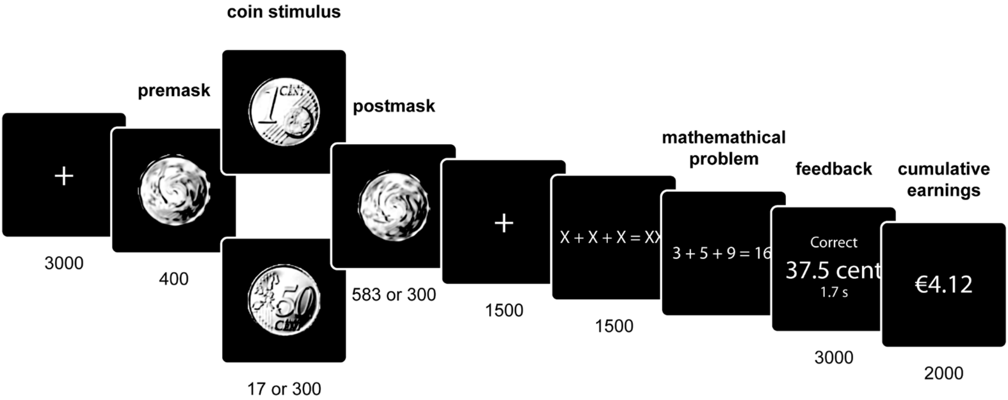

Figure 1. The course of a trial. Numbers refer to presentation durations in milliseconds. In all conditions, the duration of the coin and the masks added up to 1000 ms. The subliminal coin presentation procedure is taken from Bijleveld et al. (2009).

Trials. The course of a trial is depicted in Figure 1. Participants saw a coin, masked in such a way that it was visible or not[1]. Then, participants saw the mathematical problem, which was an equation of three single-digits adding up to a sum. Participants indicated whether this expression was true (e.g., 2 + 3 + 9 = 14) or false (e.g., 4 + 5 + 8 = 21), using the 'z' and '/' keys on the keyboard. After responding, they received feedback on their performance (accuracy, earned reward, and speed). Rewards linearly declined with time, such that the value of the presented coin (i.e., 1 or 50 cent) decayed

1 In a previously reported signal-detection test that was conducted under exactly the same experimental conditions, we demonstrated that people could not discriminate between 1 and 50 cent coins when these were presented for 17 ms, even though people had consciously inspected these stimuli before the test (Bijleveld et al., 2009; see also Pessiglione et al.,2007).

with 14% of the original reward every second. More formally, the reward was given by the formula R = V – V * T / 7000, with R ≥ 0, in which R is the earned reward, V is the value of the presented coin, and T is the time taken to solve the arithmetic problem of that trial (milliseconds). When participants were not accurate, they received nothing on that trial. Finally, participants saw their cumulative earnings.

Materials. The mathematical problems comprised 56 fixed sets of 3 digits. In these sets, two digits never added up to 10, to keep difficulty constant. On half of the trials, they were added up correctly. On the other half of the trials, the ostensible sum was the accurate value plus or minus 2. Mathematical problems were presented in a random order, independent of condition.

Results

Speed. Only accurate responses within the 7000 ms time window in which a reward could be earned were analyzed. Values that differed 3 standard deviations or more from the mean of the participant were regarded as outliers and discarded. In total, 1.3% of all trials were excluded from the analysis. Mean speeds per condition were submitted to ANOVA according to the experimental design. This analysis revealed only the predicted Reward x Presentation interaction, $F(1, 28) = 13.57$, $p < .001$, other F's < 2.1. Inspection of the means (Figure 2a) revealed that in the supraliminal condition, participants were significantly slower when 50 cents were at stake, compared to 1 cent, $F(1, 28) = 7.22$, $p < .05$. In contrast, in the subliminal condition, participants were faster in the 50-cents condition compared to the 1-cent condition, $F(1, 28) = 5.12$, $p < .05$ (Kirk, 1995).

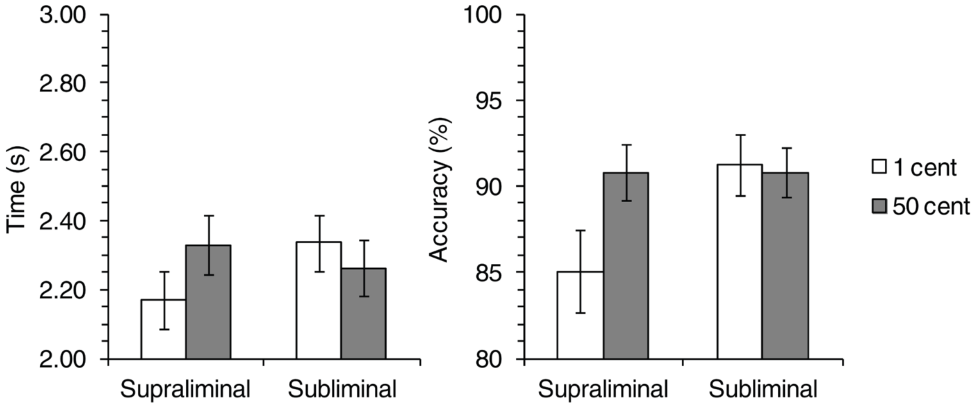

Figure 2. Results of Experiment 1. Left: Time (seconds) participants took to give a response. Right: Accuracy (percentage). Error bars represent standard errors of the mean.

Accuracy. Accuracy scores (Figure 2b) were submitted to the same ANOVA. The only effect that proved significant was the Reward x Presentation interaction, $F(1, 28) = 5.54$, $p < .05$, other F's < 2.8, p's $> .11$. Whereas accuracy was high and unaffected by rewards in the subliminal condition, $F < 1$, high rewards produced higher accuracy than low rewards in the supraliminal condition, $F(1, 28) = 4.78$, $p < .05$.[2]

2 We also explored whether people earned more money on supraliminal or subliminal trials. In Experiment 1, there were no reliable differences between conditions (overall M = €8.71), $t(28) = .61$, $p = .55$. In Experiment 2, participants earned slightly more money in the subliminal condition (M = €3.07), compared to the supraliminal condition (M = €3.02), $t(119) = 2.6$, $p < .05$. We thank one of the reviewers for suggesting to report this additional analysis.

Discussion

The present data are novel in showing qualitative differences between rewards of which humans are conscious vs. not. Whereas valuable reward cues increased speed when unconsciously perceived, they decreased speed when participants were conscious of them. The process behind these changes in speed, however, only becomes apparent when the accuracy data are considered too. For unconscious reward information, speed increased with reward value while accuracy remained constant. This suggests that unconscious valuable rewards increase the investment of effort in the task, but does not make people more or less cautious. In contrast, for conscious information, high (compared to low) rewards made people slower, but more accurate. These findings demonstrate that people were relatively more cautious on high-reward trials, using higher standards of accuracy at the expense of speed. Together, these results demonstrate that only conscious rewards impact on speed-accuracy tradeoffs.

Due to the tradeoff between speed and accuracy, however, we cannot conclude that participants invested more effort in the task in response to high, conscious rewards: participants were relatively more accurate, but also slower. As reward-induced increases in effort are known to be very primary (they precede higher processing in time, Knutson, Delgado, & Phillips, 2008; they are underpinned by lower brain structures, Pessiglione et al., 2007), conscious concerns of caution likely operate in addition to effort enhancements that are initially induced by valuable rewards (Bargh & Morsella, 2008). Accordingly, increased effort increments (in terms of speed) in response to conscious high rewards may just fail to materialize, rather than that they do not occur in the first place. This raises the important and intriguing question of whether consciously presented rewards can behave like unconsciously presented rewards, when the tendency to change speed-accuracy tradeoffs is reduced. Experiment 2 was designed to test this idea.

Experiment 2

The rationale behind Experiment 2 was the following: If conscious and unconscious valuable reward cues both increase effort, but only conscious reward cues instigate a change in speed-accuracy tradeoffs, then *eliminating* the possibility for such tradeoffs should reveal effects of increased effort – for unconscious but also for conscious reward cues. For this purpose, we replicated Experiment 1 with one major change. That is, we added a condition in which participants would get paid only if they were accurate on 90% of all trials (this challenging accuracy target-level was based on the mean accuracy in Experiment 1). As this change in the payoff structure of the task dramatically enhances the relative importance of accuracy over speed, we reasoned that this procedure would induce people to maintain a high standard for accuracy on all trials – irrespective of that particular trial's reward and the conscious awareness of the reward (see Wickelgren, 1977). What remains, then, is the initial impact of high (vs. low) rewards on increased effort. Accordingly, under these circumstances we expect low and high rewards to always produce a high number of accurate responses. However, we expect high (vs. low) rewards to produce faster responses (due to the extra investment of effort), whether consciously perceived or not.

Method

Participants and design. 121 undergraduates took part in this study, completing 40 trials, 10 repetitions per condition of the 2(reward: 50 cents vs. 1 cent) x 2(presentation: supraliminal vs. subliminal) x 2(standard: no standard vs. 90% standard) mixed design. The latter factor was a between-subjects factor. Participants received the money they earned.

Procedure. The procedure and events in trials of the no-standard condition were identical to Experiment 1. In the 90%-standard condition, participants received the additional instruction that they were only to be paid, if they were accurate on at least 90% of all trials.

Results and discussion

Speed. Outliers were dealt with in the same way as in Experiment 1, resulting in 2.2% of trials being excluded from the analyses. Mean speeds per condition were submitted to an ANOVA, according to the experimental design. This analysis yielded a main effect of standard, $F(1, 118) = 20.08$, $p < .001$, showing slower responses when an accuracy standard was imposed (see Figure 3a for means). Moreover, there was a significant Reward × Presentation interaction, $F(1, 118) = 5.32$, $p < .05$, indicating that the effect of reward was stronger when coins were presented subliminally rather than supraliminally. These effects were qualified by a significant three-way interaction, $F(1, 118) = 5.77$, $p < .05$.

To interpret this three-way interaction, we conducted a 2 (reward) x 2 (presentation) repeated-measures ANOVA separately for the two levels of standard (i.e., no standard and 90%-standard). In the no-standard condition, we found the predicted Reward × Presentation interaction, $F(1, 118) = 11.09$, $p < .01$, and no significant main effects.

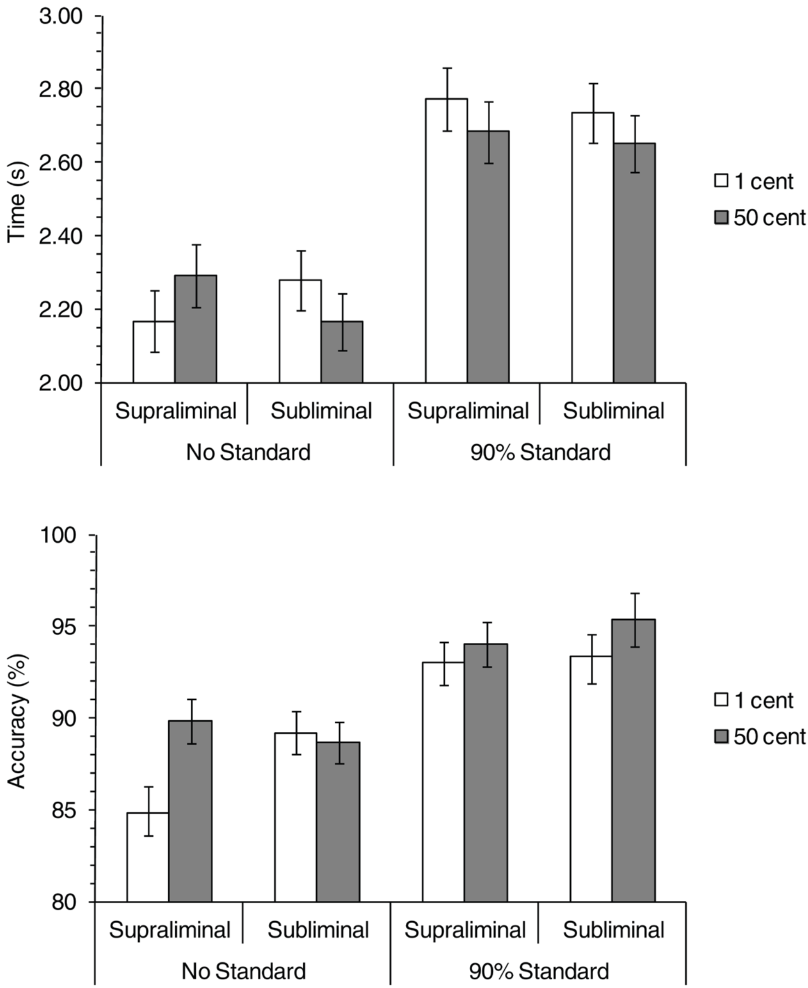

Figure 3. Results of Experiment 2. Top: Time (seconds) participants took to give a response. Bottom: Accuracy (percentage). Error bars represent standard errors of the mean.

Testing the simple effects revealed that in the supraliminal condition, participants were slower when a high reward was at stake, $F(1, 118) = 5.60$, $p < .05$. In contrast, in the subliminal condition, participants were faster when in pursuit of a high reward, $F(1, 118) = 5.29$, $p < .05$. In the 90% standard condition, we found only a main effect of reward, $F(1, 118) = 5.89$, $p < .05$, revealing that participants were faster when a high reward was at stake. Importantly, this effect was not qualified by a Reward × Presentation interaction, $F(1, 118) < 1$.

Accuracy. Accuracy scores were submitted to the same ANOVA. This yielded a main effect of standard, $F(1, 118) = 30.45$, $p < .001$, indicating that participants were more accurate when given an 90%-accuracy standard (for means, see Figure 3b). We also found a significant main effect of reward, $F(1, 118) = 5.30$, $p < .05$, revealing a higher number of accurate responses when a high reward was at stake. Moreover, the three-way interaction approached significance, $F(1, 118) = 3.76$, $p = .06$. For this reason, and to perform the same analyses as conducted for speed, we performed a 2 (reward) × 2 (presentation) repeated-measures ANOVA separately for the two levels of standard (i.e., no standard and 90% standard). In the no-standard condition, we found the same pattern as in Experiment 1. Specifically, there was a main effect of reward, $F(1, 118) = 3.82$, $p = .05$, indicating that participants were more accurate when a high reward was at stake. This effect was qualified by a significant reward × presentation interaction, $F(1, 118) = 5.38$, $p < .05$, that revealed that the reward effect was only present in the supraliminal condition. Indeed, within this condition, participants were significantly more accurate for higher rewards, $F(1, 118) = 8.41$, $p < .01$. In the 90%-standard condition, as expected, no effects proved significant, indicating that participants were equally accurate across conditions.

The findings of Experiment 2 replicate and extend those of Experiment 1 by demonstrating that preventing people from making speed-accuracy tradeoffs for rewards of different value (by imposing dominant importance on accuracy) causes consciously perceived rewards to produce the same effort enhancements as that of unconsciously perceived rewards. Specifically, regardless of whether rewards were presented subliminally or supraliminally, people were faster for high rewards, while accuracy remained high. Experiment 2 thus corroborates the idea that supraliminal *and* subliminal valuable rewards enhance the investment of effort. On top of that, conscious valuable rewards do something else: they raise standards of accuracy at the expense of speed in situations where both dimensions play a role.

General discussion

In two experiments, we provided a demonstration of qualitative differences between the pursuit of rewards of which one is conscious, and of which one is not. In the experiments, we paid people more when they were faster on an arithmetic task, but only when they were accurate. We presented new evidence that valuable rewards initially enhance the investment of effort (make people faster), regardless of whether rewards are consciously perceived. In addition, our data demonstrate that people make different speed-accuracy tradeoffs for rewards that differ in value, provided that these rewards are consciously perceived.

The present findings fit well with recent advances in the literature concerning differences between supraliminal and subliminal stimuli in influencing cognition and behavior. Specifically, research on masked priming demonstrates that only supraliminal stimuli gain access to a 'global workspace', that is involved in broadcasting information across the brain, so that this information can be used as input for a wide array of cognitive processes and systems (Baars, 2002; Dehaene & Naccache, 2001; Morsella, 2005). The supraliminal rewards in our research can be seen as stimuli that potentially are broadcasted, and via that route change the speed-accuracy tradeoff. Still, albeit in specific ways, subliminal stimuli also can exert control over other processes, for instance by preparing the execution of tasks (Lau & Passingham, 2007). Extending this research, our data reveal the role of subliminal rewards in facilitating processes that are relevant for performance on speed and accuracy.

A particularly interesting implication of the current findings is that depending on parameters that are set by circumstances, rewards change tradeoffs between speed and accuracy. Indeed, rewards that are consciously perceived may evoke the same reactions as do unconsciously perceived rewards (Bijleveld et al., 2009; Pessiglione et al., 2007). Whether or not this occurs depends on whether different speed-accuracy tradeoffs can be made in response to different rewards in the first place. If characteristics of the situation prevent this tendency – for instance when accuracy is a priori much more important than speed – reward-induced enhancements of effort unambiguously translate into performance. Instead, when circumstances put equal importance on speed and accuracy, conscious and unconscious rewards affect tradeoffs in a different way. Interestingly, according to the present findings the default setting seems to be that people become faster while not sacrificing accuracy. This basic response to valuable rewards may help humans to optimally take advantage of the environment (e.g., to successfully compete with others) when rewards are present.

Chapter 6

Once the money is in sight: Distinctive effects of conscious and unconscious rewards on task performance

Abstract: Monetary rewards facilitate performance on behavioral and cognitive tasks, even when these rewards are perceived without conscious awareness. Also, recent research suggests that consciously (vs. unconsciously) perceived rewards may prompt people to more strongly concentrate on task stimuli and details. Here we propose that the latter is sometimes dysfunctional, in that it prevents improvements in task performance. We used an Attentional Blink paradigm, in which such enhanced concentration on task stimuli is detrimental to performance. Participants were consciously (supraliminally) or unconsciously (subliminally) exposed to a high-value or low-value coin that they could earn by performing well on an Attentional Blink trial. As hypothesized, high-value rewards increased performance when they were presented subliminally, while this performance benefit vanished when high-value rewards were presented consciously. We discuss this finding in the context of recent research on unconscious goal pursuit.

This chapter is based on: Bijleveld, E., Custers, R., & Aarts, H. (2011a). Once the money is in sight: Distinctive effects of conscious and unconscious rewards on task performance. *Journal of Experimental Social Psychology, 47,* 865-869. doi: 10.1016/j.jesp.2011.03.002

Once the money is in sight: Distinctive effects of conscious and unconscious rewards on task performance

In colloquial life, money is everywhere. Humans learn about its use and function starting at a young age (Berti & Bombi, 1988), and it is therefore not surprising that the psychological effects of money are widespread and profound (Lea & Webley, 2006). Money has been used as a powerful motivator for centuries, which makes sense: For money, humans are willing to work. Specifically, when monetary rewards are at stake, people perform better on tasks, generally increasing their chances at reward attainment. But is this always true? Following current perspectives on conscious and unconscious processes in motivation and goal pursuit, we propose that monetary rewards can impact performance unconsciously (Bargh, Gollwitzer, & Oettingen, 2010; Custers & Aarts, 2010). Furthermore, we propose that conscious awareness of these rewards can additionally prompt people to more strongly concentrate on task stimuli and details, and we investigate a situation in which such increased concentration is counterproductive. In so doing, we test the intriguing possibility that monetary reward cues only increase performance when they are processed unconsciously.

Traditionally, research on reward effects has employed explicit reward cues (or instructions) that can readily be consciously perceived. In typical experiments, participants learn that they will receive money contingent on their performance and are told—or informed by means of a visual cue—how much can be earned in an upcoming task (e.g., Eisenberger & Aselage, 2009; Glucksberg, 1962; Richter & Gendolla, 2009). Such studies suggest that monetary rewards that are at stake generally increase task concentration and engagement, but that this is not always functional as to improving performance (rewards may even be detrimental). Here, we dissociate between unconscious and conscious reward processing to enhance our understanding of when monetary reward cues leads to better performance—and when they do not.

Remarkably, recent research shows that conscious awareness of rewards is not a necessary condition for them to increase task performance. Specifically, in an experiment (Pessiglione et al., 2007), participants were shown a coin (of high or low value) that they could earn by forcefully squeezing a handgrip. Not surprisingly, people squeezed harder when a high-value coin was at stake. Strikingly, however, people also exerted more force for high-value coins when these were presented subliminally (i.e., too briefly to be consciously perceived). Thus, bypassing conscious awareness of the reward at stake, just a slight amount of reward-cue input is sufficient to increase task performance.

This finding has been replicated for cognitive tasks. Subliminal rewards seem to increase cognitive performance to the same extent as do 'normal' (consciously perceived) rewards, as revealed by converging evidence from working memory tasks (Zedelius, Veling, & Aarts, 2011; Capa, Bustin, Cleeremans, & Hansenne, 2011), mathematical tasks (Bijleveld, Custers, & Aarts, 2010), and physiological measurements (Bijleveld, Custers, & Aarts, 2009). These findings indicate that monetary rewards enhance performance on various cognitive tasks, including those reliant on working memory, without awareness.

Recent work in cognitive neuroscience offers an account for these findings. Specifically, reward cues are processed in subcortical brain structures, such as the ventral striatum. While these lower-level structures presumably function independently of conscious awareness, they play a central role in assessing the rewarding value of outcomes. Importantly, these subcortical areas are known to directly connect to brain areas that are implicated in working memory and action control in goal pursuit, located in the frontal cortex (Aston-Jones, & Cohen, 2005). Whereas such higher-order processes are traditionally thought to require conscious intention and awareness to occur (Baars & Franklin, 2003; Baddeley, 1993), the interconnected nature of the subcortical reward center and frontal-cortical areas suggests the possibility that rewards can facilitate cognitive task performance directly and unconsciously. In line with this notion, and building on the conceptual distinction between consciousness and attention (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Koch & Tsuchiya, 2007; Lamme, 2003), Dijksterhuis and Aarts (2010) recently proposed that goals may recruit working memory and attentional control processes, but that these processes do not necessarily require conscious awareness of the goal to occur. Consistent with this suggestion, recent research shows that people can be unconsciously motivated to engage in working memory processes (Aarts, Custers, & Veltkamp, 2008; Hassin, Bargh, Engell, & McCulloch, 2009).

Although the studies alluded to above seem to indicate that rewards evoke the same response irrespective of whether they are perceived consciously, this is not always the case. Instead, several lines of research suggest that (or goals) may change the way people process incoming information and deal with task stimuli when these rewards permeate into consciousness (Baars, 2002; Bijleveld et al., 2010; Dehaene & Naccache, 2001; Dijksterhuis & Aarts, 2010; Zedelius et al., 2011). That is, because consciously perceived rewards cause people to reflect on what is at stake, conscious awareness of rewards may prompt people to more strongly concentrate on task stimuli and details. Consistent with this idea, paying money according to performance induces people to focus more strongly on the task that is instrumental in attaining the money (Baumeister, 1984; Hertwig & Ortmann, 2001). Paradoxically, however, this enhanced concentration on task information may sometimes interfere with effective performance, e.g., when enhanced concentration also entails better processing of irrelevant information. In other words, while people may hold the belief that increased concentration on the task helps them to perform better, this may in fact backfire in some tasks.

Inspired by this recent literature, we propose that valuable rewards may affect performance or not as a function of whether the reward is consciously perceived. While unconsciously perceived rewards facilitate cognitive (working memory) processes, this should in principle enhance task performance. Nevertheless, focusing too much on task details in response to a consciously perceived valuable reward may thwart this performance enhancement. To test this idea, we used an Attentional Blink paradigm—a paradigm examining the human ability to process serially presented information—in which consciously focusing on details of the task is a dysfunctional strategy.

Rewards and the Attentional Blink

The Attentional Blink (AB) is a phenomenon that occurs when two target stimuli appear in between distracters and in close temporal proximity. While people can generally detect the first target with high accuracy (T1), they can only detect the second target (T2) fairly successfully if it follows the first either directly or after at least 500 ms (Raymond, Shapiro, & Arnell, 1992). If the second target follows the first after 200–500 ms, the AB occurs: during this interval, detection accuracy is severely diminished. The general explanation for this effect pertains to the occurrence of a two-stage process, in which an initial perceptual process is followed by a second stage in which stimuli are transferred into working memory. If both targets successfully pass through these two stages, they can be accurately reported, which is the (only) goal in the AB task. Several studies show that improved performance on the AB task is dependent on working memory functioning (Arnell, Stokes, MacLean, & Gicante, 2010). Therefore, valuable monetary rewards should in principle induce people to perform better on the AB.

While motivational aspects of the AB increasingly enjoy empirical attention (Raymond & O'Brien, 2009), recent research suggests that consciously perceived monetary rewards do not enhance AB performance (Olivers & Nieuwenhuis, 2005, for a null finding). An explanation for this comes from studies showing that focusing too much on AB stimuli is detrimental (instead of beneficial) for performance. Indeed, in the AB, concentrating on task stimuli does not selectively facilitate processing of targets but also of distracters, thereby increasing their potential for interference. For example, when participants are instructed to adopt a more absent-minded processing goal they paradoxically perform better—instead of worse (Olivers & Nieuwenhuis, 2006). Taken together, concentrating too much on the task—a strategy that we hypothesized is adopted only after a valuable reward is consciously perceived—thwarts the otherwise favorable reward effect on AB performance (see also Arend, Johnston, & Shapiro, 2006; Dale & Arnell, 2010).

In sum, we propose that unconsciously perceived valuable rewards facilitate working memory processes (Dijksterhuis & Aarts, 2010), and hence improve performance on the AB. When consciously perceived, however, valuable rewards likely change people's task strategy to focus too much on subsequent task stimuli, including the distracters, which undermines the effects of rewards on AB performance. The present experiment tests this idea by examining effects of consciously (supraliminally) and unconsciously (subliminally) presented high-value vs. low-value monetary rewards on the AB.

Method

Participants and design

Fifty-three students (15 males; mean age = 20) participated. Participants learned that on each trial they would first see a coin. In line with typical AB tasks, the coin was followed by a stimulus-presentation stream. Participants could earn the coin by accurately reporting the two targets. The experiment started with 15 practice trials, followed by 128 experimental trials, 32 repetitions per lag (see below), which were crossed in a 2(reward: 1 cent versus 50 cents) × 2(presentation: subliminal versus supraliminal) design. Experimental trials were presented in two blocks of equal length.

Procedure and trials

Figure 1 illustrates the course of a trial. Each trial started with a fixation cross (500 ms), after which participants saw a coin. Participants learned that the coin was sometimes difficult to see. Accordingly, coins were presented either supraliminally (i.e., consciously visible; 300 ms) or subliminally (20 ms). The coin was either of high (50 cents) or low (1 cent) value. It was preceded by a pre-mask and followed by a post-mask to ensure that participants would not be able to consciously see the coin when it was presented

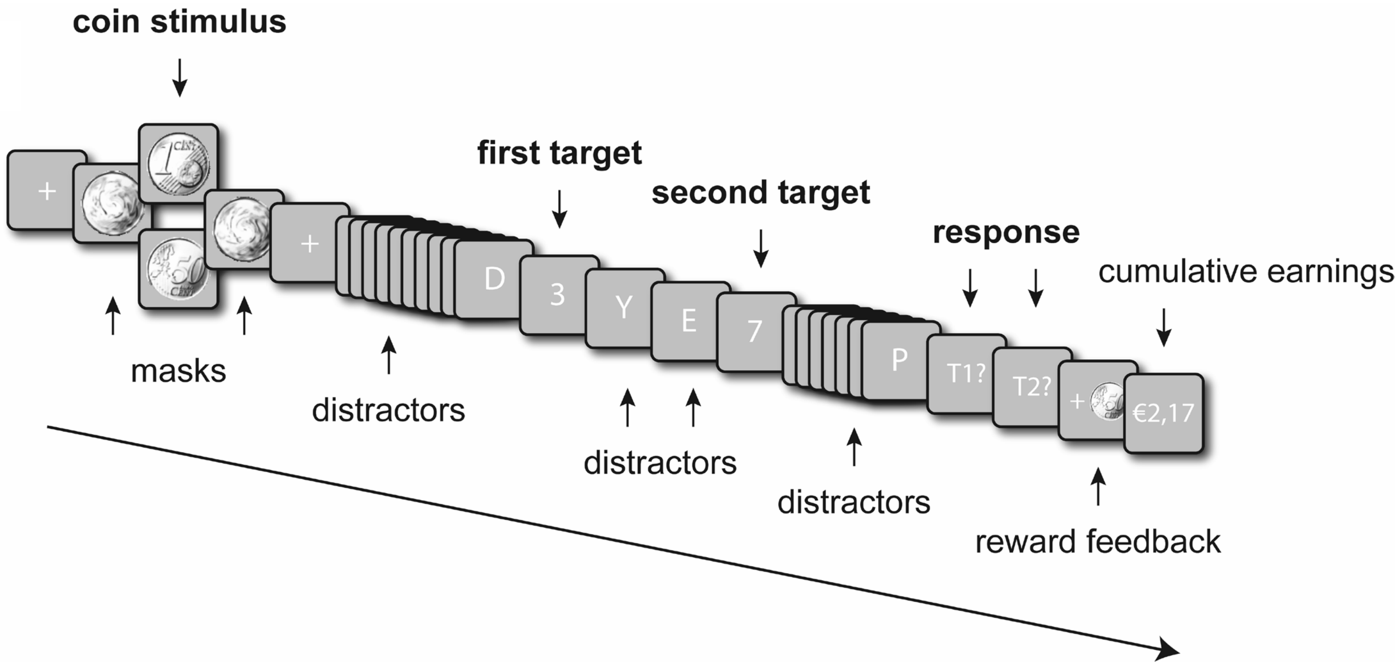

Figure 1. The course of a trial. First, participants saw a coin of high or low value that was masked such that it could be consciously perceivable or not. Then, 21 items were displayed in fast succession (50 ms each; each followed by a 50 ms blank). Among the distracter items (letters) were two targets (digits), that participants had to report on the end of each trial. The interval between the two targets (i.e., lag) varied (1, 2, 3, or 7). When participants correctly reported the two digits, they received the coin.

very briefly[1]. Irrespective of condition, the pre-mask, the coin, and the post-mask were always on screen for 1000 ms. After the post-mask, participants saw another fixation cross (1500 ms).

Next, participants saw a typical AB stream, containing 19 distractors (uppercase white letters) and two targets (white digits). Distractors and targets were randomly drawn from the alphabet or the digits 2–9, respectively. However, the letters I, O, Q, and S were left out because of their resemblance to digits; the digit 5 was left out because of its relation to the high-value coin. In rapid succession, items were presented for 50 ms each, followed by 50 ms blanks. The first digit (T1) appeared on the 10–13th temporal position. The position of T2 (i.e., the Lag factor) was 1, 2, 3, or 7 temporal positions after T1. After having seen the AB stream, participants reported the two targets in order. Next, participants received feedback: when they had correctly identified T1 and T2, they saw a coin with a plus-sign (indicating reward attainment). When they were incorrect, they saw a coin blotted out by a red cross (indicating no reward). Finally, they saw their earnings, cumulative over trials.

Results

To assess performance on the AB task, average T1 and T2 identification accuracy were submitted to an ANOVA according to the design. Trials were scored as accurate when T1 and T2 were reported in order.

Figure 2 (top panels) shows the results for T1. There was only a main effect of Lag, $F(3, 153) = 142.80$, $p < .001$, $\eta^2_p = .74$, indicating

1 Subliminality of the stimuli was confirmed in a separate task. Twenty different participants were randomly presented with a set of 1 cent and 50 cents coins, masked in the same way as the 20-ms condition. Participants indicated the value of each presented coin (1c or 50c). Performance at discriminating between the coins was no better than chance, $M_{accuracy} = .516$ ($SD = .113$), $t(19) = .61$, $p = .55$.

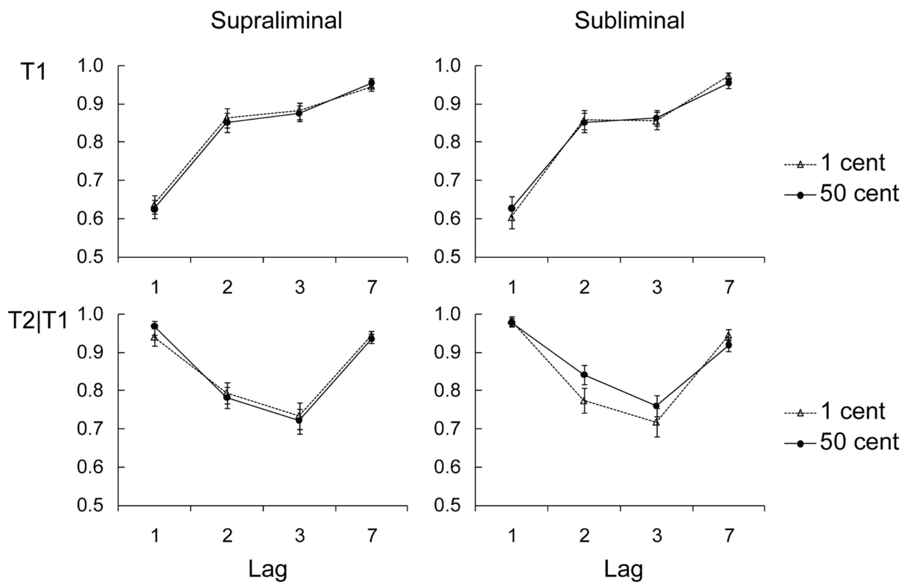

Figure 2. Performance (accuracy) as a function of reward presentation, lag, and reward value. Top panels indicate detection of the first target (T1). Bottom panels indicate detection of the second target on trials where the first was accurately detected (T2|T1).

that accuracy was higher at longer lags (other *F*'s < 1). Figure 2 (bottom panels) shows the results for T2 when T1 was identified correctly, which is the standard measure for the AB effect. There was a main effect of Lag, $F(3, 153) = 61.18$, $p < .001$, $\eta^2_p = .55$, indicating a strong AB effect (Raymond et al., 1992). Importantly, this effect was qualified by the Reward x Presentation x Lag interaction, $F(3, 153) = 2.64$, $p = .05$, $\eta^2_p = .049$. Inspection of the pattern of means suggests that the direction of this interaction is in line with the hypothesis that rewards mainly improve AB performance when they are presented subliminally (vs. supraliminally). To test this hypothesis, we conducted 2(Reward) x 4(Lag) analyses separately for the subliminal and supraliminal conditions.

In the subliminal condition, there was a main effect of Lag, $F(3, 153) = 39.00$, $p < .001$, $\eta^2_p = .43$. Moreover, there was a marginally significant effect of Reward, $F(1, 51) = 2.82$, $p = .10$, $\eta^2_p = .05$. Importantly, these effects were qualified by the predicted Reward × Lag interaction, $F(3, 153) = 3.83$, $p = .01$, $\eta^2_p = .07$. Consistent with our predictions, the pattern of means indicated that the drop in accuracy on lags 2 and 3—as compared to 1 and 7—was shallower when a high reward was at stake. To establish this pattern statistically, we tested whether the quadratic contrast of the Lag factor interacted with Reward, which turned out to be the case, $F(1, 51) = 9.78$, $p = .004$, $\eta^2_p = .16$. In other words, subliminal rewards improved AB performance.

In the supraliminal condition, there was a main effect of Lag, $F(3, 153) = 50.24$, $p < .001$, $\eta^2_p = .50$, indicating the presence of the AB effect. Importantly, there was no effect of Reward, $F(1, 51) < 1$, nor a Reward × Lag interaction, $F(3, 153) < 1$. Thus, in line with our predictions, supraliminal rewards did not improve AB performance.

To further substantiate the idea that subliminal but not supraliminal rewards significantly increase performance during the specific AB interval (i.e., lags 2 and 3),we conducted a separate 2(reward: 1 cent vs. 50 cents) × 2(presentation: subliminal vs. supraliminal) × 2(lag: 2 vs. 3) ANOVA. This analysis revealed the predicted Reward x Presentation interaction, $F(1, 51) = 5.38$, $p = .024$, $\eta^2_p = .10$, confirming that rewards enhanced performance during the AB interval when they were subliminally presented, $F(1, 51) = 7.23$, $p = .010$, $\eta^2_p = .12$, but not when they were supraliminally presented, $F(1, 51) < 1$.

Discussion

The present research showed that subliminal presentation of a valuable reward improves performance on the Attentional Blink task (Raymond et al., 1992), whereas supraliminal presentation of the same valuable reward does not. The former finding indicates that unconscious rewards can increase performance on a task that relies on working memory and attention processes, thus offering support for recent models that propose that people can engage in working memory processes in the absence of awareness of the goals they pursue (Dijksterhuis & Aarts, 2010). Importantly, however, our data also suggest that this facilitating response is thwarted when people consciously reflect on the reward, likely due to a dysfunctional task strategy of concentrating too much on the task at hand (Olivers & Nieuwenhuis, 2006).

In support of this suggestion, research shows that conscious, task-related strategies paradoxically impede performance in various other domains as well, such as category learning (DeCaro, Albert, Thomas, & Beilock, 2011), decision making (Dijksterhuis & Nordgren, 2006), and skilled motor performance (Lewis & Linder, 1997). Moreover, rewarding performance with money is thought to encourage exactly these strategies, as this induces people to become more concerned with doing well on the task and with complying with task instructions (Hertwig & Ortmann, 2001). The current findings thus contribute to a growing body of literature that shows that increased task focus can hurt performance, and support the specific idea that such negative performance effects are rooted in consciousness (Baumeister, Masicampo, & Vohs, 2011; Dijksterhuis & Aarts, 2010).

Previously, research on unconscious processes in the pursuit of rewards and goals has generally taken the approach of showing that unconsciously induced motivation (e.g., via priming) has the same qualities as consciously induced motivation (Bargh, 2006; Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001; Bijleveld et al., 2009; Custers & Aarts, 2005; Gollwitzer, Parks-Stamm, & Oettingen, 2008). This approach has certainly been informative, but has led some to suggest that the effects of unconscious manipulations (e.g., priming effects on behavior) are mediated by conscious processes, e.g., biasing of conscious perceptions (see Custers & Aarts, 2010, for a discussion). By revealing an effect that only holds for unconscious rewards, we provide compelling evidence in support of the idea that the unconscious component has a favorable effect by itself, free of any conscious intervention.

The present research suggests that consciously reflecting on a reward prompts people to use strategies that they think will increase the probability of reward attainment (Bijleveld et al., 2010). While this may sometimes support performance, the present research shows that such a money-induced task focus is not always a good thing (Beilock & Carr, 2001; Dijksterhuis & Nordgren, 2006; Olivers & Nieuwenhuis, 2006). Furthermore, as money is generally assumed to be a powerful motivator for performance (Lea & Webley, 2006), our findings offer intriguing and novel evidence indicating how money may not be desirable (cf. Deci, Koestner, & Ryan, 1999). Accordingly, by demonstrating that the reward-effect that otherwise would occur may be thwarted when people are aware of what is at stake, the present work breaks new ground in examining the role of conscious awareness in the pursuit of rewards and goals.

Chapter 7

When favourites fail: Tournament trophies as reward cues in tennis finals

Abstract: In tournaments in various sports that feature one–on–one competition, the trophy is sometimes prominently displayed near the athletes during the final. Based on recent research on subtle reward cues, we propose that such trophies have the potential to induce choking under pressure in the match favourites, who are known to be most at risk. To test this idea, we analysed real-life tennis performance data (service performance and rally performance) from professional tournaments. While favourites generally outperformed underdogs during rallies, they did not do so in finals in which (a) large amounts of money were at stake and (b) a trophy was on display near the court. These findings support the idea that tournament trophies may distract favourites by continuously reminding them of what is at stake, and via that route may severely thwart their performance.

This chapter is based on: Bijleveld, E., Custers, C., & Aarts, H. (2011b). When favourites fail: Tournament trophies as reward cues in tennis finals. *Journal of Sports Sciences, 29*, 1463-1470.

When favourites fail: Tournament trophies as reward cues in tennis finals

Those who are under pressure to excel are at risk of failure. This idea has received support from researchers who have shown that high motivation to succeed may paradoxically cause failure in various performance settings, including the classroom (Rosenthal & Crisp, 2007), the concert hall (Yoshie, Kudo, Murakoshi, & Ohtsuki, 2009), and the football pitch (Jordet & Hartman, 2008). *Choking under pressure*, specifically, refers to the phenomenon that people perform worse than would be expected given their skill, in situations in which perceived pressure is high. Often carried out in the laboratory, research on the topic has identified psychological and physiological mechanisms that explain choking under pressure (for a review, see Beilock & Gray, 2007). Yet, field studies that delineate what real-life factors contribute to choking under pressure are relatively rare. We investigate the impact of subtle cues from the environment—in this case, the trophies that are sometimes displayed near the court during tennis tournaments' finals. We propose that these trophies serve as reward cues that remind players of the incentives that are at stake, and via that route may provoke suboptimal performance in those who are likely to be most at risk: the favourites.

Two main theories, which are thought to be complementary, are often employed to explain how choking under pressure occurs. First, *distraction theory* proposes that performance pressure causes irrelevant thoughts and worries to strain working memory (Baddeley, 2003). This results in a situation in which useful processes (e.g., predicting the ball's future locations) have to compete for limited resources with non-useful ones (e.g., thinking about what happens if one loses the match), thus debilitating performance on tasks that rely on working memory and executive functioning (Beilock, Kulp, Holt, & Carr, 2004; Markman, Maddox, & Worthy, 2006). Second, *explicit monitoring theory* proposes that performance pressure causes athletes to deploy attention to step-by-step components of proceduralised skills that are normally executed routinely and outside of awareness. This dysfunctional way of using attention disrupts performance on tasks that rely on well-learned movements (Baumeister, 1984; Beilock & Carr, 2001).

While these theories are informative as to the question *how* pressure thwarts performance, it is less clear what aspects of performance situations cause such debilitating pressure in the first place. Laboratory studies often use multiple sources of pressure at the same time (e.g., peer pressure, anticipated evaluation, monetary incentives), and thus cannot serve as a basis for conclusions as to *what* exactly caused the choking under pressure to occur (Beilock & Gray, 2007). Nevertheless, recently researchers have shown that monetary rewards greatly contribute to choking. When excessive amounts of money can be gained, people tend to underperform on all kinds of tasks, including those involving motor skills and those requiring working memory (Ariely, Gneezy, Loewenstein, & Mazar, 2009; Mobbs et al., 2009).

In addition, researchers have shown that some people are more vulnerable than others (e.g., Beilock & Carr, 2005). Importantly, those who have enjoyed previous successes—and thus are the favourites in a competition—face serious additional demands and seem especially prone to choking under pressure (Baumeister, Hamilton, & Tice, 1985; Kreiner-Phillips & Orlick, 1993). This latter idea has received support from recent databank research on soccer penalty shootouts in high-stakes tournaments, which suggests that players tend to miss more penalties after (vs. before) they have gained superstar status (e.g., by becoming “FIFA World Player of the Year”) (Jordet, 2009). It thus seems to be the case that when pressure is high (e.g., in high-incentive games), favourites are at risk.

Grounded in recent research on the effects of reward cues, we test the possibility that the presence of subtle cues—when they signal that a valuable incentive is at stake—can make a difference as to whether or not favourites choke under pressure. Recent experimental work has shown that reward cues can trigger motivation, also when they are extremely delicate (Bijleveld, Custers, & Aarts, 2009, 2010; Custers & Aarts, 2010; Pessiglione et al., 2007). Moreover, in line with the choking-under-pressure literature, it has become clear that subtle reward cues have the potential to debilitate performance. That is, when reward cues enter conscious awareness, processing of the reward may disrupt other ongoing (mental) processes (Bijleveld, Custers, & Aarts, 2011a; Zedelius, Veling, & Aarts, 2011). Clearly, this hurts performance.

Sometimes, such reward cues are evidently present in finals of tennis tournaments. That is, in some finals, the trophy is prominently displayed near the court, where it can be clearly seen by players. We propose that these trophies function as reward cues, continuously reminding players what is at stake. If this is a lot (i.e., the tournament is very rewarding) and players are at risk for choking (i.e., they are match favourites), we hypothesise that they will perform worse than would be expected given their ability. While favourites should normally be able to outperform underdogs (favourite status is based on world rankings, and thus reflects previous successes), they may fail to do so when they are reminded of the high-incentive situation by a trophy. To test this idea, we conducted a databank study of finals of tennis tournaments, in which we addressed performance as a function of (a) how much prize money was at stake, (b) status as a favourite vs. underdog, and (c) whether the trophy was displayed in sight of the players.

While testing this hypothesis, we take a novel approach to an existing problem in research on choking under pressure. That is, by definition, the diagnosis of choking under pressure requires some estimate of how well people perform under normal circumstances—in the analysis of sports statistics, this requirement has proven difficult to meet, as within-player data are often unavailable or hard to interpret (Beilock & Gray, 2007; Wallace, Baumeister, & Vohs, 2005). We make the assumption that favourites should normally outperform underdogs in direct competition, and take failure on their part to do so as an indicator of substandard performance. Our approach, then, does not rely on within-player statistics and thus overcomes commonly encountered problems with assessments of choking-under-pressure based on existing sports statistics.

We looked at two aspects of tennis performance—service performance and rally performance—in order to be able to speculate about the mechanism by which the observed choking under pressure, if any, occurred. Recall that choking under pressure is thought to occur via distraction (in the case of aspects of sports that rely on working memory), explicit monitoring (in the case of aspects of sports that rely on the execution of learned skills), or both (in the case of aspects of sports that rely on both working memory and skill execution). Specifically, we suggest that rally performance (vs. service performance) relies more heavily on working memory, and should thus be relatively vulnerable to distraction-based choking under pressure. Good performance in rallies relies on consideration of multiple options simultaneously and on constant updating of information, which are sports-related functions that are thought to be supported by working memory (Beilock & Gray, 2007). In line with the above reasoning, researchers have shown that straining working memory hurts the quality of strategic decisions in dynamic play situations (Rowe & McKenna, 2001), even for experts who can efficiently process tennis-related visual information (e.g., Williams, Ward, Knowles, & Smeeton, 2002). Yet, working memory load has proven *not* to impair experts' ability to put a golf ball (Beilock, Carr, MacMahon, & Starkes, 2002), a skill that is at least somewhat similar to serving in tennis (i.e., both are single, untimed executions of well-practiced motor skills).

The above leads us to suggest that distraction-based choking under pressure should mainly impact rally performance, and to a lesser extent service performance. By contrast, explicit monitoring-based choking under pressure should impact service performance at least as strongly, as this mechanism of choking under pressure is known to specifically harm such well-learned skills (Beilock & Gray, 2007). While the main objective of the current research is to test *whether* money at stake and trophies near court together impair favourites' performance, looking at service vs. rally performance thus enables us to speculate about *how* any of such performance impairments may have come about.

Method

Selection of games

We used the following criteria for inclusion of games in our sample. First, the game had to be a final of a professional tennis event played in 2007, 2008, or 2009, ranging in standing from relatively modest (ATP World Tour 250 series, WTA International) to very prominent (Grand Slam). Second, of these finals, specific player and performance statistics had to be available (i.e., pertaining to service and rally performance). We used OnCourt software (KAN-soft, Russia) to extract these statistics, which turned out to be available for 324 (87%) of all finals. Finally, and this was critical, we needed to know whether or not the trophy was visible to the players during the match. To this end, we contacted the administrators of the tournaments (that still existed), asking the specific question whether the trophy was in clear sight of the players during the final? In other words: During the match, was the trophy near the court? Or was it somewhere else (and hence out of sight) during the match? In total, responses to our inquiries yielded data on 106 matches, 49 of which (46%) featured a trophy in sight.

Selection of performance indicators

Of the available performance indicators, three exclusively reflected skilled service performance: (1) first service percentage (i.e., the percentages of services that land in the correct box); (2) number of aces; and (3) number of double faults. The other four predominantly relied on rally performance: (1) percentage of points won after first service; (2) percentage of points won after second service; (3) percentage of points won on receiving points; and (4) number of break points won.

Data preparation

To determine which of the players were the favourites and which were the ‘underdog’, we looked up the world ranking for each of the players at the time the tournament was played. For example, the favourite of the 2009 Rogers Cup final was Andy Murray (world ranking 3, at the time), while Juan Martin del Potro (world ranking 6) was classified as the underdog in that match. The level of reward that was at stake was operationalised as the cash prize that was awarded to the winner. We chose to use this variable (i.e., instead of the amount of ATP or WTA points that was at stake), for two reasons. First, using money as an independent variable makes our study more comparable to experimental research on choking under pressure, in which money is often a central aspect of pressure-induction procedures. Second, the ATP ranking system was changed in 2009, rendering studies from before vs. after that year incomparable. Also, the ATP ranking system is different from the WTA system, which would introduce unwanted bias that is rather complex to control for. As visual inspection of the distribution of the money variable revealed positive skewness, a square root transformation was applied. However, highly similar findings were obtained when applying a logarithmic transformation, or no transformation at all. The independent variables and covariates that were continuous (see below) were centred before they were used in analyses. Two multivariate outliers were identified and deleted (following the Cook's distance method proposed by Chatterjee & Hadi, 2006, p. 105); this did not affect the overall pattern of results.

Analytic strategy

To test the hypothesis that the amount of money at stake was related to worse performance for favourites when a trophy was near the court, we conducted analyses for service (i.e., first service percentage, number of aces, number of double faults) and for rally performance (i.e., percentage of points won on first service, percentage of points won on second service, percentage of receiving points won, number of break point conversions) separately. Specifically, for each group of performance indicators, we tested a multivariate general linear model, including trophy presence (dichotomous) and the amount of money that was at stake as predictors. Moreover, sex and match duration (conceptualized as the total points played in the match) were included as covariates in the analyses, as these are by nature related to certain aspects of tennis performance (e.g., number of aces) and thus should be controlled for. These analyses were conducted on the match level, with status (i.e., favourite vs. underdog) as a within-match variable (Kenny, Kashy, & Cook, 2006). Finally, we explored whether trophy presence and monetary reward could be used to predict outcomes of tennis matches as a whole. Throughout the analyses, interactions were interpreted following procedures suggested by Aiken and West (Aiken & West, 1991).

Results

Preliminary analyses

To test whether having a trophy near court was related to the amount of prize money of a tournament, we computed the point-biserial correlation between the two variables. Importantly, this correlation was low, $r(102) = .09$, and not significant, $p = .35$, indicating that trophy presence was independent of monetary reward. To exclude the possibility that trophy presence was confounded with certain styles of playing, we tested whether trophy presence was associated with certain court surfaces (clay, grass, hard court, carpet). This association was not significant, $\chi^2(3) = .75$, $p = .86$, showing that trophies were equally likely to be displayed near courts of different surfaces. Descriptive statistics of the main independent and dependent variables are presented in Table 1.

Independent Variable	*M (SD); Mdn*	
Monetary Reward (10k$)	32.6 (43.3); 8.8	
Monetary Reward (transformed)	4.65 (3.33); 3.0	
	M (SD)	
Dependent Variables	*Favourites*	*Underdogs*
Service Performance		
First service (%)	62.2 (9.2)	62.7 (8.3)
Aces (#)	5.9 (6.8)	4.8 (5.3)
Double faults (#)	2.8 (2.4)	3.1 (2.2)
Rally Performance		
Winning on first service (%)	71.7 (11.3)	66.8 (11.1)
Winning on second service (%)	50.6 (12.9)	47.7 (11.8)
Winning on receiving points (%)	40.4 (9.7)	36.7 (9.7)
Break points won (#)	3.1 (2.0)	2.5 (2.0)

Table 1. Descriptive statistics of continuous variables.

Service performance

For the analysis of service performance, we first looked at the multivariate effects, to test the overall pattern across the three service performance indicators. There were only main effects of Sex, $F(3, 95) = 13.06$, $p < .001$, $\eta^2_p = .29$, and Match Duration, $F(3, 95) = 27.51$, $p < .001$, $\eta^2_p = .47$. These effects indicated that men tended to hit more aces and less double faults than did women, and that players hit more aces and more double faults when matches were longer.

As none of the effects related to our hypotheses were significant on the multivariate level, we did not further consider the univariate analyses that addressed specific performance indicators. To be sure, we re-ran these analyses with aces and double faults as percentages rather than as absolute frequencies. This yielded highly similar (null) findings. The pattern of estimated means of the performance indicators is depicted in Figure 1.

Rally performance

For the rally performance analysis, we also looked at the multivariate effects first to test the overall pattern of performance when the four rally performance indicators are considered together. There appeared to be main effects of Sex, $F(4, 95) = 12.12$, $p < .001$, $\eta^2_p = .34$, Match Duration, $F(4, 95) = 11.44$, $p < .001$, $\eta^2_p = .33$, and Status, $F(4, 95) = 3.23$, $p = 016$, $\eta^2_p = .12$. These effects were qualified by a Status x Match Duration interaction, $F(4, 95) = 5.02$, $p = .001$, $\eta^2_p =.17$. Critically, the Status x Monetary Reward x Trophy Presence three-way interaction was also present, $F(4, 95) = 3.36$, $p = .013$, $\eta^2_p = .12$. To interpret these general effects, we looked at the univariate analyses for the specific performance indices separately. For the sake of brevity, we only report the effects of covariates when they interacted with other factors. Estimated means are presented in Figure 1.

Winning on the first service. For percentage of winnings on the first service, there was a main effect of Status, $F(1, 98) = 11.68$, $p = .001$, $\eta^2_p = .11$, indicating that favourites won more often on their first service than did underdogs. Also, there was a Status x Match Duration interaction, $F(1, 98) = 4.10$, $p = .046$, $\eta^2_p = .04$, reflecting that smaller performance differences between favourites and

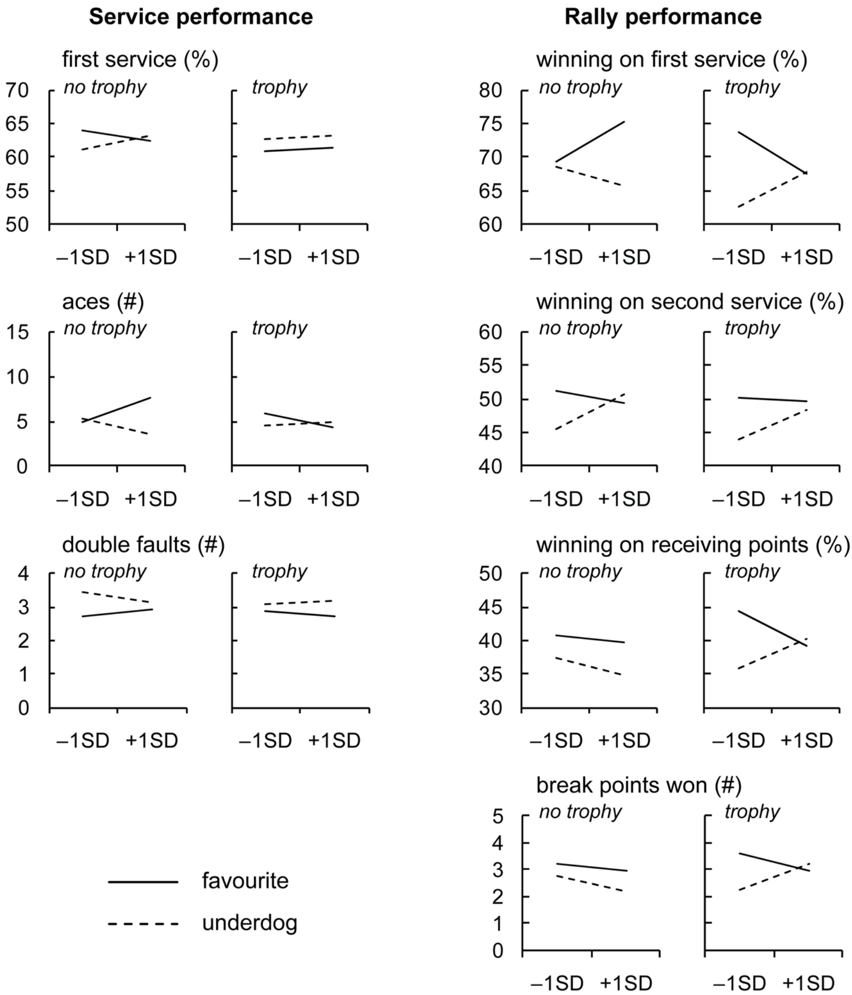

Figure 1. Service and rally performance as a function of (a) how much prize money was at stake, (b) status as a favourite vs. underdog, and (c) whether the trophy was displayed in sight of the players. The horizontal axis of each panel represents the amount of money at stake. The rightmost column of panels reveals the statistically reliable effect that when the trophy was near the court and much money was at stake, favourites no longer outperformed underdogs during rallies.

underdogs were associated with longer matches. More importantly, the predicted three-way interaction was significant, $F(1, 98) = 9.79$, $p = .002$, $\eta^2_p = .09$. To interpret this interaction, we looked separately at matches with vs. without a trophy near the court. This allowed us to specifically test how Monetary Reward affected performance, given the presence (vs. absence) of a trophy.

For matches in which the trophy was not present, we found a main effect of Status, $F(1, 53) = 5.44$, $p = .024$, $\eta^2_p = .09$, indicating that favourites performed better than underdogs. Furthermore, money had a slightly different effect on underdogs vs. favourites, as indicated by a marginally significant Status x Monetary Reward interaction, $F(1, 53) = 3.11$, $p = .083$, $\eta^2_p = .06$. As this effect seemed rather incidental (i.e., it did not show on other indicators), we chose not to provide a post-hoc interpretation.

For matches in which the trophy was present near the court, we also found a main effect of Status, $F(1, 43) = 5.91$, $p = ..019$, $\eta^2_p = .12$. Moreover, the predicted Status x Monetary Reward interaction was significant, $F(1, 43) = 7.66$, $p = .008$, $\eta^2_p = .16$, that revealed that favourites and underdogs were differentially affected by money. Specifically, when relatively little money was at stake (-1SD), favourites clearly outperformed underdogs, $F(1, 43) = 12.33$, $p = .001$, $\eta^2_p = .22$. However, when more money was at stake (+1SD), favourites performed no better, $F < 1$, indicating worse performance than what would be expected on the basis of their world rankings.

Winning on the second service. Next, we analyzed the percentage of winning on the second service. No effects of interest proved significant.

Winning on receiving points. For the percentage of receiving points won, there was again an effect of Status, $F(1, 98) = 7.67$, $p = .007$, $\eta^2_p = .07$. Furthermore, the Status x Monetary Reward x Trophy Presence three-way interaction approached significance, $F(1, 98) = 3.59$, $p = .061$, $\eta^2_p = .04$, revealing a similar pattern as for points won on the first service.

For matches in which the trophy was not present, favourites outperformed underdogs, $F(1, 53) = 4.60$, $p = .037$, $\eta^2_p = .08$. This was not qualified by a Status x Monetary Reward interaction, $F < 1$. For matches in which the trophy was visibly present, however, the Status x Monetary Reward interaction, $F(1, 43) = 5.14$, $p = .029$, $\eta^2_p = .11$, again indicated that favourites and underdogs were differentially affected by money: When little money was at stake (-1SD), favourites strongly outperformed underdogs, $F(1, 43) = 6.67$, $p = .013$, $\eta^2_p = .13$, but there was no difference when relatively much money (+1SD) was at stake, $F < 1$, indicating substandard performance.

Break points won. For the number of break points converted, there was a main effects of Status, $F(1, 98) = 4.99$, $p = .028$, $\eta^2_p = .05$. Moreover, there was a marginally significant Status x Monetary Reward x Trophy Presence three-way interaction, $F(1, 98) = 3.02$, $p = .086$, $\eta^2_p = .03$, which suggested the presence of the same pattern as for the previous indicators.

Indeed, for matches in which the trophy was not present, favourites slightly outperformed underdogs, as evidenced by a marginally significant effect of Status, $F(1, 53) = 3.38$, $p = .072$, $\eta^2_p = .06$. This effect was not qualified by the Status x Monetary Reward interaction, $F < 1$. For matches in which the trophy was visibly present, however, the Status x Monetary Reward interaction was significant, $F(1, 43) = 4.07$, $p = .050$, $\eta^2_p = .09$, showing that favourites and underdogs were differentially affected by money. In line with the previous indicators, it appeared that favourites won more break points than did underdogs, but only when little money (-1SD) was at stake, $F(1, 43) = 5.02$, $p = .030$, $\eta^2_p = .11$. In the face of a larger monetary reward (+1SD), there was no difference, $F < 1$, indicating substandard performance by favourites.

Rank difference as a potential moderator

While these results imply a key role for whether the player in question is the favourite or the underdog, one might argue that the rank difference between the two is equally important. For instance, it could be the case that the effects established above are driven by the matches in which underdogs and favourites are far apart on the world ranking list. For that reason, we were also explored the influence of differences in rank between the favourite and the underdog as a potential moderator. We re-ran the above analyses while including the dichotomized variable (median rank difference of the sample = 13 places) that indicated whether the difference between the players was relatively small (≤ 13) or relatively large (> 13), in terms of world rankings. This analysis revealed no main effect of this factor, nor any (higher-order) interactions, multivariate F's < 1.84. Critically, the Status x Monetary Reward x Trophy Presence three-way interaction was still intact, multivariate $F(4, 91) = 4.14$, $p = .004$, $\eta^2_p = .15$. This analysis suggests that the role of being the favourite has an impact by itself, and that this impact is independent of the extent to which there are objectively quantifiable ability differences between the favourite and the underdog.

Match outcome

While the above results paint a fine-grained picture of tennis performance as a function of trophy presence, monetary reward, and favourite status, we also explored whether these variables have the potential to change match outcomes. Using Sex and Match Duration as covariates again, we conducted a logistic regression with Trophy Presence and Monetary Reward as independent variables, predicting whether the favourite won (1) or not (0). This analysis yielded no main effects of trophy presence, and monetary reward, and no interaction between the two, Wald χ^2's < 1.25, *p*'s > .26. Thus, whereas trophy presence and money at stake showed impaired performance in favourites on more fine-grained performance measures, our analysis suggests that they do not directly affect match outcomes.

Furthermore, we analyzed whether Trophy Presence and Monetary Reward were related to the proportion of points won by the favourite. Our general linear model analyses, again with the same covariates, yielded the predicted Trophy Presence x Monetary Reward interaction, $F(1, 98) = 5.39$, $p = .022$, $\eta^2 = .05$. Follow-up analyses suggested that when there was no trophy near the court, Monetary Reward was not significantly related to the proportion of points won by the favourite, $\beta = -.03$, $t(55)= .22$, $p = .681$. Instead, when the trophy was on display, more money at stake was related to a smaller proportion of points won by the favourite, $\beta = -.34$, $t(45) = -2.40$, $p = .021$. This finding thus shows that the pattern of results we found on the individual rally performance indicators was still intact on the aggregate level, providing strong support for our hypothesis.

Discussion

Whereas favourites normally outclass underdogs on several aspects of performance in the finals of tennis tournaments, the present study shows that they fail to do so in matches in which (a) a lot of money is at stake and (b) a trophy is displayed in their sight. This effect can be explained based on the idea that favourites are more vulnerable to choking under pressure than are underdogs (Baumeister et al., 1985; Jordet, 2009), and that monetary rewards may trigger choking when just a subtle reward cue near the court—a trophy—continuously reminds players of what is at stake. Interestingly, these instances of lower–than–expected performance emerged only on measures that reflected performance during rallies (i.e., percentage of points won after the first service, percentage of receiving points won, number of break points won), and not on indices that reflected service performance (i.e., first service percentage, number of aces, number of double faults).

As it seems reasonable to assume that rally performance relies on working memory to a greater extent than does service performance, the present findings suggest that the choking under pressure that we observed originated in distraction. Indeed, distraction-based choking under pressure is known to specifically impact tasks that require working memory (Beilock & Gray, 2007). Somewhat speculatively, the trophy—together with much money being at stake—may have induced favourites to use their working memory for irrelevant thoughts (e.g., ruminating) rather than for tennis-relevant processes (e.g., predicting the direction of the ball), thereby interfering with effective performance during rallies. By contrast, the present data provide no evidence that the service, which basically is the execution of a well-learned skill, suffers from pressure. Thus, the current data suggest that courtside trophies primarily impair performance in favourites by triggering distracting thoughts, and not so much by changing favourites' attentional focus.

While the latter null finding is intriguing and somewhat unexpected, it is in line with recent research that shows that monetary rewards (as compared to other stressors) are specifically associated with worries about the situation's outcome, making people more sensitive to distraction, but not to explicit monitoring (DeCaro, Albert, Thomas, & Beilock, 2011). Also, the null finding for service performance may be explained from the idea that specific types of training can render well-learned skills relatively resistant to choking under pressure (i.e., practice while paying step-by-step attention to skill execution helps players to get used to pressure situations, which have the same effect on attention). Of course, the players in our sample probably received all kinds of skill training, including this specific type. However, to prevent choking in situations in which working-memory functioning is vital (such as during rallies), training regimes that involve practicing rallies under actual stress or under cognitive load (e.g., playing rallies while rehearsing digit strings) are likely to have additional merit. While perhaps less common in professional tennis, players may learn during such training to control irrelevant thoughts and worries when it matters most—an ability that may have been very useful to the favourites in our sample (see Beilock, 2010).

As was outlined in the introduction, the present research also contributes to the choking under pressure literature in a methodological sense, by suggesting a new approach to understanding sports statistics. While leading definitions of choking employ *lower-than-expected performance* as a diagnostic criterion (Beilock & Gray, 2007), the diagnosis of choking requires some estimate of 'normal' performance, which has proven difficult to extract from sports statistics. In the present work, we took a novel approach to establishing such an estimate based on the reasoning that, under normal circumstances, favourites can be expected to outperform underdogs. Accordingly, when a favourite fails to do so, their performance can thus reasonably be considered to have suffered from choking—after all, it was lower than expected based on their ranking. Importantly, this approach operates within the confines of mainstream definitions of choking, and can potentially be applied to all sports that are characterized by zero-sum, one–on–one competition (e.g., tennis and judo, but not golf and speed skating). These may prove fruitful domains for studying choking under pressure, as they allow for a relatively clean post-hoc diagnosis of when choking under pressure has (vs. has not) occurred.

Although the current approach opens up new avenues for research, the analysis of dynamic one–on–one sports data is by nature limited in that it is not always clear whether a reference athlete's substandard performance is caused by the opponent improving his or her game and the reference athlete not keeping up, or whether it is caused by the reference athlete making mistakes. In part, the present approach avoids this problem by operationalising 'normal performance' relative to the opponent rather than as an absolute estimate. Still, it is important to keep this limitation in mind, especially when analysing aspects of sports in which the one player's failure equals the other's success (e.g., rally performance in tennis, scoring points in judo). Accordingly, the question of how choking-related mechanisms affect the game dynamics of one–on–one sports (e.g., how they affect individual players' cognitions) remains an interesting topic for further study.

Most importantly, the present study suggests that the seemingly trivial presence of a trophy near the court—just a subtle reward cue—can have substantial consequences with respect to what tennis finals look like. When the trophy is on display during a high-stakes final, this may well delight spectators with an exciting match.

Nederlandstalige samenvatting
(Summary in Dutch)

Mensen zijn in het dagelijks leven vaak bezig met het nastreven van plezierige uitkomsten. Denk bijvoorbeeld aan het koken van een pan spaghetti, het verrichten van arbeid om geld te verdienen of het inschenken van een glaasje wijn. Het verkrijgen van deze beloningen gaat echter niet zomaar: bijna altijd is enige inspanning vereist. Om die reden moeten mensen de hele dag afwegingen maken die te maken hebben met het nastreven van beloningen: welke beloning is interessant en waardevol voor mij? En hoeveel inspanning zal ik leveren om hem te krijgen? In dit proefschrift ga ik in op de vraag hoe mensen deze afwegingen maken.

Bedachtzame berekeningen

In de hedendaagse psychologie worden afwegingen tussen beloningen en vereiste inspanning vaak beschouwd als bewuste, bedachtzame berekeningen. In dit soort berekeningen, zo wordt verondersteld, nemen mensen onder andere de waarde van een beloning mee, samen met hun verwachting of het bereiken van deze beloning binnen hun macht ligt, en zo ja, hoeveel inspanning dit kost. Op basis van dit soort bewuste calculaties, zo wordt vaak gedacht, bepalen mensen welke beloning ze nastreven en op welke manier ze dat gaan doen.

Hoewel deze kijk op het nastreven van beloningen in de psychologie heel wijdverspreid is, zijn er goede redenen om te veronderstellen dat deze bedachtzame berekeningen niet het hele verhaal zijn. In tegenstelling tot wat we vroeger dachten blijken veel geavanceerde processen die belangrijk zijn voor het nastreven van beloningen namelijk ook *onbewust* te kunnen verlopen. Denk hierbij bijvoorbeeld aan het inschatten van de waarde van een beloning, het vasthouden van deze informatie in het werkgeheugen, en het opbrengen van inspanning om de beloning te verkrijgen. Door dit soort bevindingen is het de afgelopen jaren steeds duidelijker geworden dat het onbewuste niet slechts een primitief en simpel systeem is, maar ook geavanceerde functies kan uitvoeren (zie bijvoorbeeld Dijksterhuis, 2007). Het zou dus goed kunnen dat mensen niet altijd bedachtzame berekeningen nodig hebben om beloningen op een effectieve manier na te streven. Wellicht kan dit ook buiten het bewustzijn om.

Een andere reden om te verwachten dat bedachtzame, bewuste berekeningen niet per se nodig zijn om beloningen na te streven komt voort uit onderzoek naar hoe beloningen verwerkt worden in de hersenen. Dit soort onderzoek laat zien dat beloningen als eerste verwerkt worden in het *striatum*, een rudimentaire hersenstructuur die doorgaans juist *niet* in verband wordt gebracht met bewuste processen. Aangezien deze structuur een sleutelrol speelt in het leveren van inspanning voor beloningen, is dit een tweede aanwijzing dat het nastreven van beloningen—of in ieder geval sommige aspecten hiervan—óók buiten het bewustzijn om kan verlopen.

Een nieuw theoretisch raamwerk

Dit proefschrift beschrijft een nieuw theoretisch raamwerk om beter te begrijpen hoe mensen beloningen nastreven via onbewuste en bewuste processen. In het kort is mijn voorstel als volgt: mensen verwerken beloningen eerst in rudimentaire hersenstructuren, waarvan het striatum waarschijnlijk de meest belangrijke is. Hoewel dit buiten het bewustzijn om gebeurt, kan deze *initiële beloningsverwerking* toch zorgen dat er meer inspanning opgebracht wordt wanneer er waardevolle beloningen op het spel staan. Op allerlei taken verbetert dit de prestatie. Na dit initiële proces kunnen beloningen op een meer uitgebreide manier verwerkt worden. Wanneer dit gebeurt spreken we van *volledige beloningsverwerking*. Behalve de bovengenoemde rudimentaire hersenstructuren zijn hier corticale hersenstructuren bij betrokken (delen van de prefrontaalkwab, bijvoorbeeld). Hierdoor hebben mensen een bewuste ervaring van de beloning, kunnen ze bewust reflecteren over wat de beloning voor hen betekent, en kunnen ze strategische beslissingen nemen om de beloning te verkrijgen. Deze bewuste reflecties en strategische keuzes—die alleen plaatsvinden wanneer een beloning bewust wordt verwerkt—kunnen een extra effect hebben op prestatie (bovenop de inspanning die opgebracht kan worden via initiële beloningsverwerking). Zodoende zijn er bepaalde gevallen waarin initiële en volledige beloningsverwerking verschillende gevolgen hebben voor prestatie.

Het raamwerk in dit proefschrift geeft een precies beeld (althans, preciezer dan voorheen) van hoe mensen beloningen verwerken en nastreven, dat van toepassing is verschillende situaties en verschillende soorten beloningen. Het is in staat nieuwe hypotheses te genereren over hoe psychologische processen, hersenprocessen en gedrag met elkaar samenhangen. Dit alles is in meer detail beschreven in hoofdstuk 1, waarin dit proefschrift in een theoretische context wordt geplaatst. Verder worden in dit hoofdstuk ook een aantal bredere implicaties van het proefschrift uiteengezet. In hoofdstuk 2 wordt het raamwerk zelf in meer detail uiteengezet en leg ik kort uit hoe al deze ideeën ondersteund worden door recent onderzoek.

Ondersteunende experimenten

In de hoofdstukken 3 tot en met 6 beschrijf ik een serie experimenten waarin gebruikt gemaakt wordt van een nieuw *beloningsprimingparadigma*. In dit paradigma krijgen proefpersonen steeds een beloning te zien—een munt die veel ofwel weinig waard is—die ze kunnen verdienen door goed te presteren op een taak (bijvoorbeeld het correct en snel oplossen van een som) die direct erna komt. Een belangrijke eigenschap van dit paradigma is dat de beloning soms zeer kort gepresenteerd is, bijvoorbeeld 20 milliseconden, zodat proefpersonen hem alleen maar initieel kunnen verwerken. Soms wordt de beloning echter langer getoond, zodat proefpersonen ruim de tijd hebben om hem volledig te verwerken. Zodoende kan dit paradigma gebruikt worden om de eigenschappen van *initiële* en *volledige* beloningsverwerking apart te onderzoeken. De kennis die dit oplevert kan vervolgens dienen als ondersteuning voor het eerder beschreven theoretische raamwerk.

Het was al eerder duidelijk dat wanneer beloningen alleen maar initieel verwerkt worden, dit nog steeds mensen kan bewegen tot het leveren van extra inspanning voor beloningen die veel waard zijn. In een experiment van Pessiglione en collega's (2007) kregen mensen een munt te zien (van hoge versus lage waarde, bewust waarneembaar versus niet) die ze konden verdienen door stevig te knijpen in een handvat. Het was niet verbazend dat mensen harder knepen voor meer waardevolle munten. Wat echter een vernieuwende bevinding was, was dat mensen zelfs harder knepen voor waardevolle munten wanneer deze *niet* bewust werden waargenomen.

De eigenschappen van initiële beloningsverwerking

Maar hoe komt het verschijnsel dat mensen zich meer inspannen na het onbewust waarnemen van een waardevolle beloning precies tot stand? Een interessante mogelijkheid is dat mensen op onbewust niveau niet alleen de waarde van een beloning meenemen, maar ook de hoeveelheid inspanning die van hen gevraagd wordt om de beloning te krijgen. Dit zou betekenen dat er een onbewust weegproces plaatsvindt tijdens de initiële beloningsverwerking, wat een idee is dat goed zou passen bij de bestaande literatuur over hoe beloningen verwerkt worden in de hersenen.

Om deze mogelijkheid te testen voerde ik een experiment uit waarin proefpersonen een beloning (munten, net als in eerder onderzoek) kregen te zien die ze konden verdienen door vier seconden lang een serie cijfers te onthouden en deze daarna correct terug te rapporteren. Tijdens deze werkgeheugentaak, die makkelijk ofwel moeilijk was—de serie cijfers was namelijk kort of lang—werd gemeten hoe groot de pupil van de proefpersoon was. Aangezien pupilgrootte samenhangt met activiteit van het sympathisch deel van het autonome zenuwstelsel, een systeem dat mensen in staat stelt inspanning te leveren, kon ik op deze manier op een ongemerkte manier meten hoeveel inspanning proefpersonen leverden tijdens het onthouden van de cijfers.

Net als in het onderzoek van Pessiglione vond ik dat mensen meer inspanning leverden voor hoge beloningen, óók als deze slechts initieel verwerkt waren en dus buiten het bewustzijn bleven. Echter, dit inspanningseffect trad alleen op wanneer er ook echt inspanning vereist was om de beloning te krijgen, namelijk alleen als de serie cijfers die onthouden moest worden relatief lang was. Deze bevinding, beschreven in hoofdstuk 3, ondersteunt het idee dat mensen op een onbewuste manier de waarde van een beloning met de hoeveelheid vereiste inspanning kunnen wegen.

In drie vervolgexperimenten, beschreven in hoofdstuk 4, bestudeerde ik deze bevinding in meer detail. Deze experimenten, die beschreven zijn in hoofdstuk 4, wijzen erop dat mensen—via initiële beloningsverwerking—gevoeliger worden voor beloningen die waardevol zijn wanneer er meer inspanning vereist is. Meer specifiek laten deze experimenten zien dat op deze manier reageren op *allerlei* soorten lichamelijke inspanningsvereisten, zelfs als deze inspanningsvereisten helemaal niets te maken hebben met de beloning die op het spel staat. Zodoende wijzen deze resultaten erop dat mensen via initiële beloningsverwerking al een grove basisafweging tussen de waarde van een beloning en inspanningsvereisten kunnen maken. Ze brengen niet zomaar inspanning op voor elke waardevolle beloning die ze tegenkomen, maar alleen als er op dat moment ook inspanning van hen vereist wordt. Op een onbewust niveau gaan mensen dus al op een efficiënte manier met hun inspanning om.

Deze eerste vier experimenten wijzen er grotendeels op dat initiële en volledige beloningsverwerking op min of meer dezelfde manier verlopen, en dat ze soortgelijke gevolgen hebben voor prestatie. Sommige van deze bevindingen lieten echter ook zien dat er omstandigheden zijn waarin onbewuste en bewuste beloningsverwerking *verschillende* effecten hebben. Uit de laatste van deze experimenten (hoofdstuk 4, experiment 3) bleek namelijk wanneer mensen een beloning bewust konden verwerken, ze niet langer inspanningsvereisten in acht namen die niets te maken hadden met de beloning en dus irrelevant waren. Deze bevinding suggereert dat er specifieke functies zijn die pas bij bewuste, volledige beloningsverwerking een rol gaan spelen.

De specifieke eigenschappen van volledige beloningsverwerking

Om meer inzicht te krijgen in de processen die plaatsvinden *nadat* een beloning initieel verwerkt is, voerde ik nog een drietal experimenten uit. Deze experimenten waren ontworpen om de hypothese te toetsen dat beloningen taakstrategieën van mensen kunnen beïnvloeden, maar alleen als ze volledig verwerkt kunnen worden (zie bijvoorbeeld het werk van Dehaene en van Baars).

Waar in de eerdere experimenten er voor mensen weinig ruimte was om taakstrategieën te gebruiken (ze hoefden alleen maar cijfers te onthouden in hoofdstuk 3, of te tikken op een toetsenbord in hoofdstuk 4), werden mensen in deze experimenten in een context geplaatst waarin ze zelf konden kiezen wat voor strategie ze hanteerden om een beloning te krijgen.

In de twee experimenten in hoofdstuk 5 kregen proefpersonen een munt te zien die ze konden verdienen door accuraat een rekensom op te lossen. Hun beloning werd echter steeds kleiner naarmate ze meer tijd namen om de som op te lossen. Zodoende konden ze op deze taak kiezen tussen verschillende strategieën: ze konden focussen op accuratesse (een grotere kans op een kleinere beloning) of op snelheid (een kleinere kans op een grotere beloning).

Uit deze experimenten bleek inderdaad dat wanneer proefpersonen een waardevolle beloning alleen initieel konden verwerken, dit leidde tot een simpele verbetering van prestatie: men was sneller bij hetzelfde niveau van accuratesse. Wanneer proefpersonen beloningen echter volledig konden verwerken, bleek dat ze een voorzichtige strategie hadden gekozen: men was meer accuraat, maar langzamer wanneer er meer op het spel stond. Deze bevinding past goed bij onderzoek uit de gedragseconomie, dat laat zien dat mensen risicomijdend worden wanneer er meer op het spel staat. Maar vooral betekent deze bevinding dat alleen wanneer een beloning volledig verwerkt wordt, deze kan leiden tot strategische beslissingen, bijvoorbeeld ten aanzien van voorzichtigheid.

Een laatste experiment paste het idee toe dat hoewel mensen vaak denken dat hun taakstrategieën hun prestatie verbeteren, deze ook het tegenovergestelde effect kunnen hebben en prestatie juist verslechteren. Dit gebeurt bijvoorbeeld in sommige taken waarin mensen zich door beloningen meer gaan concentreren op de taak die leidt tot het verkrijgen van de beloning. Concentratie kan er namelijk toe leiden dat mensen niet alleen nuttige, maar ook afleidende informatie beter gaan verwerken, wat niet goed is voor de prestatie. De *Attentional Blink* is zo'n taak waarin dit kan gebeuren. In deze taak moeten mensen twee cijfers detecteren in een snel flitsende serie letters. In een van mijn experimenten, dat beschreven is in hoofdstuk 6, kregen mensen een beloning als ze deze cijfers correct konden rapporteren. Uit de resultaten bleek dat initieel verwerkte beloningen prestatie verbeterden, een bevinding die goed paste bij de andere experimenten in mijn proefschrift. Dit faciliterende effect was echter helemaal verdwenen wanneer mensen de beloning volledig konden verwerken. Deze bevinding wijst erop dat mensen een verkeerde taakstrategie hebben gekozen (namelijk: meer concentreren) bij hoge beloningen die bewust verwerkt werden. Met andere woorden: eerst wordt prestatie wel verbeterd via initiële verwerking, maar dit kan later weer teniet worden gedaan door de bewuste keuze van een verkeerde strategie.

Uit al deze bevindingen, samen beschouwd, volgt dat het nastreven van beloningen gevormd wordt door opeenvolgende onbewuste en bewuste processen. Zodoende ondersteunen ze het theoretische raamwerk dat beschreven staat in hoofdstuk 2. Aan het einde van het proefschrift exploreer ik de rol van beloningen in het echte leven. In dit geval onderzocht ik hoe de trofeeën die soms langs de lijn staan bij de finales van professionele tennistoernooien—subtiele beloningssignalen, net als in de experimenten—de prestatie van de finalisten beïnvloeden. Het blijkt dat deze bevindingen uit het veld goed passen bij recent onderzoek naar het verschijnsel *choking under pressure* (slechtere prestatie wanneer er heel veel op het spel staat), maar zeker ook bij de ideeën en bevindingen die in dit proefschrift uiteengezet zijn.

Slot

In dit proefschrift probeerde ik een genuanceerd beeld te schetsen van hoe beloningen leiden tot prestatie, en hoe dit gebeurt via onbewuste en bewuste processen. Hoewel mensen een heel eind kunnen komen met onbewuste processen om beloningen na te streven (ze zorgen bijvoorbeeld voor een efficiënt gebruik van inspanning), bleek dat ook deze hun beperkingen hebben (als inspanningsvereisten irrelevant zijn voor het verkrijgen van een beloning worden deze bijvoorbeeld alsnog meegenomen). Bewuste processen gaan daarna spelen, als een beloning volledig verwerkt kan worden. In veel gevallen zijn deze processen nóg adaptiever en geavanceerder (ze leiden bijvoorbeeld tot het nemen van strategische beslissingen). Aan de andere kant hebben ook deze hun mankementen (deze strategische beslissingen zijn bijvoorbeeld niet altijd goed voor de prestatie).

Deze bevindingen geven interessante aanknopingspunten voor verder onderzoek, aangezien ze wellicht kunnen helpen om andere verschijnselen beter te begrijpen. Zo is het bijvoorbeeld goed mogelijk dat ook het nemen van financiële risico's in het onbewuste begint, maar dat mensen deze initiële impuls vervolgens via volledige beloningsverwerking beteugelen. Ook vind ik het een interessante vraag hoe het precies komt dat beloningen afbreuk kunnen doen aan het plezier dat mensen aan taken beleven. Een kind, bijvoorbeeld, zal niet snel uit zichzelf het gras gaan maaien nadat het één keer geld heeft gekregen om dit te doen. Het zou goed kunnen dat verder onderzoek, gebaseerd op dit proefschrift, interessante nieuwe kennis over dit verschijnsel kan opleveren. Zo zijn er nog voldoende nieuwe wegen om in te slaan—en voldoende nieuwe mogelijkheden om meer te leren over de onbewuste en bewuste fundamenten van het menselijk streven naar beloningen.

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Biography

Erik Bijleveld was born in Aphen aan den Rijn in 1983. He completed his BSc and MPhil in Psychology at Leiden University in 2007. The research reported in this dissertation was carried out at Utrecht University, where Erik was a PhD student. Currently, he is an Assistent Professor at Utrect University.

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