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

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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.

1. Introduction

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 tradeoffs 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,

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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 three 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 tradeoff 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 tradeoffs 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.

2. Experiment 1

2.1. Method

2.1.1. Participants and design

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

2.1.2. 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.

2.1.3. Trials

The course of a trial is depicted in Fig. 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 speed, such that the value of the presented coin (i.e., 1 or 50 cent) decayed with 14% of the original reward every second. More formally, the reward was given by the formula $R = V - V * T/7000$, with $R \geqslant 0$, 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

[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).