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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).

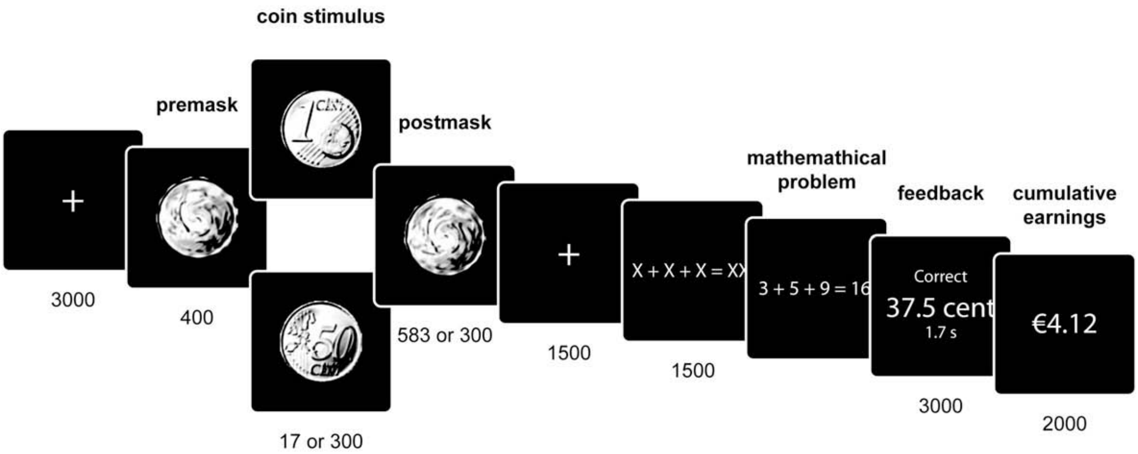

Fig. 1. The course of a trial. Note: numbers refer to presentation durations in milliseconds. In all conditions, the duration of the coin and the masks added up to 1000 ms. The subliminal coin presentation procedure is taken from Bijleveld et al. (2009).

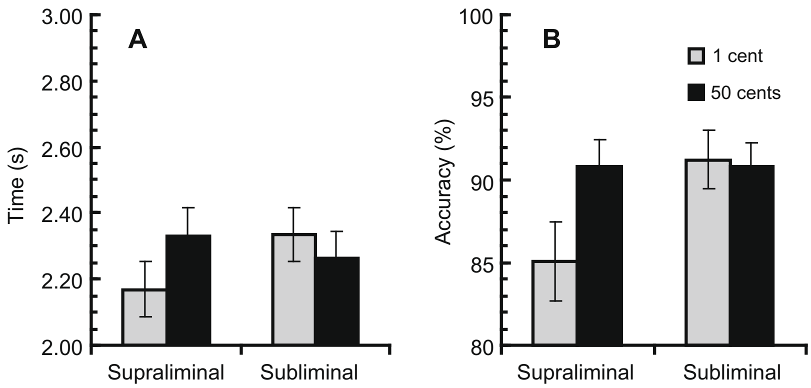

Fig. 2. Results of Experiment 1. Note: (A) time (s) participants took to give a response. (B) Accuracy (%). Error bars represent standard errors of the mean.

that trial. Finally, participants saw their cumulative earnings.

2.1.4. Materials

The mathematical problems comprised 56 fixed sets of three 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 ±2. Mathematical problems were presented in a random order, independent of condition.

2.2. Results

2.2.1. Speed

Only accurate responses within the 7000 ms time window in which a reward could be earned were analyzed. Values that differed three 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 analysis. Mean speeds per condition were submitted to ANOVA according to the experimental design. This analysis revealed only the predicted reward × presentation interaction, $F(1, 28) = 13.57$, $p < .001$, other F's < 2.1. Inspection of the means (Fig. 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).

2.2.2. Accuracy

Accuracy scores (Fig. 2b) were submitted to the same ANOVA. The only effect that proved significant was the reward × 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.

2.3. 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.

3. 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.

3.1. Method

3.1.1. Participants and design

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

3.1.2. 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.

3.2. Results and discussion

3.2.1. Speed

Outliers were dealt with in the same way as in Experiment 1, resulting in 2.2% of trials being excluded from analysis. 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 Fig. 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) × 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. 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, $F(1, 118) < 1$.

3.2.2. Accuracy

Accuracy scores were submitted to the same ANOVA. This yielded a main effect of standard, $F(1, 118) = 30.45$,

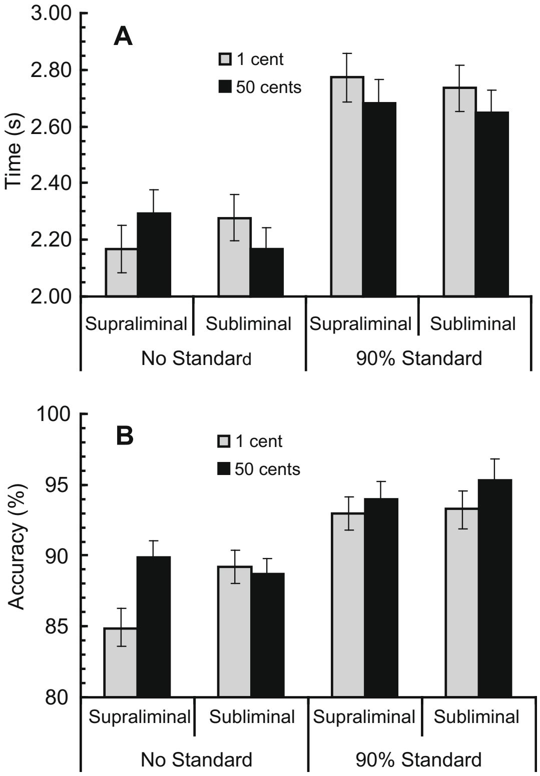

Fig. 3. Results of Experiment 2. Note: (A) time (s) participants took to give a response. (B) Accuracy (%). Error bars represent standard errors of the mean.

$p < .001$, indicating that participants were more accurate when given an 90%-accuracy standard (for means, see Fig. 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.

4. 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.

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