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Brief article

The influence of reward associations on conflict processing in the Stroop task

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ABSTRACT

Performance in a behavioral task can be facilitated by associating stimulus properties with reward. In contrast, conflicting information is known to impede task performance. Here we investigated how reward associations influence the within-trial processing of conflicting information using a color-naming Stroop task in which a subset of ink colors (task-relevant dimension) was associated with monetary incentives. We found that color-naming performance was enhanced on trials with *potential-reward* versus those without. Moreover, in *potential-reward* trials, typical conflict-induced performance decrements were attenuated if the incongruent word (task-irrelevant dimension) was unrelated to reward. In contrast, incongruent words that were semantically related to reward-predicting ink colors interfered with performance in *potential-reward* trials and even more so in no-reward trials, despite the semantic meaning being entirely task-irrelevant. These observations imply that the prospect of reward enhances the processing of task-relevant stimulus information, whereas incongruent *reward-related* information in a task-irrelevant dimension can impede task performance.

1. Introduction

Reward is known to be an effective motivator of behavior and a driving force for learning (for a review see Wise, 2004). Numerous studies in humans have demonstrated that reward anticipation is associated with performance improvement in diverse behavioral domains, including response speed and accuracy (e.g., Bijleveld, Custers, & Aarts, 2010; Knutson, Adams, Fong, & Hommer, 2001), visual discrimination and visual search (e.g., Engelmann & Pessoa, 2007; Kristjansson, Sigurjonsdottir, & Driver, 2010), cognitive control (e.g., Locke & Braver, 2008), negative priming (e.g., Della Libera & Chelazzi, 2006), and memory processes (e.g., Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Krebs, Schott, Schutze, & Duzel, 2009; Wittmann et al., 2005).

While reward generally exerts enhancing effects on behavior, the presence of conflicting information is known to disrupt performance, as commonly demonstrated by conflict paradigms such as the Stroop color-naming task (Stroop, 1935). In this task, subjects respond to the ink color of a color word (e.g., "RED") while ignoring its semantic meaning. Typically, subjects' performance is facilitated in trials in which the information in the task-relevant (ink color) and task-irrelevant (word meaning) dimensions are congruent, and impeded if they are incongruent (MacLeod, 1991). According to influential parallel distributed processing models of the Stroop effect, information from both input dimensions is conveyed in parallel, and the ultimate response depends on the relative activation of the two pathways (Carter & van Veen, 2007; Cohen, Dunbar, & McClelland, 1990). In the color-naming Stroop task, it has been proposed that automatic reading of the irrelevant word meaning strongly co-activates the

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corresponding pathway in parallel to the processing of the relevant ink color, and, if incongruent, interferes with performance.

More recently, observations that brain regions implicated in human cognitive control are also critically involved in reward-based learning (Miller & Cohen, 2001; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004; Ullsperger & von Cramon, 2003) have given rise to the question of how far processes related to reward and conflict interact (Holroyd & Coles, 2002; Jocham & Ullsperger, 2009). Supporting such an interaction, it has been demonstrated that reward information has the potential to disrupt the behavioral adjustments that are typically observed subsequent to incongruent trials in a flanker task (van Steenbergen, Band, & Hommel, 2009). According to this study, the commonly observed behavioral adjustments (for a review see Egner, 2007) might be counteracted by the receipt of reward, thereby suggesting a shared mechanism (van Steenbergen et al., 2009). However, these observations were limited to sequential effects, and reward was delivered incidentally (i.e., subjects' responses were not instrumental to obtaining rewards) and thus it remains unknown how conflict processing would be modulated if reward is associated with components of the task itself.

We sought to investigate this question by associating reward with two of the four ink colors in a Stroop task. While subjects responded to the ink color, the irrelevant semantic meaning of the word could be congruent, incongruent, or neutral with regard to the ink color. In addition to these typical Stroop-paradigm categories, the irrelevant word could be semantically linked to a color that was either part of the *potential-reward* ink-color subset or not. However, the semantic information was entirely task-irrelevant and thus never associated with obtaining reward.

Based on the notion that cognitive control in concert with attention can differentially emphasize the pathways of potential competing inputs we hypothesized that reward associations in the relevant dimension would further promote effective stimulus processing. Specifically, we predicted general response facilitation and reduced interference in *potential-reward* as compared to no-reward trials. Additionally, we hypothesized that reward associations with an ink color would generalize to its semantic representation (i.e., word meaning). Consequently, incongruent word meanings that are implicitly linked to reward, might cause greater interference by emphasizing the incongruent information.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Twenty healthy right-handed subjects participated (mean age ± SD: 22.5 ± 3.2, 14 female) and gave written informed consent in accordance with the Duke Medical Center Institutional Review Board for human subjects. Subjects were paid a basic amount of $15 plus an average reward bonus of $15.

2.1.2. Paradigm and procedure

Subjects performed a version of the classic color-naming Stroop task in which they responded to the ink color of words while ignoring their semantic meaning. A small gray fixation square (visual angle 0.3°) was maintained in the center of a black screen (Fig. 1A). In each trial a colored capitalized word was presented above fixation for 600 ms, randomly chosen from the following set: "RED", "YELLOW", "BLUE", "GREEN", or "BROWN" (vertical 0.8°, horizontal ranging from 2.1° to 4.6°). The words were separated by a variable stimulus onset asynchrony (SOA) of 1800–2200 ms and were written in one of four ink colors (red, yellow, blue, or green). Subjects were instructed to respond as quickly as possible by pressing the button associated with the current ink color (*Color*; task-relevant dimension) while ignoring the semantic meaning (*Word*; task-irrelevant dimension; Fig. 1B). Responses were given with the index and middle fingers of the left and right hands, with color-button assignments and color-reward associations counterbalanced across subjects. The semantic meaning of a given word could be congruent (e.g., "GREEN" written in green) or incongruent (e.g., "RED" written in green) with regard to the ink color. Furthermore, trials consisting of words with no conflicting response mapping (e.g., "BROWN" written in green) were intermixed to provide a neutral category.

While responses to two of the four possible ink colors were associated with the potential for monetary reward (*potential-reward*), the remaining two colors represented standard Stroop trials (*no-reward*; Fig. 1B). Accordingly, a fast and correct response in *potential-reward* trials resulted in a 10-cent gain, while an incorrect or slow response resulted in a 10-cent penalty. In order to keep all subjects in a similar reward range, the response time-out was adjusted dynamically based on individual performance. This procedure led to an average gain of $2.50 per run for each subject (70:30 gain-to-loss ratio). Following a short training session, subjects completed six experimental 6-min runs, yielding a total of 480 *potential-reward* and 480 *no-reward* trials. During four 20-s breaks within each run, the updated dollar amount was displayed, serving as performance feedback.

The information conveyed by the irrelevant semantic meaning of the word resulted in equally distributed congruency conditions for both *potential-reward* and *no-reward* trials (Fig. 1B): *congruent, incongruent reward-unrelated, incongruent reward-related*, and *neutral*. It should be emphasized that, although the irrelevant incongruent word could be implicitly "*related*" to either the *potential-reward* or no-reward ink-color subset, the monetary incentives were exclusively dependent on the ink-color dimension. This manipulation allowed us to investigate the explicit effects of reward in the relevant dimension (*potential-reward* versus *no-reward*), as well as indirect effects of reward associations that were entirely irrelevant to the task (*incongruent reward-related* versus *reward-unrelated*).

The averaged response times (RT) and error rates were submitted to repeated-measures analyses of variance (rANOVAs) to verify the overall main effects of the relevant dimension (*Color*: *potential-reward*, *no-reward*) and the