Reward interacts with modality shift to reduce cross-modal conflict

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Previous studies have shown that reward can enhance cognitive control and reduce conflict in visual processing. Here we investigate (a) whether and how reward influences cross-modal conflict control and (b) how the shift of attention across modalities modulates the effect of reward on cross-modal conflict control. In four experiments, a cue indicating the reward availability of a given trial (reward vs. no reward) was presented prior to a target. The target was either a visual or an auditory letter, which was accompanied by a distracting letter from the other modality. The identity of the distracting letter was either the same as or different from the identity of the target letter (congruent vs. incongruent). When the cue modality was constant (Experiment 1) or changed across different experimental blocks (Experiment 3), the interference effect (i.e., the response time difference between incongruent and congruent trials) was smaller following a reward cue than a no-reward cue, suggesting that reward can reduce cross-modal conflict. In contrast, when the cue modality was changed trial-by-trial in an unpredictable way (Experiments 2 and 4), reward reduced cross-modal conflict only when the cue and the target were from different modalities and had a long stimulus onset asynchrony (SOA) between them but not when they shared the same modality or had a short SOA between them. These results suggest that reward can facilitate

Pessoa, 2015; Soutschek, Stelzel, Paschke, Walter, & Schubert, 2015; Vuillier, Whitebread, & Szucs, 2015; Wang, Yu, & Zhou, 2013). For example, Padmala and Pessoa (2011) presented a picture of a house or building together with a letter string on the picture and asked participants to indicate whether the picture was a house or a building. The identity of the letter string could be neutral (“XXXXX”), congruent (“HOUSE”), or incongruent (“BUILDING”) with the picture (e.g., a house picture). A cue was presented prior to the target, indicating whether participants could earn monetary reward after they made a fast and accurate response. They found that the interference effect (i.e., response times [RTs] in the incongruent condition minus RTs in the neutral condition) was reduced when the cue predicted monetary reward as compared with a no-reward cue. This reduced interference effect by reward was accompanied by decreased activity in the left fusiform gyrus, a region for representing words (i.e., distractor), and with decreased activity in the medial demand was high (e.g., when modality shift was required) but not when the control demand was low (Marien et al., 2014). Similarly, in a digit recall task, Bijleveld, Custers, and Aarts (2009) manipulated the

cue modality could be either the same as or different from the modality of the target, leading to a modality shift in the latter case (cross-modal conditions) as compared with the former case (ipsimodal conditions; Turatto et al., 2002; Wang et al., 2012). We expected that the shift from the cue modality to the target modality in the cross-modal conditions would result in a switch cost as compared with the ipsimodal conditions. To cope with the switch cost, an adaptive control system might be recruited, leading to a potential interaction between reward and modality shift in modulating the control of the cross-modal conflict (Marien et al., 2014).

Method

Pa a

A new group of 20 college students (11 males, 18 ; 25 years old) took part in Experiment 2. All the participants were right-handed, had normal or corrected-to-normal vision, and self-reported normal hearing.

A a a a a a

The apparatus and materials were the same as in the previous experiment.

D a

The procedure was the same as in Experiment 1 with the following exceptions: The cue modality was manipulated on a trial-by-trial basis: Either an auditory cue (high tone or low tone) or a visual cue (# or &) was presented in each trial. Specifically, for half of the trials in each block, a visual cue was presented to indicate reward availability of the current trial, and for the other half of trials, an auditory cue was presented. The visual cue and the auditory cue trials were randomly mixed and equally distributed in each block.

The experiment had a 2 (cue–target modality congruency: ipsimodal vs. cross-modal) 3 2 (target modality: visual target vs. auditory target) 3 2 (reward: reward vs. no reward) 3 2 (target congruency: congruent vs. incongruent) within-subject factorial design. There were 48 trials for each of the 16 experimental conditions. The 768 trials were divided into 16 blocks of equal length with eight blocks in each target session. The order of the visual and auditory sessions was counterbalanced across participants. Each participant received 32 practice trials for the visual target session and 32 practice trials for the auditory target session to become familiarized with the task. The baseline RTs were calculated based on the participant's responses in these practice trials.

Results

Omissions and incorrect responses were excluded from analysis. For each participant, trials with RTs more than three standard deviations above or below the mean RT in each experimental condition were discarded as outliers (1.3%). A 2 3 2 3 2 3 2 ANOVA on RTs (Figure 3) showed a significant main effect of cue–target modality congruency, 2 3

0.35, with more errors on incongruent trials than on congruent trials (4.6% vs. 2.4%). No other effects reached significance.

Discussion

In Experiment 2, we observed longer RTs in the cross-modal conditions than in the ipsimodal conditions, suggesting an impaired target processing when there was a shift from the cue modality (audition/vision) to the target modality (vision/audition). This RT cost was consistent with other studies (Turatto et al., 2002; Turatto et al., 2004), indicating an attentional switch cost when modality shift is required even though the target modality was kept constant throughout the visual or auditory session. Importantly, our results showed that -[yard than in switchdirs316.s303Tj/F41i-shift was required in the cross-modal session but not required in the ipsimodal session.

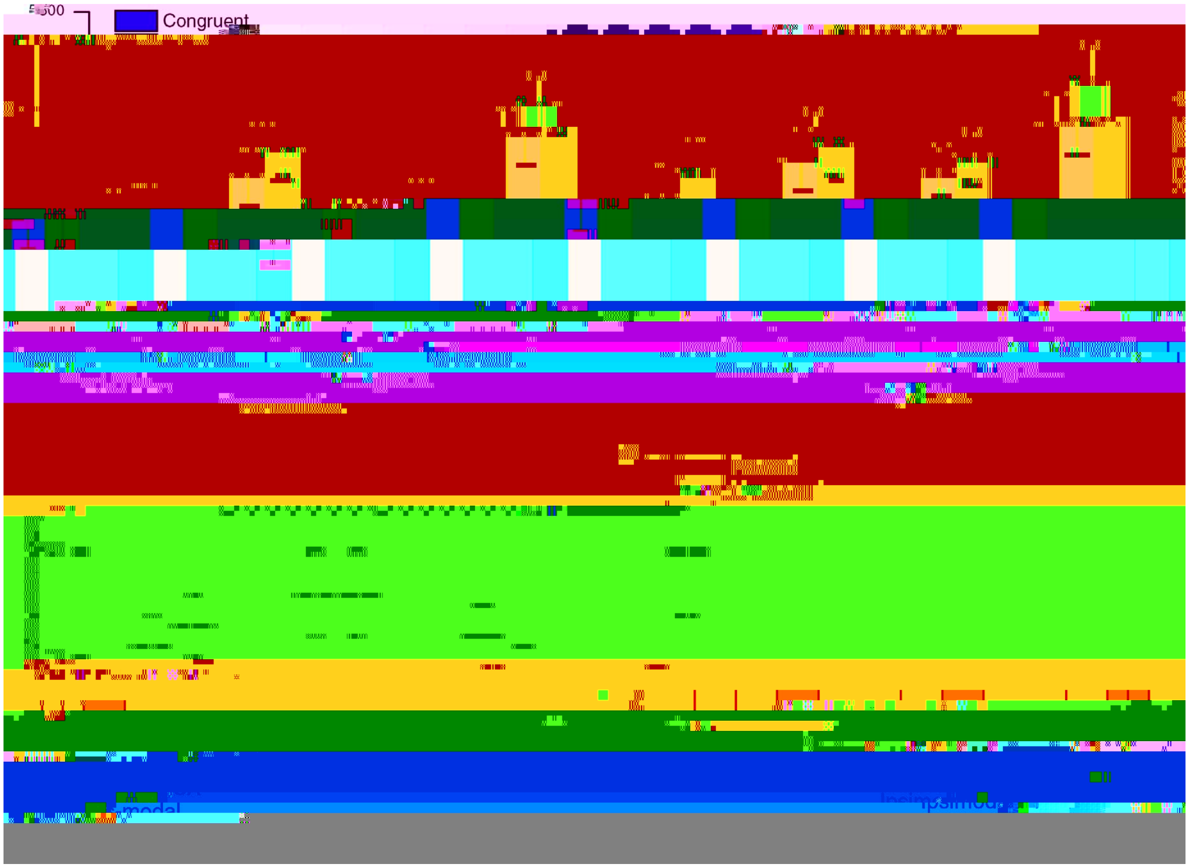

Figure 5. Experiment 4. Top: Mean RTs with standard errors as a function of the experimental condition. Bottom: the interference effects with standard errors as a function of the experimental condition.

ANOVA on the error rates showed an interaction between reward and target congruency, (1, 19) = 4.42, = 0.049, η^2 = 0.19, and a marginally significant interaction between SOA and cue–target modality congruency, (1, 19) = 4.24, = 0.053, η^2 = 0.18. Collapsing the data over SOA and cue–target modality congruency, we found a higher error rate for the incongruent than for the congruent conditions, but only for the no-reward trials (2.8% vs. 2.2%), (1, 19) = 2.45, = 0.024, and not for the reward trials (2.6% vs. 2.7%), (1, 19) = 0.36, = 0.724. Similarly, collapsing the data over reward and target congruency, we observed a higher error rate for the ipsimodal than for the cross-modal conditions, but only for short SOA trials (3.0% vs. 2.1%), (19) = 3.01, = 0.007, and not for long SOA trials (2.4% vs. 2.7%), (19) = 0.52, = 0.612.

Discussion

In Experiment 4, we observed more delayed RTs for the cross-modal conditions than for the ipsimodal conditions, replicating the finding of the modality shift cost when this shift was unpredictable (Experiment 2). Moreover, we found that the cross-modal interference effect was smaller for the reward than for the no-reward conditions at the long SOA but not at the short SOA, indicating that the modulatory effect of the interaction between reward and modality shift on cognitive control occurs only when there is enough time for modality shift. The absences of the modulatory effect for the cross-modal conditions at the short SOA may simply be because there was not enough time for the system to initiate proactive control (Chiew & Braver, 2016).

General discussion

In four experiments, we investigated (a) whether reward could reduce cross-modal conflict and (b) whether reward interacts with modality shift to modulate cross-modal conflict. We found that reward can enhance cognitive control and reduce cross-modal conflict irrespective of the target modality (Experiments 1 and 3). However, this reward-driven conflict resolution depended crucially on the preparation of modality shift between the reward-predictive cue and the subsequent target. Specifically, when information concerning modality shift or no shift could be obtained before the cue and the target were presented and the system could be prepared in advance, reward reduced cross-modal conflict irrespective of whether there was a modality shift for the current trial (Experiment 3). In contrast, when information concerning modality shift or no shift could not be known before the presentation of the cue and the target, reward reduced cross-modal conflict only when modality shift was required. Furthermore, this conditional reward-driven conflict resolution occurred only when there was enough time for the system to initiate proactive control (Experiments 2 and 4).

One of the important components of reward is motivation (“wanting”; Berridge & Robinson, 2003). A cue indicating reward delivery for successful performance would activate the motivational component of reward, which could elicit behavior changes (Notebaert & Braem, 2015). A number of studies suggest that reward-induced motivation promotes behavior performance and enhances cognitive control (Botvinick & Braver, 2015; Chiew & Braver, 2016; Kang, Zhou, & Wei, 2015; Padmala & Pessoa, 2011; Pessoa, 2009; Soutschek et al., 2015; Wei & Kang, 2014). Extending the evidence in the visual domain, our findings demonstrate that reward can enhance conflict resolution in the cross-modal context, reducing cross-modal conflict regardless of the target modality. Taken together, these results suggest a general role of reward in enhancing cognitive control.

Previous studies have shown that the onset of the cue triggers the preparation for the following cognitive control, and this preparatory state can be modulated by

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of how reward interacts with the adaptive control system during cross-modal conflict resolution. Indeed, there are ongoing debates on similar issues in the visual domain. For example, Padmala and Pessoa (2011) proposed that reward enhances top-down control and selectively attenuates the processing of distractor stimuli, which in turn facilitates conflict resolution. In contrast, Soutschek et al. (2015) argued that reward reduces conflict by improving target processing rather than distractor inhibition (Soutschek et al., 2015). In the same vein, reward could reduce cross-modal conflict either by enhancing the identity representation from the target modality or by inhibiting the identity representation from the distracting modality or both. Further studies are needed to reveal the specific role of reward in modulating the perceptual/semantic representations of the target and the distractor.

Another finding in the present study was that the reward effect on reducing cross-modal conflict was modulated by the available time between the cue and the target. Specifically, reward reduced cross-modal conflict only when there was sufficient time available for the preparation (i.e., with a long SOA between the cue and the target) and not when the time was insufficient for the preparation (i.e., in the short SOA conditions). This finding is consistent with a recent study that showed the reward effect on cognitive control was influenced by both the task-related expectation and time. In this study, Chiew and Braver (2016) used a cued flanker task to investigate the potential interaction between reward and task-informative cues (indicating the congruency of the target stimuli) in cognitive control. In their experiment 1, the reward and task information were presented simultaneously; they found that reward reduced the flanker interference when the cue indicated the task information. In their experiment 2, the reward cue and task-informative cue were presented sequentially, leading to an early reward condition (i.e., the reward cue presented before the task-informative cue) and a late reward condition. Results in the early reward condition, but not the results in the late reward condition, replicated findings in their experiment 1. The authors suggested that reward promoted strategic use of the informative cues to influence selective attention, and sufficient time was needed for initial proactive control. In line with this suggestion, in the present study, sufficient time during the preparation phase was also needed for the adaptive coping with the unpredictable modality shift and for the strategic distribution of cognitive resources.

A third observation in the current study is shorter RTs for the ipsimodal conditions than for the cross-modal conditions (Experiments 2 and 4). The onset of the cue is likely to induce an automatic allocation of attention to the cue modality, facilitating the subsequent processing of the target if the target is from the same modality (Parmentier, Elford, Escera, Andrés, & San Miguel, 2008; Turatto et al., 2002). Similar results have been reported by Weissman et al. (2004), who showed faster RTs for visual targets when the preceded cue was presented in the visual modality as compared to the auditory modality. Nevertheless, although the modality of the target could be primed by the modality of the cue, this overall modality priming had no impact

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