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RESEARCH ARTICLE

Independent effects of reward expectation and spatial orientation on the processing of emotional facial expressions

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Abstract The present study investigated the effect of reward expectation and spatial orientation on the processing of emotional facial expressions, using a spatial cue–target paradigm. A colored cue was presented at the left or right side of the central fixation point, with its color indicating the monetary reward stakes of a given trial (incentive vs. non-incentive), followed by the presentation of an emotional facial target (angry vs. neutral) at a cued or un-cued location. Participants were asked to discriminate the emotional expression of the target, with the cue–target stimulus onset asynchrony being 200–300 ms in Experiment 1 and 950–1250 ms in Experiment 2a (without a fixation cue) and Experiment 2b (with a fixation cue), producing a spatial facilitation effect and an inhibition of return effect, respectively. The results of all the experiments revealed faster reaction times in the monetary incentive condition than in the non-incentive condition, demonstrating the effect of reward to facilitate task performance. An interaction between reward expectation and the emotion of the target was evident in all the three experiments, with larger reward effects for angry faces than for neutral faces. This interaction was not affected by spatial orientation. These findings demonstrate that incentive motivation improves task performance and increases sensitivity to angry faces, irrespective of spatial orienting and reorienting processes.

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Introduction

Motivation and emotion are highly related concepts, such that we are motivated to obtain outcomes that are pleasurable and to avoid outcomes that are aversive. Motivation is commonly defined as what drives one to work to obtain a reward or to avoid punishment, and positive or negative emotions may be aroused after evaluating the outcomes (Lang and Bradley 2010; Pessoa 2009). Studies suggest that motivation and emotion may share common processing mechanisms and operate in highly reciprocal ways in the brain (Baxter and Murray 2002; Pessoa 2009; Shigemune et al. 2010; Tsukiura and Cabeza 2008; Wei and Kang 2014; Wittmann et al. 2008; but see Kaltwasser et al. 2013).

On the one hand, processing emotional stimuli may activate motivational circuits in the brain. For example, neuroimaging studies have demonstrated that imagining a pleasant scene (Costa et al. 2010) or viewing a romantic partner's picture (Aron et al. 2005) activates brain areas related to motivation, such as the ventral tegmental area (VTA), nucleus accumbens (NAc), and medial prefrontal cortex (mPFC). On the other hand, one's motivational state may affect responses to emotional stimuli (Beaver et al. 2008; Shigemune et al. 2010; Wei and Kang 2014; Wittmann et al. 2008). Recently, Beaver and colleagues (Beaver et al. 2008) demonstrated that appetitive motivation, as revealed by the "behavioral approach system" (BAS) (Gray 1990), predicts neural responses to angry faces, suggesting that there is a close relationship between motivation and the neural circuits for processing threatening emotional stimuli. Specifically, variation in the BAS in healthy participants predicts the activation of neural regions implicated in aggression when participants view facial signals of aggression in others.

Although one's internal and sustained motivational traits affect emotional processing, we recently conducted a study that investigated the effect of trial-by-trial changes in monetary incentives on the processing of emotional faces using the cue–target paradigm (Wei and Kang 2014), which was in line with recent evidences demonstrating the role of reward in facilitating task performance (Chelazzi et al. 2013; Chiew and Braver 2011; Padmala and Pessoa 2011; Pessoa and Engelmann 2010; Savine and Braver 2010; van den Berg et al. 2014; Veling and Aarts 2010). Rewards, including monetary incentives, have been used to increase the motivational engagement of participants performing cognitive tasks (Chelazzi et al. 2013; Pessoa 2014). In Wei and Kang (2014), a cue indicating the reward condition of each trial (incentive vs. non-incentive) was presented at the center of the screen, followed by the presentation of a picture of an emotional face at the center of the screen. Participants were asked to discriminate the emotional expression of the target face. The results revealed that the reward effects (i.e., RTs in non-incentive conditions versus those in incentive conditions) were larger for emotional faces than for neutral faces and were regulated by the task relevance of the emotionality of the target face. The results demonstrated that reward expectation may facilitate the representation and identification of emotional faces, as compared to neutral faces.

One possible explanation for the ability of monetary incentives to influence emotional processing, as described above, is that the incentive cues may increase the motivational state of participants and thereby increase attentional resources toward task-relevant stimuli (Chelazzi et al. 2013; Padmala and Pessoa 2011). If this is the case, the interaction between reward and emotion may depend on the available attentional resources, especially the resources directed to the target location. However, the incentive cue may increase perceptual sensitivity to emotional stimuli because of the rapid communication between reward and emotion circuits in the brain. In this scenario, it is possible that the interaction between reward and emotion is independent of attention. Indeed, brain structures involved in both emotion and reward (e.g., insula, VTA, NAc, mPFC) tend to be located separately from the fronto-parietal attentional network.

In the present study, we sought to examine whether the interaction between reward and emotion is modulated by the attentional resources that are currently deployed at the target location by using a spatial cuing paradigm (Posner 1980; Posner and Cohen 1984). It is well documented in the field of spatial attention that a peripheral onset cue captures attention to its location and affects participants' behavioral performance for the upcoming target (for reviews, see Posner 2014; Wright and Ward 2008). Attentional resources are believed to be deployed at the cued locations when the cue–target stimulus onset asynchrony (SOA) is shorter than 300 ms, yielding faster RTs to the target appearing at the cued location compared to RTs to the target appearing at an un-cued location (Posner and Cohen 1984). However, when the cue–target SOA is longer than 300 ms, inhibition of return (IOR) should occur, such that the cued location no longer holds attentional resources and the location is tagged as a "searched place," improving performance for a target appearing at a new location (i.e., the un-cued location), compared to the cued location (Klein 2000; Posner and Cohen 1984; Posner et al. 1984).

In the present study, we used a spatial cueing paradigm to investigate possible differential effects of reward expectation on the processing of emotional faces at short or long SOAs. A colored cue was presented at the left or right periphery, with its color indicating a monetary incentive or non-incentive condition, followed by the presentation of an angry or a neutral face at the cued or un-cued location. The cue–target SOA was short (200–300 ms) in Experiment 1 and long (950–1250 ms) in Experiments 2a and 2b. Participants were asked to discriminate the facial expression of the target face as being angry or neutral (see Fig. 1). The aims of the present study were twofold. First, we sought to examine whether the interaction between reward and emotion would be present if the cue and the target were presented peripherally and whether this effect would be regulated by valid and invalid spatial cues at short or long SOAs. Second, although some recent studies have tried to chart the relationship between reward and spatial orientation (Baines et al. 2011; Bucker and Theeuwes 2014; Engelmann and Pessoa 2007; Failing and Theeuwes 2014; Small et al. 2005), they have all used non-emotional stimuli as targets. It is of theoretical interest whether the incentive and spatial cuing effects for emotional targets would be differential at short and long SOAs. Thus, by examining both spatial facilitation effects and IOR effects, we explored the effects of monetary incentives on both the orienting and reorienting of attentional systems to emotional targets at different periods of time. We expected that monetary incentives would facilitate behavioral reactions to the angry and the neutral targets in both the short and long SOA conditions. If the rapid communication between the reward and emotion systems is not affected by attentional orienting and reorienting processes, we should observe independent effects of spatial cue and monetary incentive on the processing of emotional targets. In contrast, if attentional resources deployed at the target location regulate the interaction between reward and emotion, we should observe differential patterns of the reward effect on the processing of the emotional target at cued and un-cued locations, and in short and long SOA conditions.

Methods

Participants

Three groups of twenty-one undergraduate and graduate students participated in Experiments 1 (seven males, 18–26 years of age), 2a (five males, 19–25 years of age), and 2b (eight males, 18–26 years of age), respectively. Participants were all right-handed, had normal or corrected-to-normal vision, and had no known cognitive or neurological disorders. This study was approved by the Ethics Committee of the Department of Psychology, Capital Normal University. Participants all gave informed consent prior to the experiments in accordance with the Declaration of Helsinki.

Design and materials

A 2 × 2 × 2 within-participant factorial design was used for all the experiments, with the first factor being the trial type (incentive vs. non-incentive), the second factor being cue validity (valid vs. invalid), and the third factor being the emotional expression of the target face (angry vs. neutral).

The facial stimuli consisted of 60 pictures from the Chinese Facial Affective Picture System (CFAPS), whose valence and arousal levels were rated on a nine-point Likert scale (Wang and Luo 2005). The CFAPS was chosen to avoid the cultural bias seen when the International Affective Picture System was used with Chinese participants (Huang and Luo 2004). The stimulus series included 30 negative (angry) faces and 30 neutral (calm) faces, with 15 male and 15 female faces in each condition. The normative valence ratings of the two categories differed significantly from each other [M ± SD: neutral = 4.6 ± 0.21; negative = 2.9 ± 0.39, $p < .001$]. Each picture occupied 4.88° × 5.99° of visual angle at a viewing distance of 65 cm.

Procedures

The presentation of stimuli and recording of response times and error rates were controlled by Presentation software (http://nbs.neuro-bs.com/). Participants were seated in a dimly lit and sound-attenuated room. At the start of each trial (Fig. 1), a white fixation cross measuring 0.4° × 0.4°

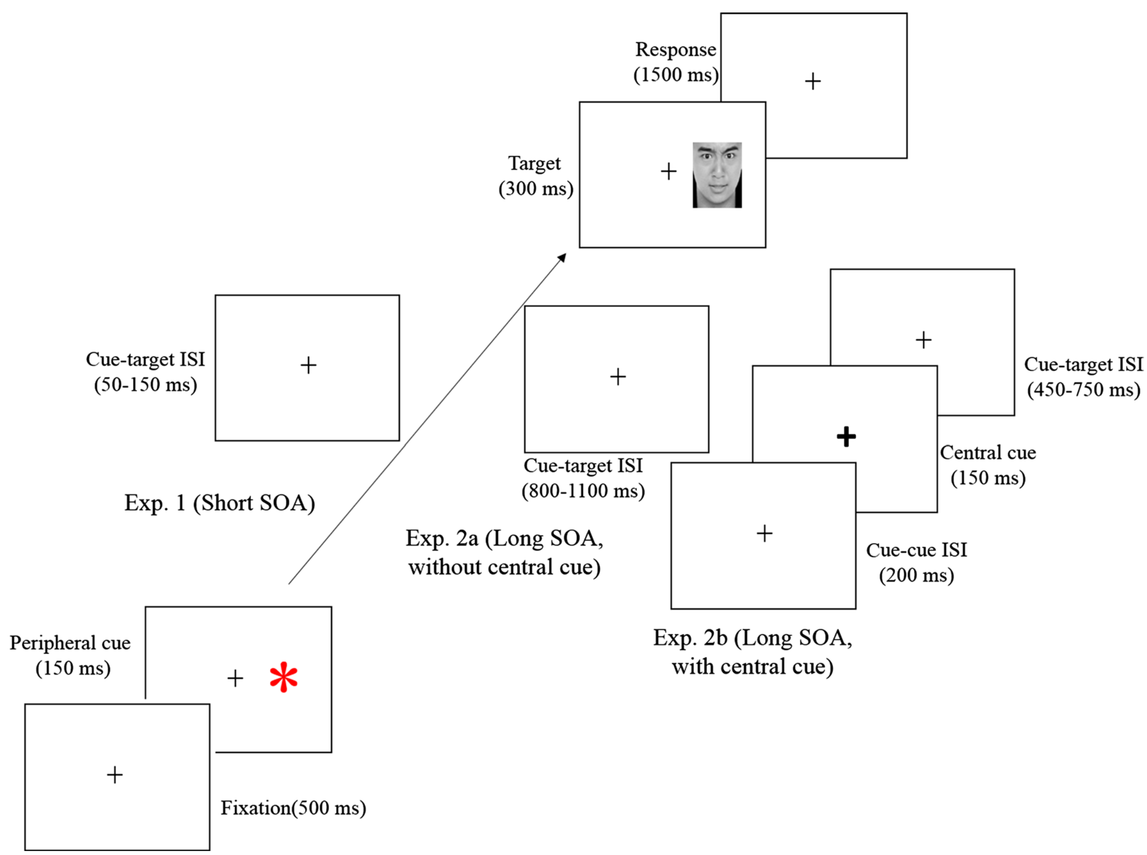

Fig. 1 Examples of trial sequence in Experiments 1, 2a, and 2b

in visual angle appeared at the center of the black screen for 500 ms, followed by a red- or green-colored "*" measuring 3.46° × 3.5° in visual angle, which was presented at the right or the left side of the fixation point for 150 ms. The center-to-center distance between the fixation cross and the peripheral cue was 5.27°. For half of the participants, the red cue indicated an incentive trial and the green cue indicated a non-incentive trial, and it was reversed for the other half of the participants.

The cue validities were different in the three experiments. In Experiment 1, the peripheral spatial cue correctly predicted the target location on 60 % of the trials. In Experiments 2a and 2b, the peripheral spatial cue correctly predicted the target location on 50 % of the trials. The cue–target SOA was 200–300 ms in Experiment 1, but 950–1250 ms in Experiments 2a and 2b (see Fig. 1). In Experiment 1, the peripheral cue was followed by a cue–target interval display with the presentation of only the fixation cross for 50–150 ms, after which the target face was presented at the valid (cued) or invalid (un-cued) location for 300 ms. In Experiment 2a, the presentation time for the cue–target interval display was 800–1100 ms. In Experiment 2b, the peripheral cue was followed by a 200 ms cue–cue interval (the fixation), after which the central fixation was highlighted for 150 ms serving as a fixation cue. After this fixation cue, a cue–target interval of 450–750 ms preceded the target presentation period of 300 ms. The reason for having or not having a fixation cue in Experiments 2a and 2b was because some studies have emphasized the role of the fixation cue in producing the IOR effect (e.g., Prime et al. 2006; but see Lupiáñez et al. 1997). By having trials with and without the fixation cue in different experiments, we can examine the possible differential influences of spatial orientation at a long cue–target SOA on the processing of reward expectation and emotional facial expressions.

In all three experiments, participants were instructed to respond to the target emotional facial expression as quickly and accurately as possible upon the presentation of the target face. There were two response buttons (left and right keys on the computer mouse) corresponding to each participant's right index finger and right middle finger. The assignments of response buttons to the target facial expressions (angry vs. neutral) were counterbalanced across participants. The responses made within 1800 ms were recorded for offline analyses. The inter-trial interval of fixation presentation was then presented for 1000–1500 ms.

Each experiment consisted of 480 trials. There were 288 (60 %) valid trials and 192 invalid trials (40 %) in Experiment 1, with equal numbers of incentive/angry, incentive/neutral, non-incentive/angry, and non-incentive/neutral conditions within the valid and invalid trials. There were equal numbers of trials (60 trials) per condition in Experiments 2a and 2b. All the trials were divided into four blocks in each experiment, with each block consisting of 120 trials (according to the above proportion of experimental trials in the corresponding experiment) presented in pseudorandomized order.

Participants received 32 practice trials before each experiment. During the practice phase, participants were informed of the cue validity, but not of the meaning of the cue color, and were required to respond as quickly and accurately as possible to discriminate the target facial expression. The average reaction time during the practice phase was used as each participant's baseline RT.

After the practice session, participants were informed of the meaning of the cue color and that they would gain an additional 10 Chinese Yuan in reward if their RTs in incentive trials were correct and faster than the baseline RT in >75 % of the total incentive trials (240 trials). At the end of each block of the formal experiment, participants were given feedback about the numbers of trials in which their RTs met the reward criteria in the current block and the accumulated number of trials meeting the criteria across the finished blocks.

Results

Incorrect responses were excluded from the analyses of the RTs. Moreover, RTs more than three standard deviations above or below the mean in each experimental condition for each participant were discarded as "outliers" (1.5 % in Experiment 1, 1.2 % in Experiment 2a, and 1.4 % in

Table 1 Mean reaction times (ms) and error rates (%) with standard errors in parentheses in terms of the experimental conditions for each experiment

	Target emotion	Incentive		Non-incentive	
		Valid	Invalid	Valid	Invalid
Experiment 1					
RTs (SE)	Angry	533 (15)	575 (16)	573 (14)	614(14)
	Neutral	565 (14)	626 (15)	571 (12)	628 (14)
Error rates (SE)	Angry	10.4 (1.4)	11.4 (1.5)	14.7 (1.4)	14.9 (1.7)
	Neutral	8.5 (1.5)	7.2 (1.2)	5.2 (1.0)	6.5 (1.1)
Experiment 2a					
RTs (SE)	Angry	542 (13)	535 (13)	580 (14)	572 (13)
	Neutral	573 (13)	564 (12)	581 (11)	578 (12)
Error rates (SE)	Angry	9.5 (1.2)	11.3 (1.2)	12.4 (1.2)	13.1 (1.6)
	Neutral	8.6 (1.7)	8.5 (1.6)	7.2 (1.4)	7.0 (1.6)
Experiment 2b					
RTs (SE)	Angry	571 (17)	554 (16)	606 (16)	600 (15)
	Neutral	609 (17)	593 (16)	628 (16)	613 (15)
Error rates (SE)	Angry	9.9 (1.2)	8.3 (1.2)	13.0 (1.4)	10.2 (1.1)
	Neutral	7.5 (0.9)	7.5 (1.0)	7.0 (1.1)	5.9 (0.9)

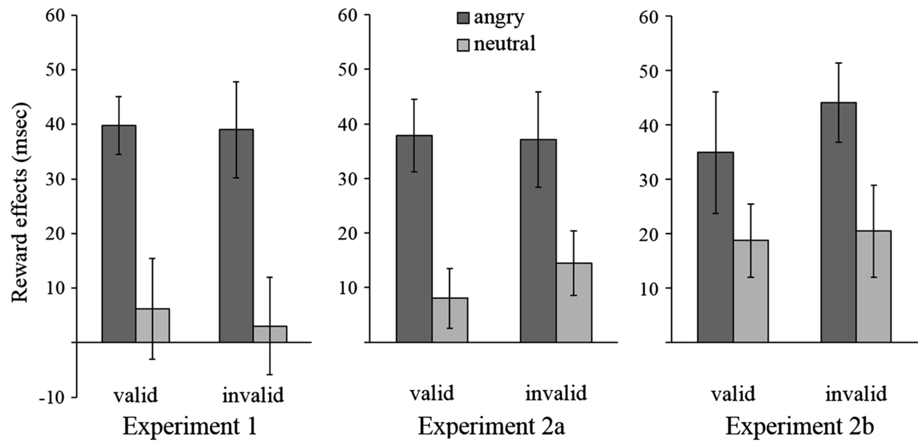

Fig. 2 Reward effects (i.e., reaction times in non-incentive conditions minus those in incentive conditions) and standard errors, with respect to cue validity and target emotion for each experiment

Experiment 2b). The mean RTs and response error rates in each experimental condition are reported in Table 1, and the reward effects between corresponding incentive and non-incentive conditions are depicted in Fig. 2 for each experiment.

Experiment 1

An analysis of variance (ANOVA) was conducted on the RTs, with trial type (incentive vs. non-incentive), cue validity (valid vs. invalid), and target facial emotion (angry vs. neutral) as within-participant factors. The results revealed a main effect of trial type, $F(1, 20) = 18.14$, $p < .001$, with faster RTs to incentive trials than to non-incentive trials (575 vs. 596 ms), a main effect of cue validity, $F(1, 20) = 205.79$, $p < .001$, with faster RTs in the valid condition than in the invalid condition (560 vs. 611 ms), and a main effect of emotion, $F(1, 20) = 5.27$, $p < .05$, with faster RTs for angry targets than for neutral targets (574 vs. 597 ms). The emotion factor interacted with trial type, $F(1, 20) = 10.62$, $p < .005$. Pairwise comparisons showed that the reward effect (RTs in non-incentive trials minus RTs in incentive trials) was significantly larger for angry targets than for neutral targets, $p < .05$, irrespective of cue validity. The emotion factor also interacted with cue validity, $F(1, 20) = 11.97$, $p < .005$. Pairwise comparisons showed that the cue validity effect (RTs in invalid trials minus RTs in valid trials) was significantly smaller for angry targets than for neutral targets, $t(20) = 3.63$, $p < .005$, irrespective of incentive condition. Further tests showed that the RTs for angry targets did not differ from the RTs for neutral targets in the valid conditions (553 vs. 568 ms), $t(20) = 1.36$, $p > .10$, but the RTs for angry targets were significantly shorter than those for neutral targets in the invalid conditions (595 vs. 627 ms), $t(20) = 3.16$, $p < .01$. No other effects reached statistical significance.

The same ANOVA on error rates revealed a main effect of target facial expression, $F(1, 20) = 15.80$, $p < .005$, with more errors being committed for the angry face than for the neutral face (12.9 vs. 6.9 %). The interaction between trial type and emotion also was significant, $F(1, 20) = 6.74$, $p < .05$. Pairwise comparisons showed that more errors were committed for angry targets than for neutral targets in the non-incentive condition (14.8 vs. 5.9 %), $t(20) = 5.52$, $p < .001$. However, this difference did not reach significance in the incentive condition (10.9 vs. 7.9 %), $t(20) = 1.42$, $p > .1$. No other effects reached statistical significance.

Experiment 2a

The same ANOVA conducted on RTs revealed a main effect of trial type, $F(1, 20) = 28.12$, $p < .001$, with faster RTs for incentive than for non-incentive trials (553 vs. 578 ms), as well as a main effect of cue validity, $F(1, 20) = 6.05$, $p < .05$, with longer RTs at the cued location than at the un-cued location (569 vs. 562 ms), indicating the presence of the IOR effect. The main effect of emotion was marginally significant, $F(1, 20) = 3.30$, $p < .08$, with faster RTs for the angry targets than for the neutral targets (557 vs. 574 ms). Moreover, trial type significantly interacted with emotion, $F(1, 20) = 11.67$, $p < .005$. Pairwise comparisons showed that the reward effect was significantly larger for angry targets than for neutral targets (37 vs. 11 ms), $t(20) = 3.42$, $p < .005$. No other effects reached statistical significance.

Analysis of the error rates revealed a main effect of emotion, $F(1, 20) = 4.77$, $p < .05$, with larger error rates for angry faces than for neutral faces (11.6 vs. 7.8 %). Additionally, the interaction between trial type and emotion was significant, $F(1, 20) = 4.59$, $p < .05$. Pairwise comparisons showed that more errors were committed for the angry faces than for neutral faces in the non-incentive condition (12.7 vs. 7.1 %, $t(20) = 3.43$, $p < .005$), but the error rates did not differ between the angry and neutral faces in the incentive condition (10.4 vs. 8.6 %), $t(20) < 1$.

Experiment 2b

The same ANOVA conducted on the RTs revealed a main effect of trial type, $F(1, 20) = 19.30$, $p < .001$, with faster RTs for incentive trials than for non-incentive trials (582 vs. 612 ms), a main effect of cue validity, $F(1, 20) = 14.15$, $p < .01$, with longer RTs at the cued location than at the un-cued location (603 vs. 590 ms), indicating the presence of the IOR effect, as well as a main effect of target emotion, $F(1, 20) = 8.82$, $p < .01$, with faster RTs for angry targets than for neutral targets (583 vs. 610 ms). Moreover, the emotion factor significantly interacted with trial type, $F(1, 20) = 6.71$, $p < .05$. Pairwise comparisons showed that the reward effect was significantly larger for angry faces than for neutral faces (41 vs. 20 ms), $t(20) = 2.59$, $p < .05$.

Analysis of the error rates revealed a main effect of emotion, $F(1, 20) = 5.76$, $p < .03$, with larger error rates for angry faces than for neutral faces (10.3 vs. 7.0 %), and a main effect of cue validity, $F(1, 20) = 9.70$, $p < .01$, with more errors in the valid than in the invalid condition (9.4 vs. 8.0 %). In addition, the interaction between trial type and emotion was significant, $F(1, 20) = 7.30$, $p < .05$. Pairwise comparisons showed that more errors were committed for the angry targets than for the neutral targets in the non-incentive condition (11.6 vs. 6.4 %), $t(20) = 3.27$, $p < .005$, but the error rates did not differ between the angry and neutral targets in the incentive condition (9.1 vs. 7.5 %), $t(20) = 1.02$, $p > .10$.

Discussion

The current study investigated the effect of spatial attention and monetary incentive on the processing of emotional facial targets at short and long cue–target SOAs, using the cue–target paradigm. Consistent with previous findings, we found the spatial facilitating effect in short cue–target SOA conditions, the IOR effect in long SOA conditions, and the effect of monetary incentives in boosting behavioral performance. Moreover, the results across the three experiments revealed an interaction between reward and emotion, such that the reward effects were larger for angry faces than for neutral faces, consistent with previous results (Wei and Kang 2014). Importantly, this interactive effect was evident at both the cued and un-cued locations, and it was evident in both the short and long SOA conditions. However, it was not influenced by cue validity, suggesting a robust interaction between reward and emotion that is independent of the spatial orienting and reorienting processes.

In all the three experiments, faster RTs were observed under the incentive conditions relative to non-incentive conditions, replicating recent findings that monetary incentives facilitate task performance (Baines et al. 2011; Engelmann and Pessoa 2007; Locke and Braver 2008; Padmala and Pessoa 2011; Savine and Braver 2010; Small et al. 2005; van den Berg et al. 2014; Veling and Aarts 2010). These results are consistent with the notion that motivational incentives can improve executive control to obtain more effective goal-directed behavior (for reviews, see Botvinick and Braver 2015; Chelazzi et al. 2013; Pessoa and Engelmann 2010).

Although we found the cue facilitating effect in the short SOA (200-300 ms) condition and the IOR effect in the long SOA (900–1250 ms) condition, these effects did not interact with reward expectation, meaning that the reward effects were comparable at the cued and the un-cued locations in both cases. Recent studies using non-emotional stimuli as targets have not reached consensus about whether reward expectation differentially affects spatial orienting and reorienting processes (Baines et al. 2011; Bucker and Theeuwes 2014; Engelmann and Pessoa 2007). For example, Engelmann and Pessoa (2007) used a short cue–target SOA (125 ms) in a spatially cued localization task, with instructions before each experimental block that outlined the reward probability, magnitude, and valence (gain, loss, or neutral). They found that perceptual sensitivity to the target increased as a function of incentive value during both valid and invalid trials, suggesting that motivation improved efficiency in both the orienting and reorienting of spatial attention. However, Bucker and Theeuwes (2014), who asked participants to discriminate a bar orientation as horizontal or vertical at short (170 ms) or long (960 ms) cue–target SOAs in low- or high-reward blocks, found the typical cue facilitation effects on initial orienting for both the low- and high-reward conditions; yet, the IOR effect was found only for the high-reward condition. They concluded that initial orienting is stimulus-driven, not affected by top-down motivational processes, while reorienting and the accompanying IOR effect involve motivational top-down processes.

The lack of interaction between reward expectation and cue validity in the current study is consistent with Engelmann and Pessoa (2007), although we manipulated the incentive value on a trial-by-trial basis instead of blockwise, as they did. In the block design, participants are informed about reward/punishment contingencies at the beginning of each block and are typically informed about the reward/punishment outcome at the end of each block to ensure sustained motivational engagement throughout a certain period of time (e.g., Engelmann and Pessoa 2007; Small et al. 2005). However, a trial-by-trial design that uses the shape or color of a cue to indicate the reward stakes of each trial should induce a transient change in participants' motivational state (e.g., Baines et al. 2011; Kiss et al. 2009; Savine and Braver 2010). By comparing the behavioral results of these studies, it seems that a sustained or transient state of motivational engagement does not play a crucial role in determining the interaction between reward and spatial orientation.

A recent electrophysiological study found independent effects of reward and spatial cues on behavioral data but not on the later event-related potential (ERP) component (Baines et al. 2011). Baines et al. (2011) used a modified cue–target paradigm and electrophysiological measures to investigate motivational and spatial biases in modulating behavioral performance and neural activities. The cue presented at the center of the screen indicated not only the reward value of a given trial, but also the probable spatial location of a subsequent target stimulus (a grating tilt) that would appear on the left or the right side of the periphery with 50 % cue validity. Although the behavioral results and early potentials, such as P1 and N1, revealed an independent modulation of reward and spatial cues, the effects of motivation and spatial attention interacted at the late time windows of brain potentials, with magnitude differences between the rewarded and non-rewarded valid trials, but not the invalid trials. The P300-like potentials and the lateralized readiness potential (LRP) were affected by the interaction of motivation and spatial attention, suggesting a differential influence of motivation in modulating late cognitive processing and response production at cued and un-cued locations. It should be noted that unlike a peripheral cue in the present study, Baines et al. (2011) used the shape of the plus sign (or cross) presented at the center of the screen to indicate the possible location of the upcoming target, thus producing a spatial facilitation effect even when the SOA was long (900–1300 ms). Although the experimental manipulations varied from study to study and the independence or interaction in the behavioral data for reward and spatial attention represented the final results of processing toward the target stimuli, the electrophysiological data may allow for a better clarification of the relationship between reward expectation and spatial orientation. Future neurocognitive studies are needed to better describe the interaction between motivation and spatial orientation.

The interaction between attention and emotion was observed only in Experiment 1, in which there were smaller cue validity effects for angry targets than for neutral targets, but not in Experiments 2a and 2b. The reduced cue validity effects for angry targets in Experiment 1 were driven by faster RTs for angry targets than for neutral targets in the invalid conditions, indicating that an angry face captures attention and hastens attentional reorienting toward its location (the invalid location). This result is consistent with the notion that threatening stimuli involuntarily take attentional priority, since they are important for survival (Ekman 1973; Pourtois et al. 2013; Vuilleumier 2005; Yiend 2010; but see Eimer et al. 2003; Holmes et al. 2003). For example, brain-damaged patients are much less likely to show extinction to faces than to shapes, suggesting that facial features and emotional expressions presented on the contralesional visual field can be attended to and that they may influence the spatial distribution of attention (Vuilleumier and Schwartz 2001).

However, we did not observe the influence of the target emotion on the IOR effects in Experiments 2a and 2b. In previous studies that investigated the interaction between emotion and spatial orienting, researchers typically used an emotional or neutral face as a cue in order to examine their differential ability to capture attention, to affect orienting and reorienting of attention toward a later non-emotional target and the preparation of a motor response to the target (Brosch et al. 2011; Fox et al. 2002; Mulckhuyse and Crombez 2014; Taylor and Therrien 2005). For example, studies have reported that threatening cues (relative to neutral cues) reduced the IOR effect, suggesting that there is stronger retention and slower disengagement of attention cued by threatening stimuli (Fox et al. 2002; Mulckhuyse and Crombez 2014). However, in the current study, the angry or neutral faces served as the targets. Although the peripheral onset cue automatically captured attention, there was no incentive to maintain attention at that location (i.e., because the cue location did not predict the target location). Attention was quickly oriented to the opposite direction during the long cue–target interval, waiting for the target to be presented equally often at the valid or the invalid location. The advantage of angry faces over neutral faces in capturing attention therefore did not differ in the valid or invalid conditions. This result is consistent with the notion that IOR is a “blind” mechanism that is unaffected by the mere occurrence of biologically relevant cues and target stimuli (Taylor and Therrien 2005). This was not true in Experiment 1, as the target was immediately presented at the location where attention was either captured (i.e., the valid location) or not (i.e., the invalid location).

We found differential incentive effects on the processing of angry and neutral target faces in all the three experiments, using incentive or non-incentive cues presented at the periphery, with larger incentive effects for angry faces than for neutral faces. These results are consistent with our recent findings, in which the incentive or non-incentive cue and the emotional facial target were presented at the center of the screen (Wei and Kang 2014). The enhanced benefit for angry faces compared to neutral faces may be the result of strong and fast reciprocal connections between the brain areas that process reward and emotional stimuli (Baxter and Murray 2002). The amygdala, which is well known to respond to negative or threatened emotional stimuli (Beaver et al. 2008; Britton et al. 2006; Hariri et al. 2002; Phan et al. 2004; Satterthwaite et al. 2011; Strauss et al. 2005; Zald 2003), has close connections with the brain areas processing reward information, including the ventral striatum (Alheid 2003) and the substantia nigra/

ventral tegmental area (SN/VTA, Price and Amaral 1981). The current results further suggest two new findings. On the one hand, this rapid communication between reward expectation and emotion is evident when the incentive cue and the emotional target are presented at the periphery, and it is evident at both short and long cue–target intervals, suggesting a robust and long-lasting interaction between reward circuitry and emotional processing in the brain. On the other hand, the effect of the incentive cue imposed on the later processing of the angry targets was not influenced by the spatial accuracy of the cue to predict the target location. An incentive cue, whether presented in the center or at the periphery, and regardless of its accuracy to predict the target location, may increase the sensitivity to detect and recognize emotional targets, thus increasing the speed of behavioral reactions.

Moreover, this increased sensitivity to angry faces was also supported by the results for the response error rates. Across the three experiments, more errors were made for angry faces than for neutral faces in general, suggesting that participants tended to "miss" the angry expression rather than making false alarms in which the neutral face was reported to be an angry face. In addition, although the error rates were larger for angry faces than for neutral faces in the non-incentive condition, the error rates for angry faces were comparable to those for neutral faces in the incentive condition. It is possible that there was a speed–accuracy trade-off in the non-incentive condition, in which participants responded faster but less accurately to angry faces. In other words, they missed some "angry" signals. However, this trade-off was adjusted in the incentive condition, in which participants had faster RTs yet more accurate responses compared to the non-incentive condition. The results indicate that there was an increased ability to discriminate between angry and neutral targets in the incentive condition. Hence, the monetary incentives seem to have directly increased participants' motivation and effort to respond correctly and faster to the target (Chelazzi et al. 2013). This top-down control process biased fast attentional allocation to the emotional target and seems to be resistant to the attentional orientation.

Further testing of the interaction between reward and emotion may involve manipulating the way that the reward is being delivered. In the field of reward-based effects on perceptual or attentional mechanisms, the possible ways in which the reward is manipulated can be classified as proactive and reactive (Pessoa 2014). The current study, similar to many other studies (Baines et al. 2011; Engelmann and Pessoa 2007; Padmala and Pessoa 2011; Savine and Braver 2010; Schevernels et al. 2014; Small et al. 2005; van den Berg et al. 2014; Veling and Aarts 2010), used the proactive paradigm by informing the participants about reward contingencies before each trial or before each block, resulting in higher motivational engagement and higher arousal for the incentive condition (Berridge and Robinson 2003; Löw et al. 2008; Knutson and Adcock 2005). It is possible that this higher arousal facilitated participants' responses to the angry faces, which also had a higher level of arousal. Studies have shown that presenting an arousing cue (e.g., a fearful face or a fear-conditioned auditory tone) enhances contrast sensitivity in subsequent visual perception (Lee et al. 2014; Phelps et al. 2006). Moreover, arousing and non-arousing visual stimuli themselves can differ in low-level visual features, such as the energy distribution of frequencies (e.g., Delplanque et al. 2007). We speculate that the rapid communication between reward and emotion might be triggered by enhanced arousal in the incentive condition, which facilitates the perception of the arousing faces with unique spatial frequencies compared to the neutral ones.

However, other studies using the reactive paradigm have examined the immediate or learned delivery of reward on the processing of a later stimulus (Anderson et al. 2011; Chelazzi et al. 2014; Della Libera and Chelazzi 2009; Hickey et al. 2010; Raymond and O'Brien 2009; Rutherford et al. 2010; Theeuwes and Belopolsky 2012; Kiss et al. 2009; Krebs et al. 2010, 2013). In this case, participants do not know the reward contingencies in advance and, thus, cannot proactively devote higher motivational engagement; instead, their responses to stimulus features are reactively affected by whether or not these features were previously linked with reward (Pessoa 2014). The typical finding is that stimuli rewarded in the past are favored later, even when they are task irrelevant and reward irrelevant in the later situation. Thus, future research should test whether a stimulus previously linked with reward will also have facilitating effects on the processing of emotional facial expressions.

To conclude, by using a spatial cuing paradigm, the present study showed that monetary incentives generally improved task performance and that reward modulated the processing of emotional facial expressions with more enhanced sensitivity to angry faces than to neutral faces. Moreover, this enhanced motivational control on emotional processing was not influenced by spatial attention bias.

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