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Prioritised self-referential processing is modulated by emotional arousal

Haoyue Qian[1,2], Zhiguo Wang[3,4], Chao Li[2] and Xiangping Gao[2]

Abstract

Stimuli related to the self are processed more efficiently in a variety of cognitive tasks. Recent studies have shown that this self-referential processing bias is modulated by emotion. However, a clear understanding of how emotional valence and arousal affect self-referential processing is still lacking. With a label–shape matching task, Experiment 1 measured a self-prioritisation effect in four different mood states. The results revealed stronger self-prioritisation effects in moods with higher arousal levels and a reliable correlation between the self-prioritisation effect and the arousal level reported by the participants; however, the effect of emotional valence was not statistically reliable. Experiment 2 further showed that alerting cues, known to raise arousal level, effectively increased the self-prioritisation effect in the same label–shape matching task. Experiment 3 clarified that alerting cues do not affect reward processing in a similar label–shape matching task, suggesting that arousal may selectively modulate self-referential processing. These observations provide clear evidence that emotional arousal modulates self-referential processing.

Keywords

Self-referential bias; mood; valence; arousal; self-prioritisation effect

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Introduction

Items associated with the self are prioritised in a range of cognitive operations. For instance, materials related to the self are better memorised (e.g., Klein, 2012; Symons & Johnson, 1997), and one's own face is processed much faster than faces of strangers (e.g., Guan et al., 2014; Ma & Han, 2010; Tong & Nakayama, 1999). Using a label–shape matching task, Sui et al. (2012) observed faster and more accurate responses to geometric shapes paired with an identity label for the self (e.g., "you" or the participant's name) compared with shapes paired with an identity label for others (e.g., *friends* and *strangers*). This self-prioritisation effect has been replicated in multiple follow-up studies (e.g., Stolte et al., 2016; Schäfer et al., 2016; Frings et al., 2014; Woźniak & Knoblich, 2019).

Emotions are typically elicited by events of self-importance, and the processing of self-related information often automatically evokes emotional responses. Several theories conceptualise emotions along two main dimensions, valence and arousal (e.g., Russell, 1980). Valence is the level of pleasantness that an event generates (a continuum from negative to positive), and arousal is the level of autonomic activation that an event creates (a continuum from calm to excited). It is known that emotional responses to self-relevant stimuli are typically more positive (e.g., Heine et al., 1999; Markus & Kitayama, 1991). In a compelling demonstration, Ma and Han asked the participants to judge whether negative personality traits accurately described themselves. This manipulation eliminated the processing speed advantage for own faces in a face perception task (Ma & Han, 2010, 2012). With a label–shape matching task, Sui et al.

[1]School of Physics and Shanghai Key Laboratory of Magnetic Resonance, East China Normal University, Shanghai, China
[2]Department of Psychology, Shanghai Normal University, Shanghai, China
[3]Institute of Psychological Sciences, Hangzhou Normal University, Hangzhou, China
[4]SR Research Ltd., Ottawa, ON, Canada

Corresponding author:
Xiangping Gao, Department of Psychology, Shanghai Normal University, 100 Guilin Road, Shanghai 200234, China.
Email: gaoxp@shnu.edu.cn.

(2016) required the participants first to read a list of depressive statements that affect their feelings (i.e., mood induction). This manipulation reduced the processing advantage for the shapes associated with the self. Along with these findings, a recent event-related potential (ERP) study revealed that self-relevant labels elicited stronger P3 responses, but this self-bias in P3 was attenuated when the participants were in a negative mood (Fan et al., 2016). These findings suggest that various self-reference biases may be driven by an implicit association between self-referential processing and positive emotions. Stolte et al. (2016), however, found no sign of correlation between a positive emotion bias and a self-referential bias, an observation that is consistent with the neuroimaging finding that emotional valence and self-reference recruit non-overlapping neural substrates (e.g., Moran et al., 2006; Watson et al., 2007).

Although the effect of valence on self-referential processing has attracted much attention in the field, the impact of arousal was largely overlooked by researchers. Nevertheless, there is a good reason to speculate an overlapping between the self-referential and emotional arousal processing. For instance, self-relevance increases the pupillary responses to and arousal ratings on emotional words (Bayer et al., 2017). In an early study, Baron and Moore (1987) showed that the memory advantage for self-referent adjectives was more robust when the arousal level was above baseline. It is also known that increasing the arousal level boosts self-focused attention, that is, an awareness of self-referent information (e.g., Wegner & Giuliano, 1980). Furthermore, arousal is known to modulate attention to salient external stimuli (e.g., Weinbach & Henik, 2014), and it has been suggested that self-relevant information is more attention-absorbing because they are more salient (Golubickis et al., 2017; Sui et al., 2015). It is reasonable to speculate that (emotional) arousal may also modulate the processing of self-associated stimuli. However, few studies have explicitly investigated this issue.

This study was set out to examine whether emotional valence, as well as arousal, modulates the self-prioritisation effect observed in the label–shape matching task (e.g., Sui et al., 2013; Sui & Humphrey, 2012). The participants in Experiment 1 completed a label–shape matching task under four emotional states with varying arousal levels and valence (happiness, anxiety, serenity, and depression; as suggested by Bradley et al., 2001). The self-prioritisation effect was examined by comparing the response times (RTs) to geometric shapes associated with the participants themselves and those associated with a celebrity. To rule out a possible confounding factor of label (material) familiarity, Experiment 1 also recorded RTs to geometric shapes associated with the name of an individual that was unknown to all participants. Based on the established relation between arousal and salience processing, we expected to observe an effect of arousal on the self-prioritisation effect. Alerting cues are known to raise the arousal level, but they do not affect valence (Weinbach & Henik, 2014). Experiment 2 assessed the impact of arousal by introducing alerting cues to the label–shape matching task. Experiment 3 further examined whether arousal specifically modulates self-referential processing with a shape–reward matching task (Sui et al., 2012).

Experiment 1

The goal of Experiment 1 was to examine the impact of valence and arousal on the self-prioritisation effect through the induction of four different emotional states.

Method

Participants. The experimental task of Experiment 1 was similar to that of Sui et al. (2016), which showed that moods modulate the self-prioritisation effect measured with a label–shape matching task. A power analysis was first carried out to determine the number of participants required to attain sufficient power (0.80) at an alpha level of 0.05. A sizable self-prioritisation effect ($dz = 1.04$) was reported in Sui et al. (2012); reproducing an effect of the same magnitude requires 10 participants. A medium-sized mood modulation effect ($dz = 0.622$) was observed in Sui et al. (2016), which requires 23 participants to replicate. Considering the potential loss of participants in a multi-session design, Experiment 1 recruited 26 participants (10 males; age range: 18–22 years; $M = 19.74$, $SD = 1.28$).

The participants were all right-handed and had normal or corrected to normal visual acuity. They first completed a Self-Rating Depression Scale (SDS; Zung, 1965) and a Self-Rating Anxiety Scale (SAS; Zung, 1971). This pre-screening procedure was necessary to exclude participants suffering from depression or anxiety disorders. One male who scored over 50 (out of 80) on the SAS scale and one female who scored over 50 (out of 80) on the SDS scale were excluded from further testing. The remaining 24 participants (nine males) completed four testing sessions in Experiment 1.

The research protocol presented here was approved by a local ethics committee, and all participants gave written informed consent before the experiment.

Mood induction. The Velten mood induction procedure (Velten, 1968) was used to elicit four different mood states: happiness, anxiety, serenity, and depression. The participants read out a list of emotional statements while listening to emotional music for 10 min. For the anxiety and serenity conditions, the emotional statements were adapted from Sinclair et al. (1997); for the happiness and depressive conditions, the emotional statements were adapted from Jennings et al. (2000). These emotional statements were first translated into Chinese by two graduate students in psychology. The valence and arousal level

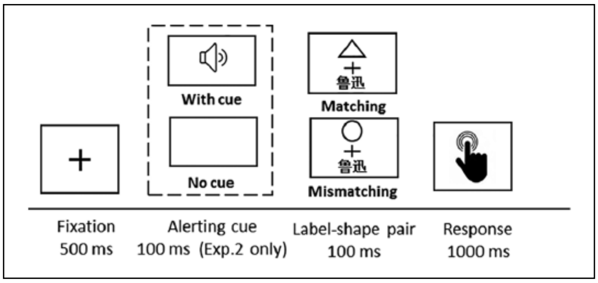

Figure 1. An illustration of the label–shape matching task (see text for details). An alerting cue was presented before the label–shape pairs on half of the trials in Experiment 2. For illustration only, stimuli are not drawn to scale.

of the translated emotional statements and that of the emotional music was rated by 48 undergraduates (20 males) on the Self-Assessment Manikin scale (Bradley & Lang, 1994). The ratings for these materials are reported in Supplementary Material (Tables S1 and S2). To prevent potential carryover effects, the four mood induction procedures were tested in separate sessions, with roughly 1-week intervals. A Latin-square design was used to counterbalance the sequences of the mood induction procedures across the participants.

Label–shape matching task. In Experiment 1, the participants completed a label–shape matching task in four sessions. In each session, participants were instructed to associate three identity labels to three new geometric shapes separately. The labels were the participant's own name, the name of a gender-matched stranger, and the name of a Chinese celebrity (Lu Xun, a famous Chinese writer). The labels were all two-character long. A total of 12 geometric shapes (triangle, circle, square, hexagon, pentagon, octagon, diamond, ellipse, sector, parallelogram, rectangle, and trapezoid) were used across the four sessions, with no repetition. The paring of the labels and shapes was counterbalanced across participants.

At the beginning of the label–shape matching task, a verbal instruction was delivered, for example, "A circle represents a stranger, a pentagon represents you, and a triangle represents Lu Xun, and your task is to decide whether the shape on the screen matches the name below it." On each trial, the participants indicated whether a label–shape pair was "correct" or "incorrect" based on the verbal instructions. The label–shape pairs were presented in white against a grey background, at a viewing distance of about 65 cm. The geometric shapes measured $3.5° \times 3.5°$ visual angle, and the labels extended $2.52° \times 1.6°$. The geometric shape was presented above a white central fixation cross ($0.8° \times 0.8°$), whereas the label was displayed below the fixation (see Figure 1). Stimulus presentation and response registration were controlled by E-Prime (Version 2.0, Psychology Software Tools, Inc.), running on a Windows PC equipped with a 17-in cathode-ray tube (CRT) monitor.

Procedure. As noted earlier, all participants completed four testing sessions. They first learned the label–shape pairings through a block of practice trials at the beginning of each session. A minimum accuracy of 80% (based on 10 trials) was required before they moved on to the mood induction procedure. After the mood induction, the label–shape matching task was performed for a second time. At the end of each session, the participants rated their valence and arousal level on the Self-Assessment Manikin scale (Bradley & Lang, 1994). The valence scores ranged between 1 (*extremely negative*) and 9 (*extremely positive*); the arousal scores also ranged between 1 (*extremely calm*) and 9 (*extremely excited*). The ratings were necessary to evaluate the effectiveness of mood induction procedures.

In the label–shape matching task, both the practice and testing trials started with the presentation of a central fixation cross (500 ms), followed by a label–shape pair that lasted for 100 ms. Half of the pairings followed the verbal instruction, and the remaining half did not. The brief presentation of the label–shape pair was followed by a blank screen of 1,000 ms, during which participants were required to respond as quickly as possible, without compromising accuracy. A standard QWERTY keyboard was used to register the response. The response keys for correct and incorrect label–shape pairs were counterbalanced across participants. On-screen visual feedback ("Correct," "Incorrect," or "Too slow") was presented for 500 ms at the end of each trial.

The label–shape matching task had 48 trials for each of the three identities: self, stranger, and celebrity. Half of the label–shape pairings conformed to the task instructions (matching), and the remaining half did not (mismatching). Because three labels and three geometric shapes were used, when a mismatching trial was presented, a shape could pair with two possible labels. Twelve trials were tested for each of these two types of mismatching pairs. A total of 20 practice trials and 144 testing trials were tested in each session.

Data analysis. The ratings collected at the end of each session were first examined to evaluate the effectiveness of the mood induction procedures. RTs from the label–shape matching task were then examined to quantify the self-prioritisation effect. For the RT analysis, only matching trials with correct responses were included (e.g., Fuentes et al., 2016; Sui et al., 2016). Statistical analysis was also performed on the accuracy data (percent correct over both matching and mismatching trials) to rule out potential speed–accuracy trade-offs. Analyses were also performed to examine the correlation between the valence (and arousal) ratings and the self-prioritisation effect.

For the RT analysis in the label–shape matching task, trials with anticipatory responses (RT < 200 ms) as well as those that were 3 *SD*s above the mean for each participant were excluded from analysis. These trials accounted for

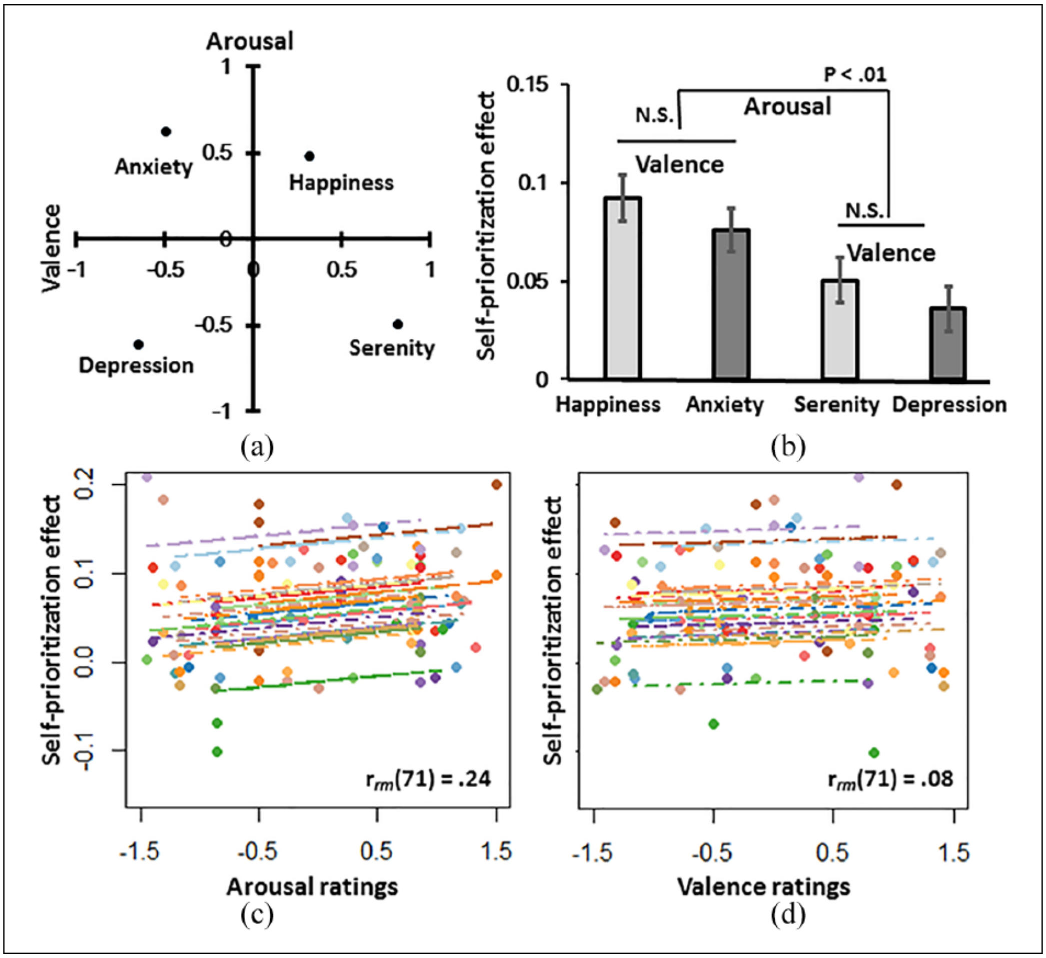

Figure 2. (a) Arousal and valence ratings (normalised *Z*-scores) following the four mood induction procedures. Valence and arousal are represented by the horizontal and vertical axes, respectively. The origin represents a neutral valence and a medium level of arousal. (b) The self-prioritisation effects in the four moods induced in Experiment 1. Values on the *Y*-axis are RT ratios (see text for details). Error bars represent standard errors of the mean. (c) The correlation between the self-prioritisation effects and arousal ratings. (d) The correlation between the self-prioritisation effects and valence ratings. In (c) and (d), data points from the same participant are drawn in the same colour; the lines represent the rmcorr fit (Bakdash & Marusich, 2017) for each participant.

less than 4.77% of the trials in each identity type. For the analyses of variance (ANOVAs), Greenhouse–Geisser corrections were applied if the sphericity assumption was violated. For all post hoc comparisons, the Bonferroni correction was applied. In addition, Bayesian factors were calculated for the effects of interest to this study, with JASP (JASP Team, 2018). A Bayesian factor analysis compares the predictive adequacy of two competing statistical models, H_1 or H_0. A Bayesian factor greater than 3 suggests moderate evidence for H_1, whereas a Bayesian factor lower than 1/3 suggests moderate evidence for H_0. A Bayesian factor over 10 suggests strong evidence for H_1 (Wagenmakers et al., 2018).

Results and discussion

The effectiveness of mood induction. Because subjective valence and arousal ratings vary greatly across individuals, repeated-measure ANOVAs were performed on normalised *Z*-scores. The raw rating scores are presented in Supplementary Material, and the overall pattern of results was the same as that reported here. The arousal and valence ratings following the four mood induction procedures are presented in the affective space, in which valence and arousal are represented along the horizontal and vertical axes, respectively (see Figure 2a).

For arousal ratings, the ANOVA revealed a significant main effect of mood induction (happiness, serenity, depression, and anxiety), $F(3, 69) = 16.01$, $p < .01$ (corrected), partial $\eta^2 = .41$, $BF_{10} > 10$. Post hoc comparisons revealed that arousal ratings following the happiness and anxiety induction procedures were higher than ratings following the depression and serenity induction procedures, all $t > 3.65$, all $p < .01$, all $BF_{10} > 10$. The arousal ratings following the happiness and anxious induction procedures were not significantly different, $t(23) = 0.577$, $p > .99$,

$BF_{10}=0.250$. The arousal ratings following the depression and serenity induction procedures were also not significantly different, $t(23)=0.619$, $p>.99$, $BF_{10}=0.255$.

For the valence ratings, the results also revealed a significant main effect of mood induction, $F(3, 69)=21.00$, $p<.01$ (corrected), partial $\eta^2=.48$, $BF_{10}>10$. Post hoc comparisons revealed higher valence ratings (more positive) following the happiness and serenity induction procedures than following the depression and anxiety induction procedures, all $t(23)>3.23$, all $p<.022$, all $BF_{10}>10$. The valence ratings following the happiness and serenity induction procedures did not differ, $t(23)=2.01$, $p_{=}.33$, $BF_{10}=1.19$; the valence ratings following the depression and anxiety induction procedures were not significantly different, $t(23)=0.78$, $p>.99$, $BF_{10}=0.283$. These results clearly show that mood induction procedures were effective (see Figure 2a).

Accuracy in the label–shape matching task. Response accuracy in the label–shape matching task was above 80% in all conditions (see Table S3 in Supplementary Material). An ANOVA was performed on the accuracy data, with variables identity (self vs. stranger vs. celebrity), valence (positive vs. negative), and arousal (low vs. high). The result revealed a significant main effect of identity, $F(2, 46)=20.57$, $p<.01$, partial $\eta^2=.47$, $BF_{10}>10$; participants were more accurate in responding to shapes associated with themselves, compared with shapes associated with a stranger or the celebrity, all $t>5.3$, all $p<.01$, all $BF_{10}>10$. The main effect of arousal also reached significance, $F(1, 23)=10.58$, $p<.01$, partial $\eta^2=.32$, $BF_{10}>10$, with higher accuracy observed in moods of high-arousal level. No other effect was significant, all $F<3.1$, all $p>.091$, all $BF_{10}<1.2$. Note that there was no two-way interaction between identity and valence, $BF_{10}=0.13$, or between identity and arousal, $BF_{10}=0.34$. These two-way interactions, if were observed in the RT analysis, are unlikely the results of speed–accuracy trade-offs.

RTs on matching trials. The mean RTs of all the experimental cells are presented in Table 1. As noted earlier, the self-prioritisation effect was estimated based on trials with correct label–shape pairings (e.g., Sui et al., 2013; Sui & Humphrey, 2012). An ANOVA on the correct RTs from those trials revealed a significant main effect for identity, $F(2, 46)=58.98$, $p<.01$, partial $\eta^2=.72$, $BF_{10}>10$, with shorter RTs to shapes associated with self than to those associated with stranger and celebrity, all $t>8.42$, $p<.01$, all $BF_{10}>10$. A significant main effect was also observed for arousal, $F(1, 23)=12.45$, $p<.01$, partial $\eta^2=.35$, $BF_{10}>10$, with longer RTs observed in moods with low arousal levels. The effect of valence did not reach significance, $F(1, 23)=1.13$, $p=.30$, partial $\eta^2=.05$, $BF_{10}=0.14$. A significant two-way interaction was observed between identity and arousal, $F(2, 46)=8.29$, $p<.01$, partial $\eta^2=.27$, $BF_{10}>10$. None of the other interactions was significant, all $F<1.69$, all $p>.19$, all $BF_{10}<0.11$.

Table 1. Mean RTs for each condition in Experiment 1.

	Serenity	Happiness	Depression	Anxiety
Match				
Celebrity	545 (41)	545 (62)	546 (42)	533 (49)
Stranger	553 (60)	531 (49)	563 (47)	546 (54)
Self	495 (58)	452 (53)	512 (64)	460 (57)
Mismatch				
Celebrity	594 (57)	524 (80)	593 (63)	575 (56)
Stranger	586 (66)	562 (64)	583 (58)	587 (57)
Self	602 (64)	547 (66)	621 (58)	580 (55)

RT: response time.
The numbers in the parentheses are *SDs*. Mismatching trials were grouped by the identities represented by the geometric shapes.

Following the data analysis protocol of previous studies (e.g., Ma & Han, 2010), an RT ratio was calculated to quantify the self-prioritisation effect in the label–shape matching task: (Celebrity − Self)/(Celebrity + Self). The RT ratios in the four mood induction conditions are presented in Figure 2b. A repeated-measures ANOVA on the RT ratios revealed a significant main effect for arousal, $F(1, 23)=17.79$, $p<.01$, partial $\eta^2=.44$, $BF_{10}>10$; the self-prioritisation effect was stronger in moods with high arousal levels. The effect of valence, $F(1, 23)=1.91$, $p=.18$, partial $\eta^2=.08$, $BF_{10}=0.621$, and the two-way interaction, $F<1$, $BF_{10}=0.476$, were not significant. To briefly summarise, arousal rather than valence modulated the self-prioritisation effect in Experiment 1.[1]

Arousal/valence ratings and the self-prioritisation effect. The RT analysis revealed that the self-prioritisation effect in the label–shape matching task was modulated primarily by arousal. We further examined whether the self-prioritisation effect correlates with the subjective valence and arousal ratings.

In the present experiment, the same group of participants was tested in four mood induction sessions. So, a simple regression/correlation analysis cannot be performed as it assumes independence of errors between observations. Instead, a repeated-measures correlation analysis was performed with the *rmcorr* package (Bakdash & Marusich, 2017) in R (R Core Team, 2013). This statistical technique allows estimation of the within-individual association for paired measures assessed on two or more occasions, and it generally has much higher statistical power because averaging over repeated measures is not needed. As shown in Figure 2c and d, a significant correlation was observed between the arousal ratings and the self-prioritisation effect, $rrm\ (71)=.24$, $p=.038$. However, the correlation between valence ratings and the self-prioritisation effect did not reach significance, $rrm\ (71)=.08$, $p=.512$.

Potential familiarity effects. Recent studies have suggested that the self-prioritisation effect in label–shape matching tasks may be a result of label familiarity, rather than self-association per se (e.g., Ivaz et al., 2016). Woźniak and Knoblich (2019) examined this issue by requiring participants to associate avatar faces with three identities (self, friend, and stranger) and replacing verbal labels (one's own name and names of friends and strangers) with unfamiliar symbols. The results revealed the usual pattern of self-prioritisation, showing that the self-prioritisation effect observed in label–shape matching tasks does not critically depend on the presence of familiar labels (or any familiar stimuli). The present study also addressed this potential familiarity confound. The participants were more familiar with the celebrity name than with the stranger names, so the RTs difference between celebrity and stranger on matching trials can be used to assess the impact of label familiarity. Same as in the analysis of the self-prioritisation effect, the RTs from celebrity and stranger trials were converted into an RT ratio: (Stranger − Celebrity)/(Stranger + Celebrity). The results revealed no effect of mood, all $F < 3.86$, all $p > .07$, all $BF_{10} < 0.98$, showing that label familiarity did not systematically vary across the four mood states induced in Experiment 1.[2]

Overall, the results of Experiment 1 clearly show that the self-prioritisation effect observed in label–shape matching tasks (e.g., Sui et al., 2013; Sui & Humphrey, 2012) is modulated primarily by arousal. However, mood induction may not be the most effective way of arousal manipulation as it may introduce changes in other emotional dimensions (e.g., Mikels et al., 2005). To further investigate the influence of arousal on the self-prioritisation effect, we conducted a second experiment with alerting cues leading to instantaneous modulation of arousal.

Experiment 2

Previous studies have shown that alerting cues can quickly raise the level of arousal (Sturm & Willmes, 2001; Weinbach & Henik, 2014). If the self-prioritisation effect is strongly modulated by arousal, the raise of arousal level with alerting cues should strengthen the self-prioritisation effect. Experiment 2 was carried out to verify this hypothesis and to provide additional support to the finding that arousal modulates the self-prioritisation effect. Because alerting cues can only raise the arousal level, a mood induction procedure was used to put the participants in a depressive mood, a mood with low arousal level.

Method

Participants. Based on the magnitude of the arousal effect on the self-prioritisation effect (RT ratios) observed in Experiment 1 ($dz = 0.86$), 26 participants were recruited for Experiment 2 (seven males; age range: 17–21 years; $M = 19$, $SD = 1.04$). All participants were right-handed and had normal or corrected to normal visual acuity. As in Experiment 1, all participants were screened with the SDS and SAS scales. One female who scored over 50 (out of 80) on the SDS scale was excluded from further testing.

Mood induction. Experiment 2 used the same mood induction procedure of Experiment 1 to elicit a depressive mood in the participants. As is clear from the results of Experiment 1, the level of arousal was the lowest following the depression induction procedure, which provides room for the raise of arousal level. Following mood induction, the arousal level was manipulated by the presence of an alerting cue (i.e., a 100 ms auditory "beep"). Such an alerting cue has been proven effective in raising the arousal level (e.g., Botta et al., 2014; Weinbach & Henik, 2014).

Label–shape matching task. As in Experiment 1, the label–shape matching task was used to assess the self-prioritisation effect. The materials and task procedure were the same as Experiment 1, except that only two geometric shapes (triangle vs. hexagon) were randomly assigned to two identity labels (self vs. celebrity). Stranger names were no longer used as Experiment 1 had ruled out a possible confound of familiarity.

In the label–shape matching task, all trials began with the presentation of a central fixation cross for 500 ms, followed by a blank screen of 200–250 ms. The alerting cue was presented during this blank screen period on half of the trials. Then, a label–shape pair was briefly presented for 100 ms, followed by a 1,000 ms blank screen during which the participants issued a response on the keyboard. Visual feedback was provided to the participants at the end of each trial. The response keys for matching and mismatching label–shape pairs were counterbalanced across participants. There were 50 trials in each of the four experimental cells in Experiment 2: 2 (identity: self vs. celebrity) × 2 (alerting cue: with vs. without). Each participant completed 20 practice trials and two blocks of 100 testing trials. Trials with and without alerting cues were randomly intermixed because the effect of alerting cues on arousal is transient (Coull et al., 2001), and blocking trials with alerting cues will introduce untoward effects (e.g., habituation).

The level of arousal was assessed in a similar task setup. The Self-Assessment Manikin scale was administered following 10 trials with alerting cues and 10 trials without alerting cues.

Data analysis. The arousal ratings were first examined to assess the effectiveness of the alerting cues. The self-prioritisation effect was quantified with the RTs from the matching trials. As in Experiment 1, RTs shorter than 200 ms and those that were 3 *SD*s above the mean for each participant were excluded from analyses. These trials accounted for less than 7% of the trials. Like Experiment 1, Bayesian

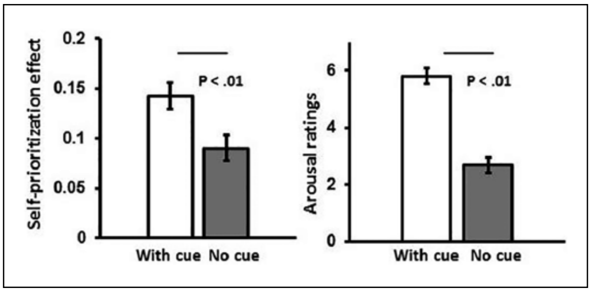

Figure 3. The self-prioritisation effect and arousal ratings as a function of alerting cues (with vs. without) in Experiment 2. Error bars represent standard errors of the mean.

factor analyses were performed in addition to null hypothesis tests.

Results and discussion

Alerting cues and arousal level. A paired *t*-test on the arousal ratings revealed that participants were more excited on trials with alerting cues compared with those without alerting cues, $t(24)=8.5$, $p<.01$, $dz=1.70$, $BF_{10}>10$, suggesting that alerting cues effectively raised the participant's arousal level (see Figure 3).

Accuracy in the label–shape matching task. Response accuracy was above 80.3% in all conditions (see Table S4 in Supplementary Material). An ANOVA on the accuracies revealed a significant main effect of identity, $F(1, 24)=37.14$, $p<.01$, partial $\eta^2=.61$, $BF_{10}>10$; higher accuracies were observed for the shapes associated with the self. The main effect of alerting cue, $F(1, 24)=2.95$, $p=.10$, $BF_{10}=0.859$, and the two-way interaction, $F(1, 24)=2.56$, $p=.12$, $BF_{10}=0.51$, were not significant, suggesting that an effect of alerting cue, if were observed in Experiment 2, is unlikely to involve any sort of speed–accuracy trade-off.

RTs on matching trials. An ANOVA on the RTs revealed a main effect for identity (self vs. celebrity), $F(1, 24)=92.03$, $p<.01$, partial $\eta^2=.79$, $BF_{10}>10$; shorter RTs were observed for the shapes associated with the self. The main effect of alerting cue (with vs. without) was not significant, $F<1$, $BF_{10}=0.20$. However, the two-way interaction was significant, $F(1, 24)=38.1$, $p<.01$, partial $\eta^2=.61$, $BF_{10}>10$, suggesting that the self-prioritisation effect was modulated by the alerting cue. As in Experiment 1, the self-prioritisation effect was quantified with an RT ratio (see Figure 3). The RT ratios did not follow the normal distribution, so a Wilcoxon test was performed. The test revealed that the self-prioritisation effect was stronger on trials with alerting cues compared with those without alerting cues, $Z=4.13$, $p<.01$, $BF_{10}>10$ (see Table 2).

Table 2. Mean RTs for each condition in Experiment 2.

	Match		Mismatch	
	Celebrity	Self	Celebrity	Self
With cue	641 (59)	481 (52)	602 (65)	620 (71)
No cue	610 (51)	510 (58)	604 (57)	635 (76)

The numbers in the parentheses are *SDs*. Mismatching trials were grouped by the identities represented by the geometric shapes.

Experiment 2 was carried out to examine whether arousal affects the self-prioritisation effect in a label–shape matching task. We first put the participants in a mood with a low level of arousal through a mood induction procedure, and then examined whether alerting cues would boost the self-prioritisation effect. The results showed that the self-prioritisation effect was stronger when the arousal level was elevated by alerting cues. Together with the findings of Experiment 1, it is clear that arousal modulates self-referential processing.

Experiment 3

The raise of arousal level would reduce reaction times; however, this should not undermine the findings of Experiment 2 as the self-prioritisation effect was quantified with an RT ratio. Nevertheless, it remains unclear whether the impact of arousal is specific to self-referential processing or it generally facilitates all sorts of cognitive processing in the label–shape matching task. Experiment 3 was carried out to examine whether the arousal level affects reward processing in a similar label–shape matching task. In Experiment 3, the geometric shapes were associated with different levels of reward to produce a reward-related effect (Sui et al., 2012).

Method

Participants. The effect of arousal observed in Experiment 2 was strong ($dz=1.34$). A power analysis showed that it requires seven participants to produce a similar effect (power$=0.8$, $\alpha=0.05$). For Experiment 3, we recruited 16 participants (six males; age range: 21–26 years; $M=23.81$, $SD=1.33$). They were all right-handed and had normal or corrected to normal visual acuity. All participants reported no symptoms of depression in the 3 months before testing.

Procedure. The mood induction procedure and the label–shape matching task were the same as in Experiment 2, except that the shapes were associated with two labels representing high ("￥5") and low reward ("￥1"), respectively. There were 48 trials in high- and low-reward association conditions. On half of the trials, the present label–shape parings conformed to the instructions. Same as Sui et al. (2012), participants gained extra rewards on some correct-response trials. The amount of reward varied according to the shapes present on those trials (i.e., higher rewards were for the shapes associated with "￥5").

Data analysis. Same as in previous studies (e.g., Sui et al., 2012), only RTs from correct label–shape matching trials were used to assess the effect of reward. RTs shorter than 200 ms, as well as those that were 3 *SD*s above the mean for each participant, were excluded from analyses (less than 2.22% of the trials). As in Experiments 1 and 2, null hypothesis testing and Bayesian factor analyses were performed on the data.

Results and discussion

Accuracy. Accuracy was above 80.5% in all conditions. A repeated-measures ANOVA, with variables reward association (high vs. low) and alerting cues (with vs. without), revealed no significant effect, all $F < 2.7$, all $p > .121$, all $BF_{10} < 1.26$.

RTs on matching trials. The RTs are presented in Table S5 in Supplementary Material. Analysis of the RTs revealed a main effect for reward association, $F(1, 15) = 4.63$, $p = .048$, partial $\eta 2 = .24$, $BF_{10} > 10$, with shorter RTs observed for the shapes pairing with the high-reward label. This observation was consistent with the results of Sui et al. (2012). The effect of alerting cues, $F(1, 15) < 1$, $BF_{10} = 0.23$, and the two-way interaction, $F(1, 15) < 1$, $BF_{10} = 0.27$, did not reach significance. These results clearly show that arousal level had little (or no) effect on reward processing in the label–shape matching task. It would be imprudent to conclude that arousal selectively modulates self-referential processing, but it is clear that arousal does not modulate all cognitive processes.

General discussion

Previous studies have shown that self-referential processing in label–shape matching tasks is modulated by mood (e.g., Sui et al., 2016). However, it remains unclear whether both valence and arousal or only one of these emotional dimensions modulates self-referential processing. This study was set out to clarify this issue with the label–shape matching task (as introduced by Sui et al., 2012). To assess the impact of valence and arousal, Experiment 1 measured a self-prioritisation effect in four moods that varied in arousal levels and valence. The results revealed a stronger self-prioritisation effect in moods with higher arousal levels; however, no noticeable impact was observed for valence (see Figure 2). Importantly, these observations were not confounded by familiarity. Experiment 2 further investigated the effect of arousal, a factor that was frequently overlooked in previous studies on self-referential processing. Experiment 2 first induced a mood of low arousal level (depression) and then presented alerting cues to raise the arousal level on half of the trials. The results revealed a stronger self-prioritisation effect on trials with alerting cues (see Figure 3). Finally, Experiment 3 provided additional evidence that the arousal may selectively modulate self-referential processing. These new empirical results clearly show that arousal plays a vital role in the interaction between emotion and self-referential processing.

The present results did not reveal any effect of valence on self-referential processing. As clearly shown in Figure 2b, the self-prioritisation effect in the label–shape matching task did not vary much along the valence dimension. The small BF_{10} values ($<1/3$) for the interaction between identity and valence (positive vs. negative) were in support of this observation. Moreover, the results presented in Figure 2d also revealed a non-significant (close to zero) correlation between the self-prioritisation effect and subjective valence ratings. These observations suggest that biases arising from self-referential processing and biases linked to positive emotion may involve different mechanisms (Stolte et al., 2016; Sui et al., 2016). The present failure to observe any valence effect on self-referential processing appears to contradict the results of some previous studies (e.g., Fan et al., 2016; Ma & Han, 2010, 2012). Here, we offer two possible explanations. First, some of those studies had used tasks that heavily depend on memory processes, such as autobiographical memory (e.g., Gutchess & Kensinger, 2018). The label–shape matching task used in this study, however, was largely a perceptual task. More critically, most previous studies have investigated the effect of valence by inducing negative moods, for instance, associating the self with negative personal traits (Guan et al., 2014; Ma & Han, 2010, 2012); The valence effect observed in those studies may have been confounded by a low level of arousal.

Previous studies have suggested that self-referential processing can be driven by factors other than positive valence, most notably, reward (Northoff & Hayes, 2011) and attentional salience (Humphreys & Sui, 2015). For instance, based on a series of experiments, Sui and colleagues showed that self-referential processing alters the perceptual priority of visual stimuli in a manner that mimics perceptual salience (Golubickis et al., 2017; Humphreys & Sui, 2015; Sui & Humphreys, 2015). It has also been demonstrated that the level of arousal modulates attention to salient stimuli (e.g., Weinbach & Henik, 2014). It is tempting to speculate that arousal may modulate the salience of self-referential stimuli, which in turn affects the various self-referential biases reported in the literature. The results of Experiment 2 are in line with this attention-based interpretation.

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ORCID iD

Haoyue Qian https://orcid.org/0000-0002-1793-6409

Open Practices

The data from the present experiment are publicly available at the Open Science Framework website: https://osf.io/bw27c/registrations

Supplementary Material

The Supplementary Material is available at: qjep.sagepub.com

Notes

1. The self-prioritisation effect was examined in four sessions spanning over a 2-month period in the present experiment. An ANOVA was performed on the RT ratios to examine whether the self-prioritisation effect varied over time. The results, however, revealed no effect involving session, all $F < 1$, all $BF_{10} < 0.7$.
2. For completeness, the results of an ANOVA on the RTs from mismatching trials are also presented in Supplementary Material.

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