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The effect of threatening facial expressions on inhibition-induced forgetting depends on their task-relevance

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ABSTRACT

Inhibition-induced forgetting refers to impaired memory for the stimuli to which responses were inhibited. The present study aimed to examine if it would be modulated by the processing of threatening facial expressions. Angry and neutral faces were presented in a go/no-go task and subsequent memory for faces was measured in a surprise recognition task. In Experiment 1, task-irrelevant angry and neutral faces appeared randomly, and participants responded to the gender of the faces during the go/no-go task. Results showed that the perception of neutral faces was possibly biased by angry faces. So, in Experiment 2, angry and neutral faces were given in separate blocks while participants still responded to the gender. Inhibition-induced forgetting was not modulated by facial expressions, as it was observed for both angry and neutral faces. Finally, in Experiment 3, where participants were assigned to respond to either angry or neutral faces, so that facial expressions were relevant, inhibition-induced forgetting was negated only in the group in whom responses to angry faces were inhibited. The findings suggest that task-relevance plays a key role in the way the processing of emotional information influences the interaction between cognitive control and memory encoding.

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Response inhibition indicates a process that suppresses irrelevant or inappropriate actions. The prototypical inhibition tasks are the go/no-go tasks and the stop-signal tasks where successful suppression of a response that is signalled by a certain stimulus input reflects the ability to inhibit prepotent responses (Logan & Cowan, 1984). To be able to successfully stop a response, response inhibition should interact with other cognitive functions, such as short-term or long-term memory (Verbruggen & Logan, 2008). Short-term memory is necessary to maintain task sets and determine whether or not to stop. Building long-term associations contributes importantly, as when the associations between certain stimuli and stopping behaviour become stronger after many repetitions in a go/no-go experiment, the processing of inhibition becomes automatic for those stimuli (Emeric et al., 2007). This automaticity frees up resources that response inhibition would otherwise have used, which implies active interactions between response inhibition and long-term memory.

How cognitive control functions including response inhibition interact with memory encoding has recently gained significant attention (Chiu & Egner, 2015; Krebs, Boehler, De Belder, & Egner, 2015; Richter & Yeung, 2012). The studies on their interactions adopted an experimental design where a conventional cognitive control task, such as a Stroop task, is given first, and then incidental memory for the stimuli presented during the cognitive control task is measured in a surprise recognition task (Krebs et al., 2015). Chiu and Egner (2015), likewise, instructed participants to perform a go/no-go or a stop-signal task before an unexpected memory task was given. Their findings showed that inhibiting responses to certain stimuli on no-go or stop trials resulted in memory impairment. This phenomenon is referred to as *inhibition-induced forgetting*. They explain that inhibiting responses consumes the

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resource that would otherwise be used for encoding, so memory for the stimuli that are withheld is subsequently impaired.

Competition for a finite resource was also demonstrated to occur between cognitive control and the processing of emotional stimuli, especially those that are threatening (Eysenck, Derakshan, Santos, & Calvo, 2007; Padmala, Bauer, & Pessoa, 2011). For example, the attentional control theory argues that anxiety in response to threatening distractors impairs attentional control in a way that deprives the processing resource of goal-relevant information (Eysenck et al., 2007). As a result, the resource that should be allocated to the processing of task-relevant information is diverted to the processing of task-irrelevant emotional information.

The term "resource" is widely used to account for uncertain mechanisms of the way in which two or more cognitive functions interact. It is often used to indicate something whose capacity is finite and so is competed for, such as attention. In Chiu and Egner (2015), the common resource that was competed for between response inhibition and perceptual encoding indicated the limited attentional resource. Similarly, the attentional control theory explains that what threatening distractors impair is successful allocation of the limited attentional resource to task-relevant information. Considering that the attentional resource was reported to be shared between cognitive control and memory encoding, and between cognitive control and emotional processing, a question can be raised on how presenting threatening stimuli during a go/no-go task would modulate inhibition-induced forgetting. Threatening information impairs the functioning of the executive control systems (Etkin, Prater, Hoeft, Menon, & Schatzberg, 2010; Eysenck et al., 2007; Padmala et al., 2011). So, presenting threatening stimuli as well as neutral ones would consume more resource to inhibit responses and thus would make inhibition-induced forgetting more evident for threatening stimuli. Alternatively, however, Gray (2004) suggested that emotional information can either have a facilitating or an impairing effect depending on the context, situation, or stages of information processing at which emotion exerts its influence. For example, the processing of negative emotion in the early perceptual stages is claimed to be involuntary or automatic (Eimer & Kiss, 2007; Mogg & Bradley, 1999). This early processing enhances sensory representations and thus leads to improvement in attention and memory (Vuilleumier, 2005). The impact of negative emotion on information processing at relatively later stages, such as response inhibition, on the other hand, depends on its intensity level (Pessoa, Padmala, Kenzer, & Bauer, 2012). Pessoa et al. showed that highly aversive or arousing stimuli, such as a painful shock, impaired response inhibition. However, emotional information of mild intensity, such as presenting a fearful face, simply enhanced sensory representations to the extent that behavioural performance was facilitated by it.

Thus, several predictions could be made about whether angry facial expressions, as representative of threatening stimuli, would modulate inhibition-induced forgetting or not based on the assumptions about on which stages of the cognitive processes angry expressions exert their influence: (a) early perceptual stages, (b) later response processing stages, or (c) the stage where perceptual encoding and response inhibition share a resource. The first possibility is that angry expressions would affect only the early perceptual stages. The early processing of negative emotional stimuli enhances sensory representations due to feedback signals from the amygdala (Vuilleumier, 2005). So, compared to when faces with only neutral expressions are shown, presenting angry faces in a go/no-go task would increase later memory in a recognition task. However, angry expressions would not have any influence on inhibition-induced forgetting, as their effect will not extend beyond the early stages. Thus, the first prediction is that angry expressions improve memory without affecting inhibition-induced forgetting.

The second possibility is that angry expressions would affect the later response processing stages but not the stage where perceptual encoding and response inhibition interact. If so, only the go/no-go performance would be affected but inhibition-induced forgetting would not. Pessoa et al. (2012) showed that presenting faces with fearful or happy expressions improved response inhibition. Likewise, showing angry faces in a go/no-go task would facilitate rather than impair response inhibition in that go/no-go performance would be enhanced with shorter response time (RT) or increased accuracy.

The final prediction is that angry expressions would affect the stage where the attentional resource is shared between perceptual encoding and response inhibition. They can either alleviate or encourage the consumption of the shared resource. In the case of alleviating, achieved either by enhanced sensory representations or by improved response inhibition, less of the resource would be used to encode faces or to inhibit responses. In this case, as processing angry faces is less resource-consuming, angry expressions would negate inhibition-induced forgetting. Alternatively, if angry expressions encourage consumption, as withholding responses to emotional faces is more difficult or resource-consuming, inhibition-induced forgetting would be more evident for angry faces.

The logic behind adopting ideas of the discrete information processing models in making predictions was to differentiate the effect of threatening information on the early perceptual encoding stages from that on the later response inhibiting stages. Theoretically, perceptual encoding and response inhibition are distinctive constructs. However, in actual neural representations, the processing of perceptual encoding and that of response inhibition may not necessarily take place in discrete stages. Rather, alternative models to discrete information processing models suggest more of a continuous processing (Miller, 1988). Still, the reason for discretely dividing the processing stages into a few was because previous studies reported contrasting effects of threatening information between on early sensory representations and on later response selection.

Experiment 1

To examine whether angry expressions modulate inhibition-induced forgetting depending on the stages of information processing at which emotion exercises its influence, incidental memory was measured after having participants perform a go/no-go task with half of the faces displaying angry and the other half displaying neutral expressions. Every face shown in Chiu and Egner's (2015) experiments displayed neutral expressions, and the authors instructed participants to respond to the gender of the faces in the go/no-go task. As in Chiu and Egner's experiments, participants were instructed to respond to the gender while half of the faces displayed angry expressions in Experiment 1. This made facial expression task-irrelevant information. Even when irrelevant to successfully performing a task, early perceptual processing of threatening stimuli takes place and influences task performance (Eimer & Kiss, 2007; Hung et al., 2010). Vuilleumier, Armony, Driver, and Dolan (2001) showed that the increased activation of the amygdala to fearful faces is not affected by spatial attention or their relevance to a task. This increased activation sends a feedback signal to the fusiform cortex, which consequently facilitates memory for faces with threatening expressions (Vuilleumier & Pourtois, 2007). Likewise, if facial expressions influence the stage where perceptual encoding and response inhibition interact even when task-irrelevant, inhibition-induced forgetting would be modulated by them. Specifically, if angry expressions facilitate cognitive functions so that less of the resource is consumed either to encode faces or to inhibit responses, inhibition-induced forgetting would be negated for angry faces but not for neutral faces. Alternatively, if angry expressions impede processing such that the resource is exhausted to inhibit responses for angry faces, inhibition-induced forgetting would be more evident for angry than for neutral faces.

Method

Participants

Forty college students (21 females, 19 males; $M = 22.35$ years; $SD = 2.23$) gave written informed consent to participate in this study. Power calculations were performed using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007). The target sample size was 30 to obtain a statistical power of .9 and a Type I error level of .05. We recruited 10 more in case of data exclusion.

Participants were all naïve to the purpose of the study and reported normal or corrected-to-normal visual acuity. Their participation was compensated with a monetary reward of 7,000 won (approximately 6.3 US dollars).

Apparatus

Participants were individually tested in a sound-attenuated, dimly lit experimental booth where they were unrestrainedly seated 60-cm away from a CRT monitor of $1,024 \times 768$ pixels and a 60 Hz refresh rate. Responses were recorded with a standard computer keyboard. The experiment was programmed with *MATLAB* (www.mathworks.com) and Psychtoolbox (Brainard, 1997; Pelli, 1997).

Stimuli

A set of 240 face images (120 females and 120 males) with none of them having the same identity was acquired from the Korea University Facial Expression Collection (KUFEC; Kim et al., 2017) and from personal collections. For each participant, 120 images (60 females and 60 males) were randomly selected and assigned to a stimulus set which served as the "old" stimuli. Participants performed a go/no-go task with this old stimulus set so that later, when an image from the set appeared in a recognition memory task, participants had to respond that they had seen the image before. The rest of the images that were not selected into the old stimulus set served as the "new" stimuli (which also consisted of 60 females and 60 males). Images from the new set did not appear in the go/no-go task but appeared in the recognition memory task, so participants had to report that they had not seen the images before.

Half of the old and new stimulus sets, respectively, displayed angry expressions while the remaining halves displayed neutral expressions. In sum, the set of 240 face images had equal numbers of female/male and angry/neutral expressions. All images were in grayscale with brightness adjusted by setting the mean luminance and target contrast.

30 indoor and 30 outdoor photos were used in a filler task which separated encoding from retrieval with a five-minute interval. The pictures were acquired from personal collections and from Aude Oliva's online database (http://cvcl.mit.edu/database.htm). They were also in grayscale with adjusted brightness.

Procedure

Participants first had 20 trials of a go/no-go task as a practice block. Half of the participants were randomly assigned to a group, which responded to female faces by pressing the "g" key but not responded to male faces. The rest of them were instructed to respond to male faces with the "g" key and to not respond to female faces. The actual gender go/no-go task was composed of four blocks of 120 trials. Each of the 120 images from the old stimulus set appeared only once in a block so that the number of exposures was kept constant at four repetitions for each face. This amount of repetition was suggested to be sufficient to induce stimulus-no-go associations (Chiu & Egner, 2015).

Each trial of the gender go/no-go task started with a white fixation circle in the middle of the screen presented for 300 ms, followed by a face image that was presented for 800 ms. Participants were required to respond within 1,000 ms from the face onset. Written feedback (correct, incorrect, or too late) followed and was given for 1,000 ms (see Figure 1). The task had 50% go and 50% no-go stimuli. While it is recommended to set a smaller proportion of no-go trials in order to have a dominant tendency to initiate motor activity (Wessel, 2018), as in Chiu and Egner (2015) we had equal proportions of go and no-go trials because the focus was on subsequent memory performance of the stimuli to which response was either inhibited or not, rather than on ensuring prepotent activation of motor control during a go/no-go task. This was possible as Chiu and Egner showed that inhibition-induced forgetting is replicated when also using a stop-signal task that produced 67% stop accuracy (two-up and one-down staircase).

After the gender go/no-go task, a filler go/no-go task of 40 trials was conducted to have a five-minute interval before a surprise recognition memory task started. Participants were randomly assigned to either respond to an indoor picture by pressing the "g" key and not respond to an outdoor picture or *vice versa*. The trial sequence was exactly the same as the gender go/no-go task.

The surprise recognition memory task followed the filler go/no-go task. The old stimulus set of 120 face images, formerly presented in the gender go/no-go task, and the new stimulus set, also composed of 120 face images, were presented in a random order. On each trial, one face image was presented until participants indicated whether the image was shown before or not. Participants were required to press the "v" key when they thought that the image shown was new and to press the "m" key when they thought that the image had appeared previously in the gender go/no-go task.

Results

Go/no-go performance

Repeated-measures ANOVA was separately conducted on the mean RT data of the go trials and the no-go commission error (CE) rates data with face emotion (angry or neutral) and number of exposure (1–4) as two within-subject variables. Trials that were incorrect, too late, or considered as outliers (above or below 2.5 SD) were excluded from the analyses (1.51% were excluded).

The main effect of face emotion was significant in the RT data with longer mean RT for angry faces ($M = 517$ ms, $SD = 33$) than for neutral faces ($M = 493$ ms, $SD = 34$), $F(1, 39) = 65.46$, $p < .0001$, $MSe = 712.41$, $\eta_p^2 = .63$ (see Figure 2A). Unlike Chiu and Egner's (2015) findings, performance did not improve with repeated exposure, as go RT did not monotonically decrease in later blocks, $F(3, 117) < 1$. The interaction of face emotion and number of exposure was not significant, $F(3, 117) = 1.10$, $p = .35$.

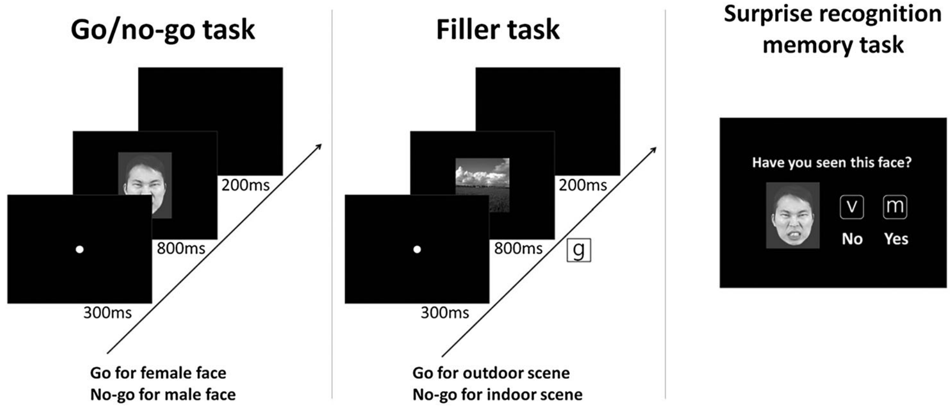

Figure 1. Example of trial sequences. Every participant performed in the following order where they started with a face gender go/no-go task and then a filler task, which was also a go/no-go task using scene pictures instead, followed. Participants of Experiment 3 performed a facial expression go/no-go task instead of a gender go/no-go task. The filler task separated the gender go/no-go task from a surprise recognition memory task with a five minute interval. Memory was tested with faces that were either shown during the gender go/no-go task or not.

Results of ANOVA on the CE rates data showed that the main effect of face emotion was significant with a higher error rate for faces with angry expressions (M = 6.75, SD = 3.70) than for faces with neutral expressions (M = 3.31, SD = 2.65), $F(1, 39) = 28.23$, $p < .0001$, MSe = 33.49, $\eta_p^2 = .42$ (see Figure 2B). No-go CE rates did not decrease with repeated exposure to the go/no-go cues, as the main effect of number of exposure was not significant, $F(3, 117) < 1$. The interaction of face emotion and number of exposure was also not significant, $F(3, 117) < 1$.

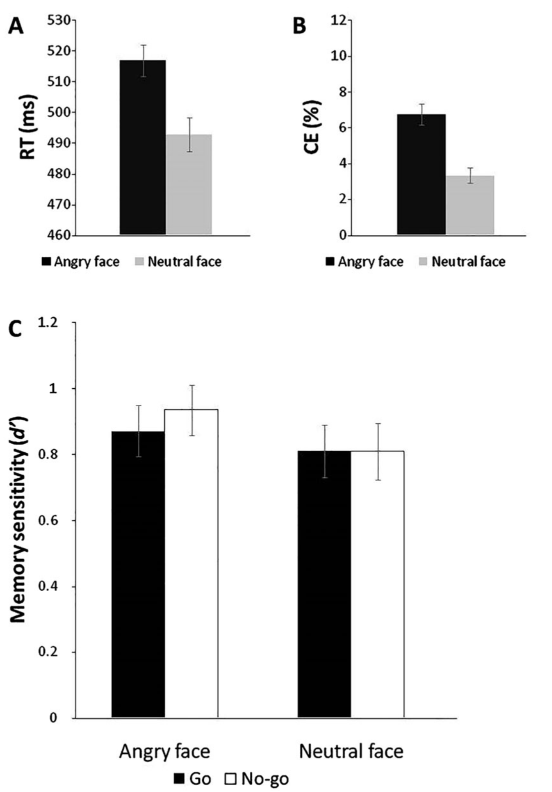

Figure 2. Results from Experiment 1. (A) Mean RT as a function of face emotion. (B) Mean CE rates as a function of face emotion. (C) Mean d-prime as a function of probe emotion and probe type. Error bars show standard error of the mean across participants.

Recognition memory

D-prime was calculated from the hit and false alarm rates of each participant as a function of probe type (go or no-go) and probe emotion (angry or neutral). Only faces from correctly performed go and no-go trials of the gender go/no-go task were included in the memory analyses (6.08% were excluded).

As in Chiu and Egner (2015), the overall hit rate was poor (M = .60, SD = .15), but the hit rates for go and no-go cues were greater than the false alarm rates for go, $t(79) = 16.61$, $p < .0001$, and no-go cues, $t(79) = 16.15$, $p < .0001$.

Repeated-measures ANOVA was conducted on the d-prime data with the above factors as within-subject variables. Unlike in Chiu and Egner (2015), the main effect of probe type was not significant, $F(1, 39) < 1$, and memory sensitivity was even slightly higher for no-go cues (M = .87, SD = .47) than for go cues (M = .84, SD = .43), indicating an absence of inhibition-induced forgetting. The main effect of probe emotion was marginally significant, as d-prime was higher for angry expressions (M = .90, SD = .40) than for neutral expressions (M = .81, SD = .41), $F(1, 39) = 3.82$, $p = .06$, $MSe = .09$, $\eta_p^2 = .09$. The interaction of probe type and probe emotion was not significant, $F(1, 39) < 1$ (see Figure 2C).

Discussion

The results of the RT data from the go/no-go task showed that participants were significantly slower in responding to angry than to neutral faces. In the CE rates data, participants also made more errors when angry faces were shown than when neutral faces were shown. In sum, unlike the previous prediction that the go/no-go performance would improve if angry expressions facilitate response inhibition at later response processing stages, presenting angry expressions impaired performance. Participants had more difficulty either determining the gender of a face or inhibiting responses when faces displayed angry rather than neutral expressions. This performance impairment for angry faces is inconsistent with Pessoa et al. (2012), in which fearful faces facilitated response inhibition. The inconsistency is possibly due to whether emotional information was relevant or not. In Experiment 1, facial expressions were irrelevant and thus would have interfered with the process of determining the gender of a face. Previous studies showed that task-irrelevant negative stimuli significantly impaired performance compared to neutral stimuli (Dolcos & McCarthy, 2006; Padmala et al., 2011). In Pessoa et al., however, fearful faces acted as cues to withhold responses when shown in a stop-signal task.

The results of the *d*-prime data of the recognition memory task showed no inhibition-induced forgetting. It was negated not just for either angry or neutral expressions but for both, which is inconsistent with any of the earlier predictions. Moreover, inconsistent with the prediction that memory sensitivity for angry faces would be significantly higher than for neutral faces when emotion affected the early perceptual stages, it was only marginally significant. One possibility which accounts for both these findings is that presenting angry and neutral expressions in a random order might have changed the perception of neutral expressions to the extent that they were not perceived as distinctively neutral. The discrete-category view suggests that each facial expression conveys a specific emotion and belongs to one discrete emotional category (Ekman, 1992). The dimensional view, in contrast, suggests that facial expressions convey emotion in a dimensional way and cannot be divided into distinctive categories (Russell, 1980). Consistent with the dimensional view, Aviezer et al. (2008) showed that the readout of emotion from faces was affected by context, indicating that negative or positive emotion can be inferred from faces with neutral expressions. Participants in Experiment 1, likewise, might have perceived neutral faces in a more threatening fashion when they were presented in a random order along with angry faces. Due to the lack of a clear division between the two expressions, memory performance differed only marginally for angry versus neutral faces, and inhibition-induced forgetting was negated for both. One probable account for why inhibition-induced forgetting was negated rather than evinced is that the enhanced sensory representations at the early perceptual stages could have extended to later stages. If this facilitating effect reached the stage where perceptual encoding and response inhibition share a common resource, inhibition-induced forgetting would be negated, as less of the resource is needed to encode faces under enhanced sensory representations.

Experiment 2

The aim of Experiment 2 was to clarify the effect of angry expressions on inhibition-induced forgetting by comparing the performance of angry faces with that of neutral faces which were not biasedly perceived. So, angry and neutral faces were dividedly presented in separate blocks. If the lack of inhibition-induced forgetting for both angry and neutral faces in Experiment 1 was due to a bias caused by angry expressions, it would take place for blocks where only neutral faces are shown. For the blocks where only angry faces are shown, in contrast, different predictions could be made. If the early perceptual processing that strengthens sensory representations and facilitates memory occurs only for angry faces, memory performance would significantly increase for angry faces. Moreover, this early processing of angry expressions may extend beyond the perceptual stages and influence inhibition-induced forgetting. If it affects in a way that facilitates encoding, angry expressions would negate inhibition-induced forgetting. Alternatively, if the processing at the interactive stage is somehow impaired, angry expressions would strengthen inhibition-induced forgetting. For the go/no-go performance, if angry expressions impair response inhibition as in Experiment 1, for they are irrelevant to the task, the go/no-go performance for angry faces would be worse than for neutral faces.

Method

Participants

Forty-eight new college students (29 females, 19 males; $M = 22.3$ years; $SD = 2.29$) were recruited from the same pool and gave informed consent to participate in Experiment 2.

Apparatus and stimuli

The same apparatus and images used in Experiment 1 were adopted in Experiment 2.

Procedure

The procedure and the design were the same as in Experiment 1 except that during the gender go/no-go task either all angry or all neutral faces were presented within a block. Thus, trials were divided into angry face blocks and neutral face blocks. As the old stimulus set was composed of 60 angry and 60 neutral face images, only 60 images were able to be shown in a block. Thus, the gender go/no-go task was composed of eight blocks of 60 trials where four blocks were the angry face blocks and the other four were the neutral face blocks. The order of the blocks was counterbalanced across participants, so one-half of the participants performed in the order of ANNAANNA where "A" stands for angry face blocks and "N" stands for neutral face blocks. The other half of the participants performed in the order of NAANNAAN.

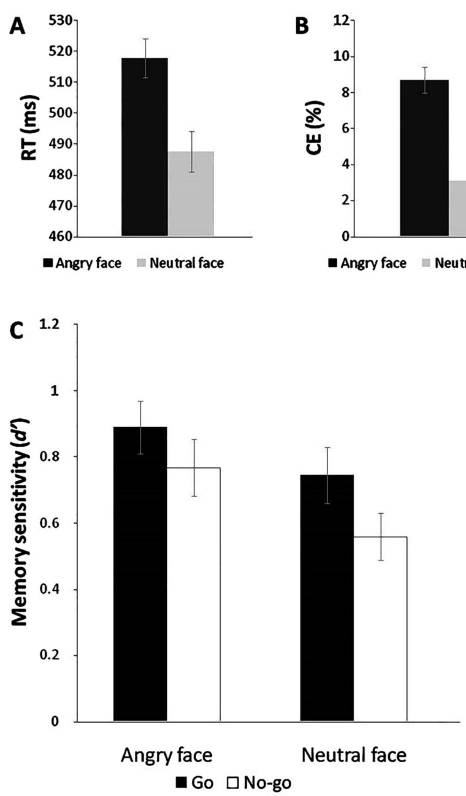

Figure 3. Results from Experiment 2. (A) Mean RT as a function of face emotion. (B) Mean CE rates as a function of face emotion. (C) Mean *d*-prime as a function of probe emotion and probe type. Error bars show standard error of the mean across participants.

Results

Go/no-go performance

Trials that were incorrect, too late, and outliers (above or below 2.5 SD) were excluded from the analyses (1.41%). Repeated measures ANOVA was conducted separately on the mean go RT data and the no-go CE rates data with face emotion (angry or neutral) and number of exposure (1–4) as within-subject variables. The main effect of face emotion was significant in the go RT data, $F(1, 47) = 121.39$, $p < .0001$, $MSe = 727.22$, $\eta_p^2 = .72$. Mean RT for angry faces ($M = 518$ ms, $SD = 43$) was significantly greater than that for neutral faces ($M = 487$ ms, $SD = 45$) (see Figure 3A). The main effect of number of exposure was not significant, $F(3, 141) = 1.35$, $p = .26$. The interaction between face emotion and number of exposure was also not significant, $F(3, 141) < 1$.

Results of the ANOVA on the CE rates data showed that face emotion was significant, $F(1, 47) = 62.62$, $p < .0001$, $MSe = 48.21$, $\eta_p^2 = .57$, as participants made significantly more errors for angry faces ($M = 8.66$, $SD = 5.00$) than for neutral faces ($M = 3.06$, $SD = 2.37$) (see Figure 3B). The main effect of number of exposure was not significant, $F(3, 141) < 1$. The interaction between face emotion and number of exposure was also not significant, $F(3, 141) = 2.07$, $p = .11$.

Recognition memory

D-prime was calculated from the hit and false alarm rates of each participant as a function of probe type (go or no-go) and probe emotion (angry or neutral) after eliminating incorrectly performed faces during the previous gender go/no-go task (6.46% were excluded). Repeated-measures ANOVA was conducted with the above factors as within-subject variables.

The main effect of probe type was significant, $F(1, 47) = 7.84$, $p = .007$, $MSe = .15$, $\eta_p^2 = .14$. *D*-prime for faces that were presented as go cues ($M = .81$, $SD = .47$) was significantly higher than that for faces that were presented as no-go cues ($M = .66$, $SD = .45$), resulting in an inhibition-induced forgetting. The main effect of probe emotion was also significant, as *d*-prime for angry faces ($M = .83$, $SD = .50$) was significantly higher than that for neutral faces ($M = .65$, $SD = .44$), $F(1, 47) = 8.19$, $p = .006$, $MSe = .18$, $\eta_p^2 = .15$. However, the interaction of probe type and probe emotion was not significant, $F(1, 47) < 1$ (see Figure 3C).

Discussion

As in Experiment 1, the RT data of the go/no-go task showed that participants were slower in determining the gender when faces displayed angry rather than neutral expressions. Also, the CE rates data showed that participants made more errors when faces were angry rather than neutral. Even when angry faces and neutral faces were shown in separate blocks, the overall performance of the go/no-go task was worse for angry than for neutral faces.

In contrast, the *d*-prime data of the recognition task were critically different from those of Experiment 1. Memory sensitivity was significantly higher for angry than for neutral faces. Inhibition-induced forgetting, on the other hand, was observed for both angry and neutral faces without displaying a significant difference. These findings are consistent with the prediction of when facial expressions affect only the early perceptual stages. Facial expressions not affecting the stage where perceptual encoding and response inhibition share a resource is possibly due to emotional information being irrelevant to the task. The enhanced sensory representations of emotional information at early stages are independent of its task-relevance, but further processing requires using the limited attentional resource as it filters out irrelevant information (Vuilleumier, 2005). Thus, the effect of facial expressions on the perceptual stages would not have extended beyond early stages.

Experiment 3

Inconsistent with the prediction that angry expressions would either alleviate or encourage the consumption of the shared resource, inhibition-induced forgetting was not modulated by facial expressions in the previous experiments. One possibility is because they were irrelevant to the task. So, in Experiment 3, rather than responding to the gender of the faces, participants were asked to respond to certain facial expressions so that emotion was relevant to the task. Participants were randomly assigned to two groups, one of which responding only to angry faces and the other responding only to neutral faces.

Presenting angry and neutral faces in a random order likely biased the perception of neutral faces in Experiment 1. However, in order to have participants respond to the facial expression of a face rather than to the gender, angry and neutral faces needed to be presented in a random order. Having participants respond to the facial expressions would make them focus on the differences between angry and neutral expressions. So, the perception of neutral faces would not be biased as in Experiment 1.

If relevance determines whether facial expressions influence the stage where the resource is shared between perceptual encoding and response inhibition, facial expressions were expected to modulate inhibition-induced forgetting when task-relevant. Because angry faces are only given either as go cues or no-go cues depending on which group participants are assigned to, predictions differ between groups. For the group which responds only to angry faces, inhibition-induced forgetting is expected. But as the enhanced sensory representations for angry expressions would facilitate memory for angry as opposed to neutral faces, memory sensitivity between go cued/angry faces and no-go cued/neutral faces is expected to differ even more. Thus, inhibition-induced forgetting would be more evident for this group. However, as a baseline condition is absent, this prediction is only theoretical without statistical support. For the group which responds only to neutral faces, on the other hand, angry faces are always inhibited. If angry expressions facilitate response inhibition when they are task-relevant (Pessoa et al., 2012), they are expected to alleviate the consumption of the shared resource with go/no-go performance being improved. The enhanced sensory representations at early stages that facilitate memory for angry faces can also alleviate the consumption. Thus, either by facilitation in response inhibition or memory encoding, inhibition-induced forgetting would be negated for this group.

Method

Participants

Forty (29 females, 11 males; *M* = 22.93 years; *SD* = 2.96) new college students from the same pool participated in Experiment 3. With using G*Power, the target sample size was 38 to obtain a statistical power of .85 and a Type I error level of .05.

Apparatus and stimuli

The apparatus and the images of faces and scenes were the same as in Experiment 1.

Procedure

The procedure and the design were the same as in Experiment 1 except that participants were instructed to respond to the emotional expression of a face. Thus, half of the participants were required to respond to angry faces by pressing the "g" key but to withhold response to neutral faces (the angry go group), while the other half were required to respond to neutral faces but not to angry faces (the neutral go group). Two genders were presented in a random order while they were irrelevant to the task.

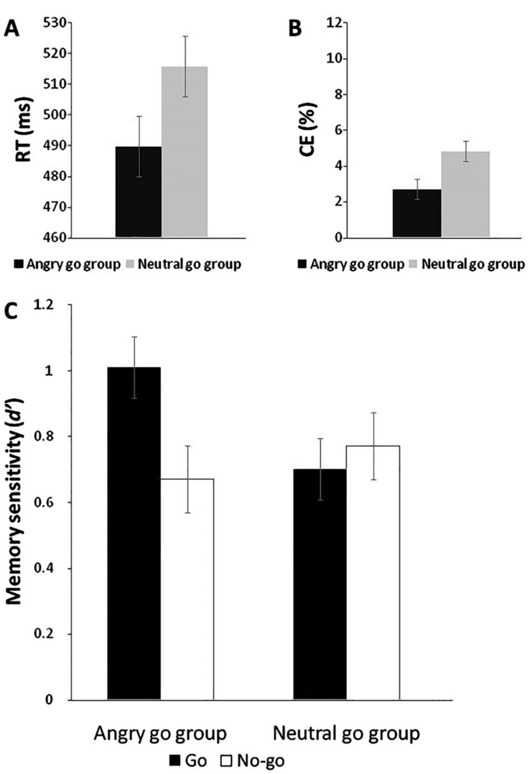

Figure 4. Results from Experiment 3. (A) Mean RT as a function of face emotion. (B) Mean CE rates as a function of face emotion. (C) Mean *d*-prime as a function of probe emotion and probe type. Error bars show standard error of the mean across participants.

Results

Go/no-go performance

Incorrect, too late, and outlier (above or below 2.5 SD) trials were excluded from the analyses (1.53%). Mixed ANOVA was conducted on the mean go RT data and the no-go CE rates data separately with number of exposure (1–4) as a within-subject variable and group type (angry go or neutral go group) as a between-subjects variable. In the go RT data, the main effect of group type was marginally significant, $F(1, 38) = 3.54$, $p = .07$, $MSe = 7705.41$, $\eta_p^2 = .09$, as mean RT of the neutral go group ($M = 516$ ms, $SD = 42$) was greater than that of the angry go group ($M = 490$ ms, $SD = 45$) (see Figure 4A). The main effect of number of exposure was not significant, $F(3, 141) = 1.81$, $p = .15$. The interaction between group type and number of exposure was not significant, $F(3, 141) < 1$.

In the no-go CE rates data, the main effect of group type was significant, $F(1, 38) = 7.25$, $p = .01$, $MSe = 24.93$, $\eta_p^2 = .16$, as CE rate was higher for the neutral go group ($M = 4.81$, $SD = 3.08$) than for the angry go group ($M = 2.69$, $SD = 1.72$) (see Figure 4B). The other main effect and interaction were not significant, $F < 1.53$, $p > .21$.

Recognition memory

Mixed ANOVA was conducted on the *d*-prime data with probe type (go or no-go) as a within-subject variable and group type (angry go or neutral go group) as a between-subjects variable after eliminating incorrectly performed faces during the go/no-go task (5.39%). The results showed that the main effect of probe type was significant, $F(1, 38) = 4.95$, $p = .03$, $MSe = .08$, $\eta_p^2 = .12$, as *d*-prime was significantly higher for go cued stimuli ($M = .86$, $SD = .44$) than for no-go cued stimuli ($M = .72$, $SD = .45$). Most critically, the interaction between probe type and group type was significant, $F(1, 38) = 11.05$, $p = .002$, $MSe = .08$, $\eta_p^2 = .23$. Further analyses showed that this was because only in the angry go group, memory sensitivity for go cued stimuli ($M = 1.01$, $SD = .41$) was significantly higher than that for no-go cued stimuli ($M = .67$, $SD = .41$), $t(19) = 3.51$, $p = .002$. In the neutral go group, in contrast, memory sensitivity did not differ significantly between go cued stimuli ($M = .70$, *SD* = .43) and no-go cued stimuli ($M = .77$, $SD = .50$), $t(19) = -.9$, $p = .38$ (see Figure 4C).

The main effect of group type was not significant, $F(1, 38) < 1$.

Discussion

The RT data of the go/no-go task showed that responses were marginally slower in the neutral go group than in the angry go group, indicating that the mean RT was shorter for angry than for neutral faces. The CE rates data showed that the neutral go group, which inhibited responses to angry faces, made more errors than the angry go group, which inhibited responses to neutral faces. These findings suggest that angry expressions facilitated go performance, while impaired inhibitory performance. This is in clear contrast with the results of Experiments 1 and 2, where angry expressions were task-irrelevant. In these experiments, the effect of angry expressions was solely impairing on performance, as it was found to be in previous studies (Dolcos & McCarthy, 2006; Padmala et al., 2011).

Interestingly, the *d*-prime data showed different patterns between the neutral go group and the angry go group; only in the angry go group was inhibition-induced forgetting observed. For the angry go group, because angry faces appeared solely as go cued faces, angry faces were never suppressed. Thus, angry expressions needed not to be processed further at the response inhibiting stages. In contrast, for the neutral go group, angry faces were always suppressed. When angry expressions needed to be processed at the response inhibiting stages, inhibition-induced forgetting was not observed. Consistent with the previous prediction that if angry expressions facilitate either perceptual encoding or response inhibition they would alleviate the consumption of the shared resource, the results of the neutral go group showed that only when emotion was relevant to the task was its effect extended beyond the early perceptual stages in a way that alleviated the consumption of the shared resource and, therefore, negated inhibition-induced forgetting. The go/no-go performance of the neutral go group showed that angry expressions were impairing to inhibitory control. Thus, it is more likely that inhibition-induced forgetting was negated in the neutral go group due to enhanced sensory representations of the angry expressions.

While the performance for no-go cued/neutral faces of the angry go group was similar to that for no-go cued/angry faces of the neutral go group, memory sensitivity for go cued/angry faces of the angry go group was higher than that for go cued/neutral faces of the neutral go group, which could have resulted from enhanced attention towards angry go trials relative to neutral go trials. If this is the case, as angry expressions only facilitated memory for go cued/angry faces, it is hard to say that angry expressions negated inhibition-induced forgetting with no-go cued/angry faces. However, the two groups had different tasks. Angry faces were always inhibited in the neutral go group, while they always initiated motor activity in the angry go group. So, comparing performance across groups should take a more cautious approach. Moreover, if angry expressions facilitated go cued faces, they would also have facilitated no-go cued faces, as Experiment 2 showed that memory sensitivity was significantly higher for angry no-go cued faces than that for neutral no-go cued faces.

General discussion

The aim of this study was to examine how threatening facial expressions would affect inhibition-induced forgetting. The results of Experiment 1 where faces with task-irrelevant angry and neutral expressions appeared randomly showed that memory sensitivity did not differ significantly between angry and neutral faces, with inhibition-induced forgetting being negated for both. It was likely that the perception of neutral expressions was biased by angry expressions, as angry and neutral faces were presented randomly and were task-irrelevant. So, in Experiment 2, angry and neutral faces were shown in separate blocks while facial expressions were still irrelevant to the task. The results showed that the overall memory performance was better for angry than for neutral faces, but inhibition-induced forgetting was not modulated by facial expressions. These findings implied that facial expressions enhanced sensory representations in early perceptual stages, but the stage where a shared resource exists was not affected as task-irrelevant information is filtered out at later stages of processing. So, to examine if the relevance of facial expressions determines whether they affect inhibition-induced forgetting or not, instead of having participants respond to gender, they were asked to respond to facial expressions in Experiment 3. When facial expressions became relevant, only in the neutral go group, where angry faces were given as no-go cues to be inhibited, was inhibition-induced forgetting negated. This lack of inhibition-induced forgetting implied that angry expressions alleviated the consumption of the shared resource by facilitating either response inhibition or perceptual encoding. Because response inhibition was impaired by angry expressions in the neutral go group, it is likely that the enhanced sensory representations facilitated memory encoding.

Implications of being affected by task-relevance

The enhanced sensory representations for angry faces facilitated memory regardless of whether facial expressions were relevant or irrelevant in Experiments 2 and 3. However, facial expressions affected inhibition-induced forgetting only when they were relevant. Moreover, the go/no-go performance was impaired by angry expressions when they were task-irrelevant, but not when task-relevant. At least some of the effects of angry expressions were determined by their relevance to the task. Previous research on the effect of emotional information on performance showed that relevance determines whether the impact would be impairing or facilitating (Lindström & Bohlin, 2011; Pessoa, 2009; Vuilleumier, 2005). For instance, emotion-induced blindness indicates the failure to perceive a probe in a rapid serial visual presentation when it is preceded by a task-irrelevant emotional distractor (Arnell, Killman, & Fijavz, 2004). This performance decrement results from the deprivation of processing resource by emotional distractors. In contrast, when an emotional stimulus is a target, it is less susceptible to temporary suppression that results in an attentional blink than a neutral target (Anderson & Phelps, 2001). The results of the go/no-go performance of the present research were consistent with these findings in that when facial expressions were irrelevant in Experiments 1 and 2, RT and CE increased for angry faces. However, in Experiment 3 where facial expressions became relevant, the angry go group was faster in RT than the neutral go group.

The results of the memory recognition task, on the other hand, had two main findings. One was that memory was better for angry than for neutral faces, and the other was that inhibition-induced forgetting was affected by emotion only when it was task-relevant. These two findings differentiate potential factors that affect emotional memory. Vuilleumier and Pourtois (2007) suggested that the activation at the fusiform cortex is enhanced for emotional faces due to direct feedback signal from the amygdala. Consistently, the first finding showed that sensory representations or attention, being modulated by the affective significance of the stimuli, was enhanced for angry faces and subsequently facilitated memory. The early bias of attention towards negative stimuli has often been reported (Eimer & Kiss, 2007; Mogg & Bradley, 1999), and studies showed that this bias facilitates memory (Lee & Cho, 2019). The second finding, on the other hand, suggests that the relevance to a task can also modulate emotional memory. Smith, Stephan, Rugg, and Dolan (2006) showed that when emotional information being retrieved was relevant to current behaviour, the connectivity enhanced between amygdala and hippocampus where the interaction is known to be associated with encoding emotional information. Relating to Smith et al.'s finding, inhibition-induced forgetting was modulated by task-relevance, possibly because only when emotional information was relevant the enhanced sensory representations, driven by signals from the amygdala (Vuilleumier & Pourtois, 2007), affected the stage where response inhibition and memory encoding interact in a way that the connectivity between amygdala and hippocampus was strengthened to alleviate the consumption of the shared resource.

It was suggested that inhibition-induced forgetting was not modulated by facial expressions in Experiment 2, as they were irrelevant. However, they were irrelevant in Experiment 1 as well while inhibition-induced forgetting was negated for both angry and neutral faces. If relevance determines whether or not inhibition-induced forgetting is modulated, similar results should have been observed in Experiments 1 and 2. One probable account of why the perceptual bias, having been created possibly by randomly presented angry expressions, negated inhibition-induced forgetting is that when task-irrelevant dimension varies, it interferes with task-relevant information (Garner, 1974). While facial expressions were task-irrelevant in Experiment 1, they varied randomly, so their effect would have interfered and affected task performance more than it did in Experiment 2.

Influence being different across information processing stages

The current findings further suggest that the impact of the task-relevance of emotional information differed across information processing stages. Its influence on the later response processing stages was consistent with the previous studies in that the go/no-go performance was impaired by angry faces when task-irrelevant (Dolcos & McCarthy, 2006; Padmala et al., 2011). Its impact on the early perceptual stages, however, was consistently facilitating with the enhanced sensory representations increasing memory sensitivity for angry faces regardless of whether they were relevant or not (Vuilleumier, 2005). Most interestingly, its influence on the stage where perceptual encoding and response inhibition share a common resource was observable only when task-relevant. The facilitating effect from early stages did not proceed further when facial expressions were task-irrelevant, so inhibition-induced forgetting was not affected by them in Experiment 2.

Conclusion

This study shows that when interactions take place between two or more cognitive functions the effects of threatening facial expressions differ across information processing stages and can be modulated by factors such as task-relevance. Task-relevance has been shown to determine whether emotional information is facilitating or impairing on task performance, and our study extends this finding by showing that emotional information modulated the interaction between cognitive control and memory encoding only when it was task-relevant.

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Data availability statement

The data that support the findings of this study are openly available at https://osf.io/u6bmn/?view_only=7b8e4e155be34f1cabd20653743b80d4

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References

Anderson, A. K., & Phelps, E. A. (2001). Lesions of the human amygdala impair enhanced perception of emotionally salient events. *Nature*, *411*(6835), 305–309.

Arnell, K. M., Killman, K., & Fijavz, D. (2004). Blinded by emotions: Target misses follow attentional capture by arousing distractors in RSVP. *Journal of Vision*, *4*(8), 359–359.

Aviezer, H., Hassin, R. R., Ryan, J., Grady, C., Susskind, J., Anderson, A., … Bentin, S. (2008). Angry, disgusted, or afraid? Studies on the malleability of emotion perception. *Psychological Science*, *19*(7), 724–732.

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, *10*(4), 433–436.

Chiu, Y. C., & Egner, T. (2015). Inhibition-induced forgetting: When more control leads to less memory. *Psychological Science*, *26*(1), 27–38.

Dolcos, F., & McCarthy, G. (2006). Brain systems mediating cognitive interference by emotional distraction. *Journal of Neuroscience*, *26*(7), 2072–2079.

Eimer, M., & Kiss, M. (2007). Attentional capture by task-irrelevant fearful faces is revealed by the N2pc component. *Biological Psychology*, *74*(1), 108–112.

Ekman, P. (1992). An argument for basic emotions. *Cognition and Emotion*, *6*(3-4), 169–200.

Emeric, E. E., Brown, J. W., Boucher, L., Carpenter, R. H. S., Hanes, D. P., Harris, R., … Schall, J. D. (2007). Influence of history on saccade countermanding performance in humans and macaque monkeys. *Vision Research*, *47*(1), 35–49.

Etkin, A., Prater, K. E., Hoeft, F., Menon, V., & Schatzberg, A. F. (2010). Failure of anterior cingulate activation and connectivity with the amygdala during implicit regulation of emotional processing in generalized anxiety disorder. *American Journal of Psychiatry*, *167*(5), 545–554.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*(2), 336–353.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191.

Garner, W. R. (1974). *The processing of information and structure*. Oxford: Lawrence Erlbaum.

Gray, J. R. (2004). Integration of emotion and cognitive control. *Current Directions in Psychological Science*, *13*(2), 46–48.

Hung, Y., Smith, M. L., Bayle, D. J., Mills, T., Cheyne, D., & Taylor, M. J. (2010). Unattended emotional faces elicit early lateralized amygdala–frontal and fusiform activations. *Neuroimage*, *50*(2), 727–733.

Kim, S., Kwon, Y., Jung, S., Kim, M., Cho, Y. S., Kim, H., … Choi, J. (2017). Development of the Korean facial emotion stimuli: Korea university facial expression collection 2nd edition. *Frontiers in Psychology*, *8*, 769.

Krebs, R. M., Boehler, C. N., De Belder, M., & Egner, T. (2015). Neural conflict–control mechanisms improve memory for target stimuli. *Cerebral Cortex*, *25*(3), 833–843.

Lee, H. J., & Cho, Y. S. (2019). Memory facilitation for emotional faces: Visual working memory trade-offs resulting from attentional preference for emotional facial expressions. *Memory & Cognition*, doi:10.3758/s13421-019-00930-8

Lindström, B. R., & Bohlin, G. (2011). Emotion processing facilitates working memory performance. *Cognition and Emotion*, *25*(7), 1196–1204.

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review*, *91*(3), 295–327.

Miller, J. (1988). Discrete and continuous models of human information processing: Theoretical distinctions and empirical results. *Acta Psychologica*, *67*(3), 191–257.

Mogg, K., & Bradley, B. P. (1999). Orienting of attention to threatening facial expressions presented under conditions of restricted awareness. *Cognition & Emotion*, *13*(6), 713–740.

Padmala, S., Bauer, A., & Pessoa, L. (2011). Negative emotion impairs conflict-driven executive control. *Frontiers in Psychology*, *2*, 192.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, *10*(4), 437–442.

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences*, *13*(4), 160–166.

Pessoa, L., Padmala, S., Kenzer, A., & Bauer, A. (2012). Interactions between cognition and emotion during response inhibition. *Emotion*, *12*(1), 192–197.

Richter, F. R., & Yeung, N. (2012). Memory and cognitive control in task switching. *Psychological Science*, *23*(10), 1256–1263.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*, *39*(6), 1161–1178.

Smith, A. P., Stephan, K. E., Rugg, M. D., & Dolan, R. J. (2006). Task and content modulate amygdala-hippocampal connectivity in emotional retrieval. *Neuron*, *49*(4), 631–638.

Verbruggen, F., & Logan, G. D. (2008). Response inhibition in the stop-signal paradigm. *Trends in Cognitive Sciences*, *12*(11), 418–424.

Vuilleumier, P. (2005). How brains beware: Neural mechanisms of emotional attention. *Trends in Cognitive Sciences*, *9*(12), 585–594.

Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2001). Effects of attention and emotion on face processing in the human brain: An event-related fMRI study. *Neuron*, *30*(3), 829–841.

Vuilleumier, P., & Pourtois, G. (2007). Distributed and interactive brain mechanisms during emotion face perception: Evidence from functional neuroimaging. *Neuropsychologia*, *45*(1), 174–194.

Wessel, J. R. (2018). Prepotent motor activity and inhibitory control demands in different variants of the go/no-go paradigm. *Psychophysiology*, *55*(3), e12871.