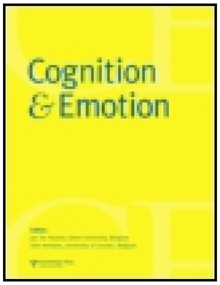

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Do emotional stimuli interfere with two distinct components of inhibition?

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BRIEF REPORT

Do emotional stimuli interfere with two distinct components of inhibition?

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Emotions have recently been shown to interfere with the efficacy of inhibitory control. However, understanding their impact requires taking into account that inhibition is not a unitary construct, but consists of distinct functions underlain by specific mechanisms. In this study, 88 participants performed two emotional versions of classic laboratory tasks designed to assess (1) the ability to inhibit a prepotent response (a stop-signal task using faces with different emotional expressions) and (2) the capacity to resist the effect of proactive interference (PI; a recent negative task that included emotional words). Overall results showed that emotional stimuli interfered with inhibition capacities in both tasks. Although tending in the same direction, these results suggest that different underlying mechanisms (e.g., top-down vs. bottom-up processes) or consecutive differences in emotional processing (e.g., different interactions with stimulus/task properties, processing stages or motivational aspects) are at play in these two inhibition-related functions.

Keywords: Executive functions; Prepotent response inhibition; Proactive interference; Emotion.

Emotional experiences are now acknowledged to interfere with the effectiveness of inhibitory control, emotional stimuli capturing attention automatically, interrupting ongoing activities and leaving fewer resources available for effortful control (Schimmack, 2005).

Understanding the impact of emotions on inhibitory control, however, requires taking into

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account that inhibition is not a unitary construct. Indeed, Friedman and Miyake (2004) have demonstrated by using latent variable analyses that prepotent response inhibition (i.e., the ability to deliberately control or suppress an automatic response) is unrelated to resistance to proactive interference (PI; i.e., the ability to resist the intrusion into memory of information that was previously relevant but has since become irrelevant). One possible explanation given by Friedman and Miyake on this separability is that prepotent response inhibition requires effortful control (i.e., the active maintenance of a task's goal), whereas resistance to PI is more automatically driven (the source of interference residing in memory and not interfering with the maintenance of the task's goal). In this context, it is therefore necessary to examine whether emotional experiences interfere with the effectiveness of these different components of inhibition in the same way.

On the one hand, a growing corpus of data supports the concept that emotions impair the ability to inhibit prepotent responses. First, Schulz et al. (2007), using two comparable emotional and non-emotional go/no-go tasks, showed that inhibiting a prepotent response was more difficult in the emotional than in the non-emotional task. Second, Verbruggen and De Houwer (2007) used a stop-signal task (SST) in which emotional stimuli preceded neutral targets. Results showed that both responding to neutral targets and stopping the response were impaired by the previous presentation of high arousal emotional stimuli. This interference effect has been linked to the attentional account that emotional stimuli attract attention away from the task, leaving fewer resources available for its correct application (Schimmack, 2005; Verbruggen & De Houwer, 2007). Finally, by using a different SST than those developed by Verbruggen and De Houwer, Herbert and Sütterlin (2011) also showed that emotional stimuli interfered with prepotent response inhibition. Indeed, they used an SST in which emotional words were the target of response inhibition. This SST thus measured the response inhibition of emotional targets, whereas Verbruggen and De Houwer's SST measured the response inhibition of neutral targets preceded by emotional stimuli.

On the other hand, emotional stimuli have been shown to improve the capacity to resist the effect of PI. Levens and Phelps (2008) used a recent negative task (RNT) that included emotional words, in which previously learned information interfered with new learning. In this paradigm, participants were given a list of three words followed by a probe word and had to determine whether the probe word was included in the list (yes-response) or not (no-response). In no-response trials, the probe word could either match an item from the preceding two lists [recent no-response (RecNR) trials] or no item of any list [non-recent no-response (NRecNR) trials]. All trials were grouped into an emotional condition containing both neutral and emotional words (i.e., three neutral and emotional words followed by either an emotional or a neutral probe) or into a neutral condition containing only neutral words. When RecNR trials (interference condition) and NRecNR trials (non-interference condition) were compared, poorer performances were observed in the interference condition. This suggested that the previously yet-no-longer relevant information interfered with the processing of the currently relevant information (i.e., PI) and that time was needed to resolve this conflict between relevant and irrelevant working memory representations (i.e., interference resolution). However, when emotional and neutral conditions were compared, interference was observed to decrease in emotional probe trials. According to Levens and Phelps, a correct response in the interference condition required to resolve a conflict between the source recognition signal of this response ("no") and the familiarity signal of the incorrect response ("yes"). A decrease in interference therefore implied an increase in source signal strength or a decrease in familiarity signal strength. Thus, two hypotheses have been put forward to explain the facilitating effect of emotional stimuli on interference resolution: The first suggests a decrease in the familiarity signal strength of the previously yet-no-longer relevant information by special mechanisms for interference resolution with emotional stimuli; and the second suggests an increase in the source signal strength of the currently relevant information by enhanced encoding of emotional source memory.

According to the literature, emotional experiences seem, therefore, to either impair or facilitate inhibition, depending on which inhibition-related function is examined. These opposite effects could be in line with the implication that different mechanisms occur in prepotent response inhibition and in resistance to PI, as suggested by Friedman and Miyake (2004). In this context, the main objective of this study was to examine the influence of emotional stimuli on both prepotent response inhibition and resistance to PI.

More specifically, our first objective was to replicate the established interference effect of emotions on prepotent response inhibition by using an SST that measured the response inhibition of emotional stimuli with facial expressions as stimuli. Indeed, a distinction must be made between an SST in which emotional stimuli precede the inhibition of neutral targets (see Verbruggen & De Houwer, 2007) and an SST in which emotional stimuli are the target of response inhibition themselves (see Herbert & Sütterlin, 2011), these two types of SST potentially involving distinct processing stages. Moreover, an interference effect of emotions on the prepotent response inhibition of emotional stimuli themselves was provided by using words as stimuli (Herbert & Sütterlin, 2011). This effect should not be restricted to verbal stimuli, however, but should also occur when pictorial stimuli are used. Thus, we used an SST that included faces with different emotional expressions as the target of response inhibition.

Our second objective was to explore the impact of emotional stimuli on resistance to PI with a paradigm that differed from that of Levens and Phelps (2008) in terms of (1) distinctiveness (i.e., the degree to which a word stands out relative to other words in a list), (2) time of stimuli presentation and (3) number of stimuli. Indeed, resistance to PI would be relatively automatically driven (Friedman & Miyake, 2004) and thus dependent on bottom-up processes influenced by the environment. Such an inhibitory mechanism would thus be particularly sensitive to properties of the paradigm. The presentation of emotional stimuli in mixed lists, as is the case in Levens and Phelps' paradigm, has been shown to be more distinctive and produce better recall by linking separate events together (Talmi, Luk, McGarry, & Moscovitch, 2007). Therefore, changes at that level (i.e., in the way emotional stimuli stand out from their surroundings) would reasonably lead to differences in the way PI is resolved for emotional stimuli. Moreover, Levens and Phelps suggested that the reduction in PI for emotional stimuli was possibly due to a decrease in the familiarity signal and an increase in source recognition. However, shortening the time of stimuli presentation could lead to a decrease in source recognition (through diminished encoding of source memory); moreover, reducing the number of stimuli (which are therefore repeated more frequently) could improve the familiarity signal.

Thus, we used an RNT that included emotional target sets of three sequential words with the same valence, in which the time of stimuli presentation was quicker and the number of stimuli fewer than those used in the paradigm of Levens and Phelps (2008).

METHOD

Participants and procedure

Participants comprised 88 volunteers from the community (55 females and 30 males; three missing values) who received no compensation for their participation and were recruited through advertisement and personal contacts. The mean age of the sample was 22.78 years (SD = 2.35, range = 18–30) and the mean number of years of education was 14.70 (SD = 1.86, range = 9–20). The inclusion criterion was being a fluent speaker of French. Exclusion criteria were a reported history of neurological or psychiatric disorders. Participants were individually tested in a quiet room. They signed an informed consent form before completing tasks for which the order was counterbalanced. This study was approved by the Ethics Committee of the University of Geneva.

Laboratory tasks

Emotional SST

This task was used to assess the interference effect of emotions on prepotent response inhibition of emotional stimuli themselves adapted from Billieux, Gay, Rochat, & Van der Linden (2010). Stimuli consisted of pictures of human faces with neutral, joy or angry expressions selected from the Karolinska Directed Expressional Faces set (Lundqvist, Flykt, & Öhman, 1998). Each face was shown for a maximum duration of 2000 ms (the face disappearing once the participant answered) and was preceded by a fixation cross displayed for 500 ms. The task had two distinct parts: an automation phase and a stop-signal phase. In the automation phase, intended to build a prepotent categorisation response, 48 trials were conducted in which participants had to categorise the gender of the faces as quickly as possible without making mistakes. The stop-signal phase was composed of 20 practice trials followed by four blocks of 96 trials (16 female and 16 male faces, each with the three different emotional expressions, presented once in each block). During this phase, a computer-emitted tone (stop-signal) was presented in 25% of the trials at predetermined intervals. The length of the interval before the occurrence of the stop-signal was 200, 240, 280 or 320 ms (two identical intervals were never presented sequentially). Participants were told not to respond when the stop-signal occurred ("stop" trials) but otherwise to keep performing the same categorisation task ("go" trials). They received feedback at the end of each block on the mean reaction time (RT) of the block and of the training phase. This feedback was needed to reduce the tendency for participants to wait until the occurrence of the stop-signal to answer. The stop-signal reaction time (SSRT) that reflects the latency of the inhibitory process (see Logan, 1994) can be estimated from the start of the stop process (experimentally controlled by the interval before the occurrence of the stop-signal) and its finish (inferred from the RT distribution in the observed no-stop trials; if responses are not stopped in n% of the stop trials, the finish of the stop process is on average equal to the nth RT distribution for the go trials). The SSRT was thus calculated (for each interval and then averaged) by subtracting the mean of the stop-signal interval from the nth RT distribution for go trials. Only the RT for correct responses was retained and every go trial lower than 200 ms or longer than the mean for go trials plus 2.5 SD was suppressed on a subject-by-subject basis. Dependent variables were the SSRT computed separately for neutral, joy and angry conditions.

Emotional RNT

This task was designed to assess the impact of emotional stimuli on the resolution of PI in working memory adapted from Gay, Rochat, Billieux, d'Acremont, & Van der Linden (2008). It was composed of neutral, positive or negative target sets of three sequential words drawn from a list of 16 neutral, 16 positive or 16 negative disyllabic words that were matched for length, lexical frequency, arousal and imagery. Each word of the target set was presented sequentially for 750 ms, separated from the next word by an interval of 100 ms, with a row of number signs displayed for 400 ms after the third word, and followed by the presentation of a single probe word for 600 ms. Participants were instructed to indicate, as quickly as possible without making mistakes, whether the probe word was presented in the last set of three words (yes-response) or not (no-response). When the probe word was not presented in the last trial's target set, two conditions were distinguished: (1) RecNR, in which probes occurred in the previous trial's target set; and (2) NRecNR, in which probes occurred three trials before the current one. There were a total of 240 trials divided into three blocks (one block by emotional condition; i.e., neutral, positive or negative words) randomised across participants, as well as two practice trials that were not scored. In each block, 40 trials required a no-response (among which 20 trials were the RecNR condition and 20 trials were the NRecNR condition) and 40 trials required a yes-response. For each condition, only the RT for correct responses was retained and every RT lower than 200 ms or longer than the mean for RT plus 2.5 SD was suppressed on a subject-by-subject basis. Dependent variables were number of errors and RT computed separately for RecNR and NRecNR in each emotional condition. Since the PI index is the more common measure used to assess PI, and in order to take into account the base performance of the participants, we also computed PI indices on the basis of errors (errors in NRecNR condition minus errors in RecNR condition) and RT (RT in NRecNR condition minus RT in RecNR condition) for each emotional condition.

RESULTS

An exploratory analysis of extreme values (box plot of multiple variables) on measures for the SST and the RNT revealed four participants with statistical extreme values (i.e., greater than the upper quartile plus three times the interquartile range). The values for these participants were thus discarded from the analyses.

Mean scores and standard deviations on measures for the SST and the RNT are presented in Table 1. Because the focus here is inhibitory control, for the sake of conciseness, we have chosen to report only inhibition-related variables.

Partial correlations performed between the SSRT of the SST and measures in the RecNR condition of the RNT (removing the variability explained by measures in the NRecNR condition) indicated no significant relationship between the SSRT of the SST and errors (r = .19) or RT (r = .08) in the RNT.

Repeated measures analyses of variance (ANOVAs) were then performed to evaluate the effect of emotional stimuli on task performances.

Concerning the SST, ANOVA with trial type (neutral vs. positive vs. negative) as the within-subject factor performed for SSRTs revealed a significant main effect of trial type, $F(2, 166) = 16.02$, $p < .001$, $\eta_p^2 = .16$. Tukey's honestly significant difference post hoc tests indicated that stopping was prolonged on negative trials compared with neutral trials ($p < .001$) and positive trials ($p < .05$); stopping on positive trials was prolonged compared with neutral trials ($p < .05$).

Concerning the RNT, ANOVAs with recency effect (recent vs. non-recent) × trial type (neutral vs. positive vs. negative) as within-subject factors were performed separately for errors and RTs. ANOVA computed for errors revealed a significant main effect of recency, $F(1, 83) = 58.49$, $p < .001$, $\eta_p^2 = .41$, and trial type, $F(2, 166) = 8.05$, $p < .001$, $\eta_p^2 = .09$, as well as a significant interaction effect between recency and trial type, $F(2, 166) = 4.59$, $p < .05$, $\eta_p^2 = .05$.[1] ANOVA computed for RTs showed a significant main effect of recency, $F(1, 83) = 84.91$, $p < .001$, $\eta_p^2 = .51$, but no effect of trial type, $F(2, 166) = 1.25$, $\eta_p^2 = .01$, or interaction, $F(2, 166) = .47$, $\eta_p^2 = .01$. With regard to recency effects, errors were higher and RTs longer on recent than on non-recent trials. ANOVA with trial type as the within-subject factor was then performed for the PI index based on errors. This analysis revealed a significant main effect of trial type, $F(2, 166) = 4.49$, $p < .05$, $\eta_p^2 = .05$. As indicated by post hoc tests, the PI index based on errors was higher on positive trials compared with neutral trials ($p < .05$) and negative trials ($p < .05$); there was no difference between neutral and negative trials. Ordinary non-parametric bootstrap analyses were finally performed (comparison of the PI index based on errors for positive trials with those based on errors for neutral trials and for negative trials) to support the robustness of these results given the low error rates. These analyses confirmed that the PI index based on errors for positive trials differed significantly from those based on errors for neutral

[1] In order to analyse this interaction effect, we also performed two additional ANOVAs with trial type (neutral vs. positive vs. negative) as the within-subject factor for recent and non-recent conditions separately. Analyses revealed a significant main effect of trial type for the recent condition, $F(2, 166) = 8.82$, $p < .001$, $\eta_p^2 = .10$. As indicated by post hoc tests, errors were higher on positive trials compared with neutral trials ($p < .001$) and negative trials ($p < .01$); there was no difference between neutral and negative trials. No significant main effect of trial type was observed for the non-recent condition, $F(2, 166) = 1.04$, $\eta_p^2 = .01$.

Table 1. *Descriptive statistics for laboratory tasks*

Task	*Variable*	*Mean (SD)*	*Error rate (%)*
SST	GO RT-neutral	474.72 (53.77)	
	GO RT-positive	475.75 (53.08)	
	GO RT-negative	480.36 (52.21)	
	STOP errors-neutral	10.67 (5.25)	33.33
	STOP errors-positive	11.43 (5.52)	35.71
	STOP errors-negative	12.09 (5.50)	37.80
	SSRT-neutral	156.45 (39.64)	
	SSRT-positive	166.63 (44.87)	
	SSRT-negative	176.20 (38.03)	
RNT	NRecNR RT-neutral	573.61 (104.44)	
	NRecNR RT-positive	579.25 (110.29)	
	NRecNR RT-negative	572.67 (100.71)	
	RecNR RT-neutral	611.24 (124.03)	
	RecNR RT-positive	623.32 (120.44)	
	RecNR RT-negative	609.60 (126.15)	
	NRecNR errors-neutral	0.83 (1.14)	4.17
	NRecNR errors-positive	1.01 (1.20)	5.06
	NRecNR errors-negative	1.04 (1.37)	5.18
	RecNR errors-neutral	1.71 (1.74)	8.57
	RecNR errors-positive	2.57 (2.25)	12.86
	RecNR errors-negative	1.86 (2.03)	9.29
	PI index based on RT-neutral	37.63 (61.61)	
	PI index based on RT-positive	44.07 (52.47)	
	PI index based on RT-negative	39.93 (72.80)	
	PI index based on errors-neutral	.88 (1.81)	
	PI index based on errors-positive	1.56 (2.19)	
	PI index based on errors-negative	.82 (1.79)	

SST, stop-signal task; GO RT, reaction time for go response; STOP errors, errors for stop response; SSRT, stop-signal reaction time; RNT, recent negative task; NRecNR, non-recent no-response condition; RecNR, recent no-response condition; PI, proactive interference.

trials (95% CI: .14–1.21) and for negative trials (95% CI: .11–1.36).

DISCUSSION

The goal of the current study was to examine the influence of emotional stimuli on two inhibitory functions: prepotent response inhibition and resistance to PI. Results showed a deleterious effect of emotions on these two inhibitory functions.

Regarding the SST, it was found that stopping latencies were prolonged on emotional trials compared with neutral ones, providing further evidence that emotional experiences interfere with the effectiveness of inhibitory control by capturing attention automatically and guiding behaviour. More specifically, greater interference was observed for negative valence than for positive valence, which corroborated previous studies showing that positive stimuli elicit less attention than negative stimuli do (therefore producing less interference; see Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001). A motivational aspect might also account for this finding. Indeed, observed prioritisation of the processing of negative stimuli may be driven by the protection of the self, as negative stimuli quickly signal potential danger in the environment and prepare us to face such danger by interrupting ongoing behaviour and mental processes (Öhman & Mineka, 2001).

In addition, the SST used in the current study is of special interest for at least two reasons. First, emotional stimuli were the target of response inhibition, implying the task specifically measured response inhibition regarding emotional stimuli. The task used has thus to be distinguished from the SST used by Verbruggen and De Houwer (2007) in which emotional stimuli preceded the inhibition of neutral targets. This distinction among the two tasks is crucial, given that a series of electrophysiological studies showed that distinct processing stages are involved in the emotional guidance of attention, as well as in the interaction of emotion and attention (see Schupp, Flaisch, Stockburger, & Junghöfer, 2006). For example, paying attention to emotional stimuli (when emotional stimuli are the target of response inhibition) rather than to neutral stimuli (when neutral targets preceded by emotional stimuli must be inhibited) could be more effective in drawing attentional resources (as attention is explicitly directed to emotional stimuli), allowing overadditive effects of the interaction between emotion and attention (Schupp et al., 2006). Second, we used faces with various expressions as stimuli, whereas verbal stimuli were previously used with an SST focusing on response inhibition of emotional stimuli (Herbert & Sütterlin, 2011). The more specific use of facial expressions is of particular relevance, as faces are powerful social cues that guide behaviour in everyday life (Yoon, Joorman, & Gotlib, 2009) and influence the production and regulation of affective states (Phillips, Drevets, Rauch, & Lane, 2003).

Concerning results found with the RNT, longer RTs and higher error rates for interference than for non-interference trials indicate that previously yet-no-longer relevant words interfered with the processing of currently relevant words, replicating the PI effect (Gay et al., 2008; Jonides & Nee, 2006; Levens & Phelps, 2008). In particular, greater interference for positive trials was observed, as demonstrated by a higher PI index based on errors for positive trials relative to that based on errors for neutral trials (and higher error rates for recent positive trials relative to those for recent neutral trials). As with the SST, a motivational aspect might account for the specificity of this finding for positive words. Indeed, enhanced memory for positive stimuli could be motivated here by the achievement or maintenance of emotional well-being (Carstensen & Mikels, 2005). Nonetheless, these results contrast with those in the study by Levens and Phelps (2008), who found a facilitation of both positive and negative stimuli on the resolution of PI in working memory. The specificity of our paradigm could explain, at least in part, these divergent findings. First, the distinctiveness of emotional stimuli was controlled in our paradigm. Indeed, each target set contained three words with the same valence, whereas Levens and Phelps (2008) used emotional target sets of mixed neutral and emotional stimuli. The memory for the emotional stimuli was thus not increased and therefore PI not reduced as it was in Levens and Phelps' study. In the latter case, the reduction in PI for emotional stimuli could be due to the distinctiveness of emotional stimuli among neutral stimuli, this distinctiveness increasing memory and therefore reducing PI (assuming that when the source memory for a stimulus is increased, the likelihood for PI to occur is decreased, as hypothesised by Levens and Phelps). Second, the time of stimuli presentation was shortened, and third, the number of stimuli was reduced. These modifications may have decreased the source signal strength (less time being dedicated to the encoding) and improved the familiarity signal (the stimuli being repeated more frequently). Thus, in contrast to the findings by Levens and Phelps, our RNT may have increased the difficulty in resolving PI for emotional stimuli (at least for the positive).

In other words, modifications in the way emotional stimuli stand out from their surroundings appear to have led to differences in the way PI was resolved for these stimuli. Indeed, special mechanisms of interference resolution with emotional stimuli may be expressed differently, in accordance with the previous integration of salient context information (i.e., all aspects that establish the overall perceptual context; Attar, Müller, Andersen, Büchel, & Rose, 2010). Thus, although our results do not run counter to the hypotheses of Levens and Phelps (2008), regarding the basis of the emotional facilitation of interference resolution, they convey a nuance concerning the context in which they operate.

We did not, however, observe the same effect for RTs as for errors. Given the fact that resistance to PI in the RNT requires the execution of several mechanisms (e.g., competition among internal representations, monitoring processes and response selection; Jonides & Nee, 2006), a possible explanation of this dissociation is that emotion only dealt with specific mechanisms of PI resolution such as response selection (therefore, having an impact on accuracy but not on response time).

Future studies are required to confirm that the divergence between our results and the results found by Levens and Phelps (2008) is actually due to differences in paradigm. One direction for upcoming experiments would be to use our RNT design and that of Levens and Phelps, as well as other experimental conditions manipulating the time of stimuli presentation and the number of stimuli. Future studies are also needed to further clarify why we observed a significant effect of valence only for errors. In addition, because of the rather low number of errors, we might question the sensitivity of the RNT used to assess PI in working memory and reflect on the use of more sensitive recent probe tasks (Nee, Jonides, & Berman, 2007).

The current study adds to a growing literature linking emotions and inhibitory control. Indeed, although previous studies found that emotionally laden stimuli interfere with the ability to inhibit a prepotent response inhibition (Herbert & Sütterlin, 2011; Schulz et al., 2007; Verbruggen & De Houwer, 2007) but facilitate resistance to PI (Levens & Phelps, 2008), our results emphasised a deleterious effect of emotions on these two inhibitory functions. In addition, the finding that valence interferes differently in accordance with the task (i.e., greater interference of angry than joy faces in the SST; interference of positive words only in the RNT) supports the idea that distinct mechanisms underlie these two inhibition-related functions (i.e., top-down vs. bottom-up processes) and possible consecutive differences in emotional processing. Most of all, the current study highlights different interactions with stimulus/task properties (e.g., pictures vs. words), processing stages (e.g., early vs. later time course of emotional processing) or motivational aspects (e.g., protection of the self vs. achievement or maintenance of emotional well-being), yielding to possible differences in emotional processing. These interactions further support the dual competition model (Pessoa, 2009), which proposes that emotion and motivation affect both perceptual and executive completion, leading to different behavioural performances in accordance with the situation. This is especially interesting for the comprehension of self-regulation failures in which affect regulation and impulse control conflict (Tice, Bratslavsky, & Baumeister, 2001).

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