The locus of the emotional Stroop effect: A study with the PRP paradigm ☆

Markus Janczyk *, Susanne Augst, Wilfried Kunde

University of Würzburg, Department of Psychology III, Röntgenring 11, 97070 Würzburg, Germany

ARTICLE INFO

ABSTRACT

Stimuli that are clearly positive or negative (hence valence-laden stimuli) have the potential to interrupt unrelated task processing. A typical example is the emotional Stroop effect (ESE) in which responding to a certain task feature (e.g., color) is delayed by the presentation of task-irrelevant valent stimuli (e.g., negative pictures) compared to valence-neutral stimuli. Here we scrutinize which processes are slowed down by irrelevant but valent stimulation. In Experiment 1, participants performed in a Psychological Refractory Period (PRP) experiment with tone discrimination as Task 1 and color discrimination as Task 2. Importantly, colors in Task 2 were accompanied by valent or neutral pictures. Valent pictures delayed responding in Task 2 (thus an ESE) and this delay was additive to the time interval between tasks. In Experiment 2, task order was reversed and the ESE in Task 1 fully propagated to the Task 2 tone discrimination. These results imply that irrelevant valence-laden stimulation delays capacity-limited processes, and we suggest that this is a late perceptual process acting on stimulus categorization.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

First things first. First things for humans, such as threatening or attractive stimuli often possess affective connotations. They appear as very negative or positive. It has been suggested that such stimuli are processed with high priority and perhaps automatically (Bargh, 2006; Chen & Bargh, 1999; Dijksterhuis & Aarts, 2003; Eimer & Holmes, 2002; Pratto & John, 1991). This priority is signified by the potential of valent stimuli to disturb ongoing information processing in unrelated tasks (e.g., Bertels, Kolinsky, & Morais, 2010; Cohen, Henik, & Moyal, 2012; De Houwer & Tibboel, 2010; Gupta & Raymond, 2012; Kunde, Augst, & Kleinsorge, 2012; Melcher, Born, & Gruber, 2011; Pereira et al., 2006; Verbruggen & De Houwer, 2007).

A typical example for such disturbance of ongoing cognitive activity is illustrated with the emotional Stroop task. In the original version, participants are to name the color of positive, negative, and neutral words while the word meaning itself is irrelevant. However, responses are delayed when words are valent, especially negative, compared to when they are neutral — the emotional Stroop effect (ESE; cf. Mathews & MacLeod, 1985; Williams, Mathews, & MacLeod, 1996, for reviews).

Recent studies used variations of this original task. For example, participants responded to the colors with key presses (e.g., McKenna & Sharma, 2004; Frings, Englert, Wentura, & Bermeitinger, 2010) or movements (e.g., Chajut, Mama, Levy, & Algom, 2010), pictures served as emotional stimuli while participants performed an unrelated categorization task (e.g., Erthal et al., 2005; Kleinsorge, 2007, 2009; Kunde & Mauer, 2008; Kunde, Augst et al., 2012; Murphy, Hill, Ramponi, Calder, & Barnard, 2010), or the emotional stimulation was presented prior to target onset (e.g., Cohen et al., 2012; Gupta & Raymond, 2012; Pereira et al., 2006). The crucial feature in all these studies is that valence-laden, especially negative, stimuli disturb ongoing information processing despite being irrelevant for task performance.

The present study aims at providing hints about the possible source for the ESE by using a well-established chronometric approach for pinpointing the particular stage of processing where a given experimental effect arises: the Psychological Refractory Period (PRP) paradigm. Before discussing what the available literature suggests about the source of the ESE, we introduce this paradigm in the next section.

1.1. The PRP paradigm and the localization of effects

The PRP paradigm is a dual-task paradigm, where two tasks are performed on each trial. The degree of their overlap is experimentally varied by manipulating the stimulus onset asynchrony (SOA), that is, the time from presentation of the Task 1 stimulus until presentation of the

Task 2 stimulus. Typically, response times in Task 1 (RT1) do not depend on the SOA, but those in Task 2 (RT2) are slower the smaller the SOA is, the PRP effect (Telford, 1931; for a review of exceptions from the PRP effect, see Janczyk, Pfister, Wallmeier, & Kunde, 2014). One influential model to account for the PRP effect is the central bottleneck model (e.g., Pashler, 1994). This model assumes that (a) pre-central, perceptual as well as post-central, motor processes can run in parallel with all other processes, but that (b) only one central process can run at any given time, hence a bottleneck. Thus, at short SOAs, the central stage of Task 2 must await release from this bottleneck from Task 1, and this idle time – called the *cognitive slack* (Schweickert, 1978) – leads to the longer RT2s. At sufficiently long SOAs no such slack occurs, thus processing of Task 2 is not interrupted and RT2s are lower (see also Fig. 1).

Two procedures exploit the PRP paradigm in order to localize experimental effects: the *locus-of-slack* and the *effect-propagation logic* (for applications, see Janczyk, 2013; Janczyk, Dambacher, Bieleke, & Gollwitzer, 2014; Kunde, Pfister, & Janczyk, 2012; Miller & Reynolds, 2003; Schweickert, 1978). The locus-of-slack logic distinguishes a pre-central, perceptual cause from later causes. Here, the manipulation of interest, *M*, is implemented in Task 2. If *M* affects and prolongs the pre-central, perceptual stage (Fig. 1a), the additional processing time stretches into the slack at a short SOA, and only at long SOAs the RT difference becomes observable (thus an underadditive combination of *M* and the SOA manipulation). In contrast, if *M* affects a later stage (Fig. 1b), the RT difference is equivalent across all SOA levels (thus an additive combination of *M* and SOA). Because it remains unclear whether *M* affects the central or the post-central stage in this latter case, the effect-propagation logic can be used subsequently for distinguishing the motor stage from earlier stages as the source for the RT effect. Here, *M* is implemented in Task 1. If *M* prolongs a stage prior to the post-central one, it delays the beginning of the central stage of Task 2 as well. In other words, at least at a short SOA, the RT difference should be observed in Task 1 and in Task 2: the effect propagates to Task 2 (Fig. 2a). If instead *M* affects the post-central stage, this only prolongs RT1, but not RT2 (Fig. 2b).

To avoid misunderstandings here, the particular SOA values used in a given experiment must not be understood as, for example, 'tapping into the perceptual or central stage'. Rather, the critical result for the locus-of-slack logic relates to the pattern of interaction between the effect under investigation and the SOA. The only requirement is that one SOA is short enough and another one is long enough to allow the cognitive slack to emerge at short SOAs.

Manipulations such as stimulus brightness or contrast, traditionally seen to affect early perceptual processes, in fact interacted underadditively with the SOA manipulation in several studies (e.g., Pashler, 1984; Pashler & Johnston, 1989). The nature of the "central
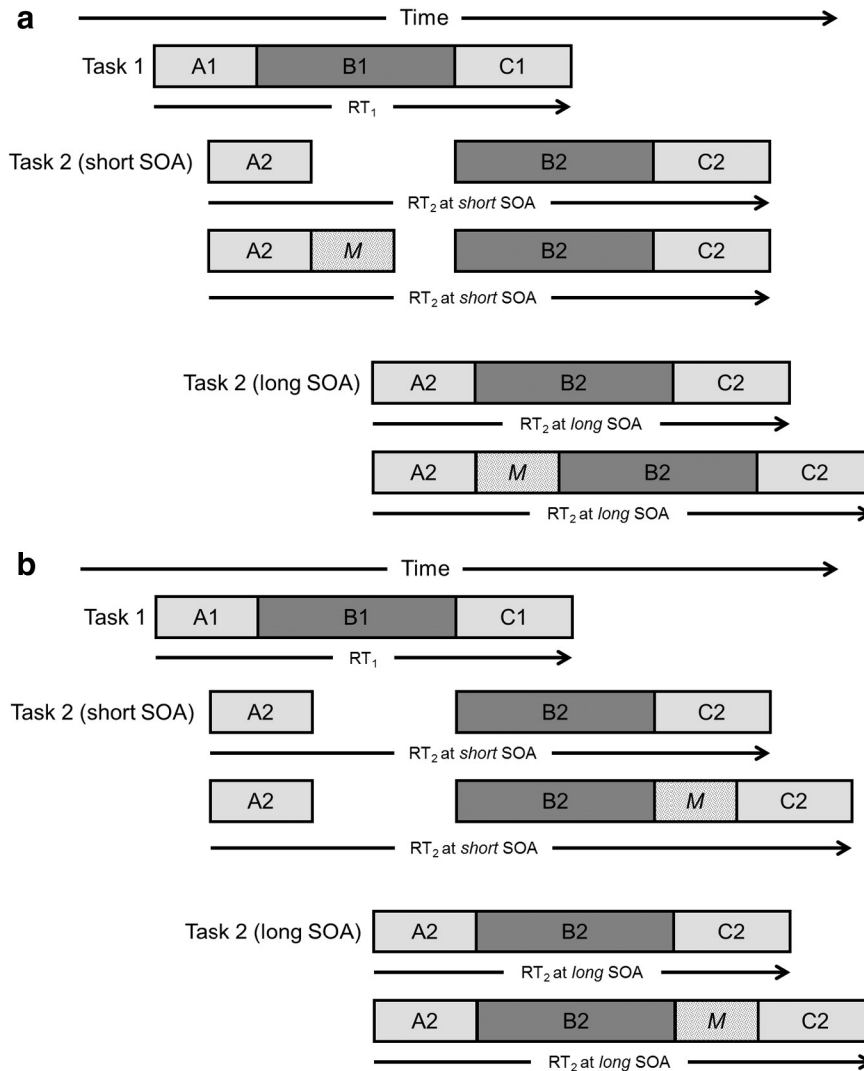

Fig. 1. Illustration of the locus-of-slack logic. (a) A manipulation *M* affecting the pre-central stage of Task 2 (A2) does not prolong RT2 at the short SOA, but does so at the long SOA. (b) *M* affects a later processing stage and prolongs RT2 at both the short and the long SOA (SOA = stimulus onset asynchrony, A1/A2 = pre-central, perceptual stage of Tasks 1 and 2, B1/B2 = central stages, C1/C2 = post-central, motor stages).

Fig. 2. Illustration of effect-propagation logic. (a) A manipulation *M* affects the pre-central or central stage of Task 1 (A1 or B1) and therefore Task 2 central processing (B2) must be postponed by the same amount of time. (b) *M* affects the post-central, motor stage and only prolongs RT1 but not RT2 (SOA = stimulus onset asynchrony, A1/A2 = pre-central, perceptual stage of Tasks 1 and 2, B1/B2 = central stages, C1/C2 = post-central, motor stages).
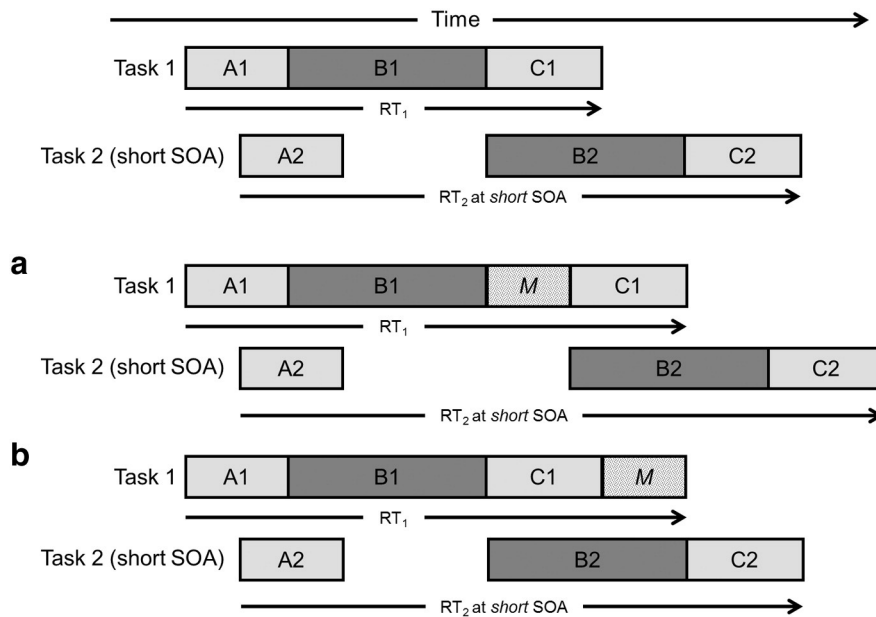
stage" has been a topic of discussions in recent years. Traditionally, it was interpreted as response selection. However, it has turned out that several other processes seem to require capacity-limited processing and can thus be considered as being "central". Beyond response selection proper this applies to short-term consolidation (e.g., Jolicoeur & Dell'Acqua, 1998), mental rotation (e.g., Ruthruff, Miller, & Lachmann, 1995), tool transformations (Kunde, Pfister et al., 2012), and level-2 perspective taking (Janczyk, 2013). Likely, however, none of these processes is involved in the emergence of the ESE. In the next section we will thus discuss what the available literature suggests about the stage responsible for the ESE.

1.2. Sources of the ESE

Given that it is known that emotional stimulation does delay responding in unrelated tasks, the logics described in the preceding section can be used to attribute the ESE to an (1) early perceptual, pre-central, a (2) central, or a (3) motor-related, post-central stage. Theoretically, emotional stimulation could potentially affect (and interrupt) all of these stages and cause the observable performance decrements.

A first possibility is that valence-laden stimuli delay (early) perceptual processing of actually task-relevant stimulus components. This assumption is intuitively plausible because valence-laden, and especially negative, stimuli appear as perceptually salient and attract visual attention (e.g., Contreras, Megías, Maldonado, Cándido, & Catena, 2012; Eastwood, Smilek, & Merikle, 2003; Huang, Baddeley, & Young, 2008; Öhman, Flykt, & Esteves, 2001; Okon-Singer, Tzelgov, & Henik, 2007; Pratto & John, 1991; Van Dillen & Koole, 2009), although the critical aspect might not be the stimuli's valence but their arousal potential (e.g., Dresler, Mériau, Heekeren, & van der Meer, 2009; Schimmack, 2005).

Fischer and Schubert (2008) employed the locus-of-slack logic to scrutinize the origin of the delay by valence-laden stimulation. They used an Eriksen-like flanker task, where targets and distractors were either positive or negative and the task was to classify the target accordingly. The resulting congruency effect was smaller (but not absent) at the short compared to the long SOA, thus it combined underadditively with SOA pointing to a contribution from a perceptual, pre-central locus.

Note that in this just mentioned study both targets and distractors entailed the task-relevant positive/negative stimulation. This is, however, a different question than asking where in the processing stream task-unrelated valence-laden stimulation is processed and leads to performance decrements, such as in the variant of the emotional Stroop task we employed here. Kunde, Augst et al. (2012) have termed this latter effect "interruption", while the former would be sort of an interference effect.[1] According to such a distinction the term ESE in itself is a misnomer and bears no relationship to the classic Stroop effect (Stroop, 1935). Algom, Chajut, and Lev (2004) argued that both are entirely different phenomena and must be distinguished from each other. Notably, while the Stroop effect – attributed to post-perceptual processes of response selection (see MacLeod, 1991, for a review) – combines additively with the SOA manipulation (Fagot & Pashler, 1992, Exp. 7), this is not necessarily true for other effects that sometimes are termed "Stroop-like". For example, the picture–word interference effect empirically combines underadditively with the SOA, thus suggesting a pre-central locus (Dell'Acqua, Job, Peressotti, & Pascali, 2007). Finally, valence-laden stimuli might prolong perceptual processing of the relevant stimulus dimension in much the same way as masking does. In fact, masking a visual stimulus combined underadditively with the SOA manipulation in a previous study as well (Paelecke & Kunde, 2007, Exp. 1 and 2).

There are claims that processing problems resulting from irrelevant emotional stimuli happen only if enough attentional resources are available. For example, under cognitively demanding conditions, the ESE supposedly becomes smaller (cf. Erthal et al., 2005; Okon-Singer et al., 2007; Pessoa, Padmala, & Morland, 2005; Van Dillen & Koole, 2009). Such findings suggest the implication of the capacity-limited central stage. Pessoa and his colleagues suggest that these effects are due to an emotional control system which stands in a suppressive relationship to a cognitive control system. Thus, when one system is active the other one is suppressed.

The involvement of the capacity-limited central stage is also likely if the classical Stroop effect (Stroop, 1935) and the ESE were not as different as advocated by Algom et al. (2004). However, as there is no overlap

---

[1] Using a different terminology, interruption might be described as *unspecific interference*, while what Kunde, Augst et al. (2012) term interference would be an instance of *specific interference* (Müsseler & Wühr, 2002).

of the irrelevant stimulus features and response features, a prolongation of response selection processes proper appears unlikely to us. Instead, we suggest that capacity-limited *late* perceptual processes acting on stimulus classification are responsible for the ESE and will cause an additive combination of the ESE and the SOA. For example, Johnston and McCann (2006) reported several experiments requiring from participants judgments of object width and all experiments pointed to the implication of a capacity-limited stage. Corroborating evidence comes also from studies on Garner interference, that is, the processing problems induced by variations of a task-irrelevant stimulus dimension on judgments of a task-relevant dimension (e.g., Garner, 1978). In several studies, Garner interference – although intuitively a perceptual phenomenon – combined additively with the SOA pointing to the implication of central stage processes (Janczyk, Franz, & Kunde, 2010; Janczyk & Kunde, 2010; Kunde, Landgraf, Paelecke, & Kiesel, 2007). In fact, it is a common feature of both, the Garner interference effect and the ESE that certain task-irrelevant stimulus dimensions affect an entirely unrelated main task.

Finally, the interruption caused by emotional stimulation could also operate at the motor stage because negative stimuli do cause a temporary freezing of all motor functions (Öhman, Flykt, & Esteves, 2001). Further, some authors suggest an impact of emotional stimuli on approach and avoidance tendencies (Chajut et al., 2010). According to this reasoning, pressing a key constitutes an approach behavior and thus causes delayed responses when a negative stimulus is presented.

1.3. The present experiments

In sum, there are arguments why the ESE may result from a pre-central stage subsuming *early* perceptual processes. There are also arguments that the ESE arises from a later capacity-limited stage, that is, the central stage subsuming several *late* perceptual processes. The goal of the present research was to empirically distinguish between these two possibilities using the well-established approach of the PRP paradigm in conjunction with the locus-of-slack and the effect-propagation logic. In two experiments, the ESE was operationalized with a task, where participants responded to the color of a frame surrounding a picture of negative, neutral, or positive valence. The other task always was binary tone discrimination. In Experiment 1, the locus-of-slack logic was used and in Experiment 2 the effect-propagation logic was implemented to rule out a post-central, motor source for the ESE.

2. Experiment 1: the locus-of-slack logic

In Experiment 1 we used the locus-of-slack logic to decide whether the ESE emerges during early perceptual, pre-central processing or at a subsequent stage, including those late perceptual processes acting on stimulus categorization.[2] In the former case, an underadditive combination of the ESE with the SOA manipulation is predicted, in the latter case the ESE should combine additively with the SOA.

2.1. Method

2.1.1. Participants

Twenty-four[3] volunteers (mean age: 26.6 years, 23 females) participated in this experiment for monetary compensation. They reported

normal or corrected-to-normal vision and provided written informed consent prior to the experiment.

2.1.2. Apparatus and stimuli

A standard PC controlled experimental procedures. Task 1 stimuli (S1) were two tones (300 Hz vs. 900 Hz, 50 ms) presented via headphones. Imperative stimuli in Task 2 (S2) were colored rectangles (blue, red, yellow) framing a picture (473 × 360 px; centered at screen center). Responses were collected with external custom-built response keys. Task 1 responses (R1) were given with the left index- and middle-finger, Task 2 responses (R2) with the right index-, middle-, and ring-finger. The pictures we used here are a selection of the picture set used by Augst, Kleinsorge, and Kunde (in press). Thirty pictures were chosen; ten with a neutral, a negative, and a positive valence, respectively. The original picture set consisted of IAPS pictures (cf. Lang, Bradley, & Cuthbert, 1995) extended by pictures from the internet. For the negative picture category, the lowest valence rated IAPS pictures from the themes mutilation, burn victims, dead bodies, and dead animal bodies were chosen and extended by same-theme pictures from the internet. For the positive category the highest valence rated IAPS pictures from the themes babies, family, animals, and baby animals were chosen and extended by same-theme pictures from the internet. Negative, positive, and additional neutral IAPS pictures went into a rating procedure. The thirty highest rated pictures on pleasantness formed the set of positive pictures, while the thirty lowest rated formed the negative set (from each ten pictures were chosen for the present study). Neutral pictures were created by cutting each negative and positive picture into 36 pieces which were then recombined in a first step. In a second step these pictures were cut into 25 pieces and all resulting pieces (from previously positive and negative pictures) were mixed randomly. For each neutral picture, 25 pieces were drawn and combined to form a new picture. These new pictures had the exactly same perceptual characteristics as the negative and positive pictures, but were neutral in valence.

2.1.3. Procedure and design

A trial started with a fixation cross (500 ms). Following a blank screen of 500 ms, S1 was presented, and with an SOA of 100 or 1000 ms, S2 was displayed until R2 was given. The trial was canceled after 4000 ms without responses. Error feedback was provided for 1000 ms when participants pressed the wrong key, failed to respond within the time limit, responded prior to stimulus onset, or gave their response to Task 2 first. The next trial started with an inter-trial interval of 1000 ms.

Participants ran through six blocks of 72 trials each, resulting from two repetitions of the orthogonal combinations of 2 SOAs (100 ms vs. 1000 ms) × 2 S1 (300 Hz vs. 900 Hz) × 3 S2 color (blue vs. yellow vs. red) × 3 S2 valence (negative vs. positive vs. neutral). Trials were presented in a random order and the particular picture for the S2 valence category was randomly drawn from the respective picture set without replacement. If all ten pictures of one valence category were presented once, the set was refilled and thus pictures repeated in a new random order. The first block was considered practice and did not enter analyses. Written instructions emphasized speed and accuracy and gave priority to Task 1. Instructions were followed by a brief familiarization block of 20 random trials after which the main experiment started. The stimulus–response mapping of both tasks was counterbalanced across participants.

2.2. Results

For RT analyses, only correct trials were considered. As outliers we excluded RTs deviating more than 2.5 SDs from the corresponding mean, calculated separately for participants and each design cell (2.4% and 2.6% for Tasks 1 and 2, respectively). Mean correct RTs and mean percentages errors (PEs) were submitted to an ANOVA with SOA (100 ms vs. 1000 ms) and S2 valence (negative vs. positive vs. neutral)

---

[2] It is tempting to write "or at a later capacity-limited central stage". However, the locus-of-slack logic itself does not speak to whether an effect arises from the central or the post-central (motor) stage which is typically not assumed as capacity-limited. This issue will be addressed in Experiment 2.

[3] A priori power analysis revealed a required sample size of $n = 20$ participants to detect an interaction effect of medium size with a power of $1-\beta = .8$ (assuming $\alpha = .05$ and $\rho = .3$; 2×3 repeated measures design). For reasons of counterbalance the actual sample size was $n = 24$.
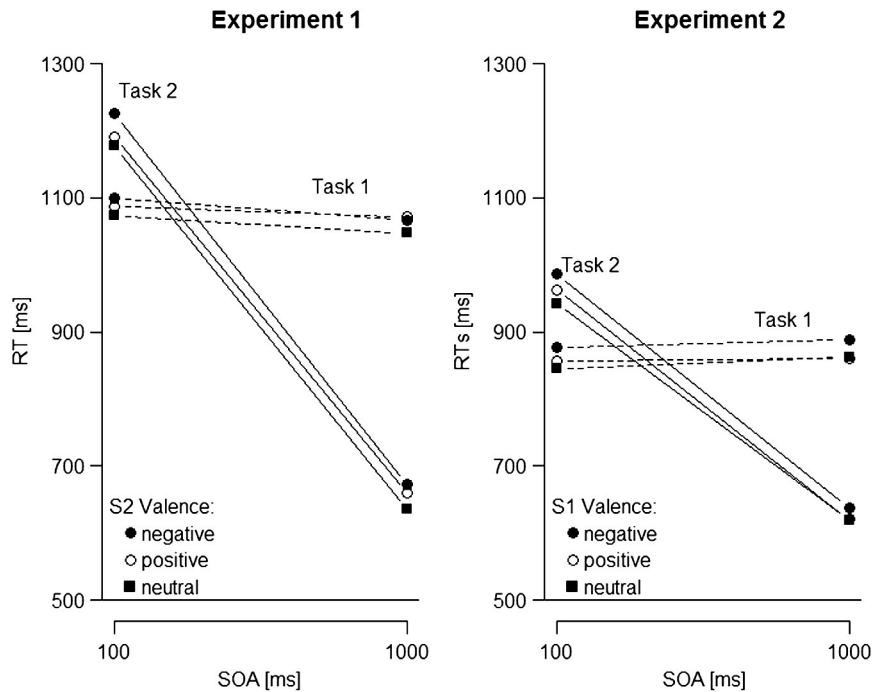
Fig. 3. Mean RTs for both tasks in Experiments 1 and 2 as a function of SOA and stimulus valence in Task 2 (Exp. 1) or Task 1 (Exp. 2) (note: SOA = stimulus onset asynchrony, S1/S2 = stimulus 1/2).

as repeated measures. A significance level of $\alpha = .05$ was adopted and Greenhouse–Geisser corrections were applied when necessary. In these cases, uncorrected degrees of freedom are reported, supplemented by the ε estimate.

Mean RTs are visualized in Fig. 3 (left panel) and PEs are summarized in Table 1. As the theoretically interesting results concern Task 2, we present these results first.

2.2.1. Task 2

Participants responded faster at the long SOA compared to the short SOA, the PRP effect, $F(1,23) = 628.93$, $p < .001$, $\eta_p^2 = .96$. Further, RTs were overall longer when a negative (912 ms) picture than when a positive (890 ms) picture occurred and both in turn were longer than RTs when a neutral (867 ms) picture was presented. Hence, the main effect of S2 valence was significant, $F(2,46) = 12.08$, $p < .001$, $\eta_p^2 = .34$. Both factors did not interact, thus they combined additively, $F(2,46) = 0.35$, $p = .647$, $\eta_p^2 = .01$. Paired t-tests (collapsed across SOAs) confirmed significant differences between the negative and the neutral S2 valence, $t(23) = 4.01$, $p = .001$, $d = 1.16$, between the positive and the neutral S2 valence, $t(23) = 2.45$, $p = .023$, $d = 0.71$, but not between the negative and positive S2 valence, $t(23) = 1.87$, $p = .075$, $d = 0.54$. For PEs, no effect reached significance, all $Fs \leq 0.80$, all $ps \geq .381$.

2.2.2. Task 1

Similar to Task 2, participants responded slower when a negative compared to a positive picture was presented. Both in turn

were slower than when a neutral picture occurred, $F(2,46) = 4.91$, $p = .012$, $\eta_p^2 = .18$.[4] No other effects reached significance, all $Fs \leq 0.38$, all $ps \geq .543$. Participants committed more errors with a short compared to a long SOA, $F(1,23) = 13.59$, $p = .001$, $\eta_p^2 = .37$. No other effects reached significance for PEs, all $Fs \leq 1.99$, all $ps \geq .166$.

2.3. Discussion

The main outcome of Experiment 1 is an ESE in Task 2 with its size being equivalent across SOAs. According to the locus-of-slack logic (Schweickert, 1978), this result excludes the pre-central stage (and thus early perceptual processes) as the source of the ESE. Rather, the effect stems from the capacity-limited central stage of processing or a later one.

Unexpectedly, valence-laden stimulation in Task 2 did not only produce an ESE in the very same task, but also in the conceptually unrelated and temporally preceding Task 1. Although this is an interesting finding, we remain reluctant in interpreting this effect because we cannot entirely rule out response grouping as its source. However, even when grouped responses (IRI < 100 ms) were excluded, RT1 was rather high in this experiment and we will get back to this in the General discussion.

---

[4] Although it is tempting to assume that the occurrence of this effect of S2 valence on RT1 was caused by a temporary disruption of Task 1 processing upon onset of the pictures, other explanations are possible. The most obvious is response grouping, that is, withholding the Task 1 response until Task 2 has been processed and then emitting both responses simultaneously or with only a brief inter-response interval (IRI). When we excluded trials with IRIs < 100 ms the main effect of S2 valence on RT1 was no longer significant, $F(2,44) = 0.62$, $p = .541$, $\eta_p^2 = .03$ (one participant produced missing cells and was excluded). In contrast, RT1 was faster with the long SOA (996 ms) compared to the short SOA (1085 ms) now, $F(1,22) = 10.45$, $p = .004$, $\eta_p^2 = .32$. The interaction was not significant, $F < 1$. Against this background we refrained from interpreting this significant effect and will discuss the level of RT1 in the General discussion.

Table 1
Mean percentages errors of Experiments 1 and 2 as a function of SOA and stimulus valence in Task 2 (Exp. 1) or Task 1 (Exp. 2) (note: SOA = stimulus onset asynchrony).

Experiment	Stimulus valence	Task 1		Task 2	
		SOA		SOA	
		100	1000	100	1000
1	Negative	2.3	0.8	6.1	6.2
	Positive	2.5	0.9	5.6	6.0
	Neutral	1.3	0.7	4.8	5.9
2	Negative	2.0	2.3	8.2	6.5
	Positive	2.0	2.7	6.9	6.1
	Neutral	2.4	2.9	7.1	5.1

3. Experiment 2: the effect-propagation logic

Results from Experiment 1 exclude a pre-central, likely early perceptual, locus of the ESE. Rather, they point to the implication of a later, most likely capacity-limited, processing stage. However, to exclude the post-central stage, we employed the effect-propagation logic in Experiment 2. To this end, the same tasks as in Experiment 1 were used, but their order was reversed.

3.1. Method

3.1.1. Participants

Twenty-four female volunteers (mean age: 23.5 years) participated for monetary compensation. They reported normal or corrected-to-normal vision and provided written informed consent prior to the experiment.

3.1.2. Apparatus and stimuli

These were the same as in Experiment 1, except that the emotional Stroop task was now implemented as Task 1 and the binary tone discrimination as Task 2. Consequently, R1 was given with the left index-, middle-, and ring-finger via three external response keys; R2 was given with the right index- and middle-finger on two external response keys.

3.1.3. Procedure and design

Procedure and design were the same as in Experiment 1. Note that the previous variable S2 valence is now referred to as S1 valence.

3.2. Results

Outliers were excluded according to the same criterion as in Experiment 1 (2.8% and 2.9% in Tasks 1 and 2, respectively). As the theoretically interesting results concern both Task 1 and Task 2 we report the results in this order. Mean correct RTs are visualized in Fig. 3 (right panel) and PEs are provided in Table 1.

3.2.1. Task 1

RT1s were overall slower when a negative (880 ms) picture compared to a positive (855 ms) picture was presented, which in turn both were slower than when a neutral (853 ms) picture occurred, $F(2,46) = 3.26$, $p = .047$, $\eta_p^2 = .12$. Neither the main effect of SOA, $F(1,23) = 0.11$, $p = .740$, $\eta_p^2 < .01$, nor the interaction, $F(2,46) = 0.50$, $p = .537$, $\eta_p^2 = .02$, $\varepsilon = .67$, was significant. Paired t-tests (collapsed across SOAs) confirmed a significant difference between the negative and the neutral S1 valence, $t(23) = 2.37$, $p = .026$, $d = 0.68$, while the other comparisons were not significant, positive vs. neutral: $t(23) = 0.14$, $p = .889$, $d = 0.04$, negative vs. positive: $t(23) = 1.69$, $p = .104$, $d = 0.49$. Mean PEs were low in general and no effect reached significance, all $Fs \leq 1.79$, all $ps \geq .194$.

3.2.2. Task 2

RT2s showed the typical PRP effect, that is, participants were faster at the long SOA than at the short SOA, $F(1,23) = 192.87$, $p < .001$, $\eta_p^2 = .89$. Most important for the present purpose is that RT2s followed the pattern observed for RT1s: they were similarly slower when a negative (810 ms) picture compared with when a positive (793 ms) picture occurred, which in turn both were slower than when a neutral (780 ms) picture was presented. Consequently, the main effect of S1 valence was significant, $F(2,46) = 4.12$, $p = .023$, $\eta_p^2 = .16$, but the interaction was not, $F(2,46) = 1.34$, $p = .270$, $\eta_p^2 = .06$, $\varepsilon = .80$. At the short SOA, the difference between the negative and the neutral S1 valence was significant, $t(23) = 2.27$, $p = .033$, $d = 0.66$, but again the other comparisons were not, neutral vs. positive: $t(23) = 1.61$, $p = .122$, $d = 0.46$, and negative vs. positive: $t(23) = 1.19$, $p = .247$, $d = 0.34$. PEs were higher at the short compared to the long SOA, $F(1,23) = 6.31$, p

$= .019$, $\eta_p^2 = .22$. The other effects missed significance, all $Fs \leq 1.52$, all $ps \geq .229$.

3.2.3. Comparison of Tasks 1 and 2

At the short SOA, the mean difference between the neutral and negative S1 valence condition was 32 ms in Task 1 and 44 ms in Task 2. These values were not significantly different, $t(23) = 1.66$, $p = .110$, $d = 0.48$.

3.3. Discussion

The ESE was observed in RT1, providing a necessary precondition to interpret the results of this experiment. Most importantly, the effect was also observed in RT2. The pattern at the short SOA closely followed that of RT1 and the differences between the neutral and the negative S1 valence conditions were of the same size in both tasks. In other words, the effect was propagated from Task 1 to Task 2. According to the effect-propagation logic, this points to a locus prior to the post-central motor stage.

4. General discussion

In two experiments we investigated the (processing) stage at which the ESE emerges. We here employed the locus-of-slack and the effect-propagation logic as two well-established chronometric methods within the PRP paradigm. Experiment 1 excludes a pre-central, early perceptual locus while Experiment 2 excludes a post-central, motor locus. In other words, the combined evidence from both experiments suggests that the ESE reflects the prolongation of the capacity-limited central stage of processing. Admittedly, the term central stage is rather vague and in the Introduction we have identified several phenomena that require that central stage as well. We suspect that late perceptual processes acting on stimulus categorization are working toward the ESE. That such processes are capacity-limited, despite their intuitively "perceptual nature", has been demonstrated earlier (Johnston & McCann, 2006). Also, influences of task-irrelevant stimulus features (i.e., Garner interference) were shown to emerge from a capacity-limited stage in PRP experiments (Janczyk et al., 2010; Janczyk & Kunde, 2010; Kunde et al., 2007).

The classical Stroop effect (Stroop, 1935) has also been shown to combine additively with the SOA (Fagot & Pashler, 1992). Thus, both the classical Stroop effect and the ESE rely on capacity-limited processing stages. However, in line with the arguments made by Algom et al. (2004) the exact nature of this process seems different: the Stroop effect is typically attributed to response selection proper (Fagot & Pashler, 1992; MacLeod, 1991). In contrast, we suggest that the ESE emerges from late perceptual processes acting on stimulus classification (Johnston & McCann, 2006), similar to Garner interference (e.g., Janczyk et al., 2010; Janczyk & Kunde, 2010; Kunde et al., 2007). Both, however, differ from other Stroop-like phenomena. For example, the picture–word interference effect was attributed to pre-central processing entirely (Dell'Acqua et al., 2007; see also Van Maanen, van Rijn, & Borst, 2009, for a unifying perspective).

The finding of additivity in Experiment 1 is particularly noteworthy against the background of the study by Erthal et al. (2005). These authors claimed that interference of the kind investigated here would be reduced by task difficulty. Reasonably then, a diminished ESE could be expected at the short SOA, that is, the condition with high task overlap that could be conceived as more difficult. In turn, this would result in an underadditive pattern − a pattern which we clearly have not observed. One way to deal with this contradiction is assuming that the demands of Task 1 in Experiment 1 were merely not sufficiently high to guarantee such shielding. This might be tested by varying the difficulty of Task 1 in the PRP paradigm. Alternatively, a closer look at the data of Erthal et al. seems warranted. In fact, neither in their Experiment 1 nor in their Experiment 2, where task difficulty was manipulated (in

Experiment 3, acute alcoholic intoxication was induced additionally), the critical interaction of this factor with the ESE was significant. The mere fact that in the "very hard" condition of their Experiment 2 the ESE was non-significant in itself cannot count as convincing evidence for their conclusion (see already Cantor, 1956). Thus, the present results contradict the claim of Erthal and colleagues. Rather it seems that only under very specific conditions (alcohol intoxication plus "hard" task difficulty) any reduction of the ESE can be observed.

A note on the overall level of RT1 in Experiment 1 is certainly necessary. Although exclusion of trials with IRIs < 100 ms eliminated the main effect of S2 valence on RT1, these were still about 1000 ms. However, the same task used as Task 2 in Experiment 2 yielded RTs that were only slightly higher than 600 ms. Although we can only offer speculations, we see one explanation likely if one considers capacity sharing models (Tombu & Jolicoeur, 2003): While the secondary task of judging the color of the picture frames is certainly rather easy, the mere expectation of possibly very negative pictures might absorb cognitive resources that cannot be devoted to the other task as a consequence. Thus, even though central processing is ongoing, it proceeds rather slowly because only few resources are available. Differences in Task 1 RTs depending on the type of Task 2 (more or less difficult) have in fact been observed in other studies (e.g., Kunde et al., 2007) suggesting that the ratio of capacity sharing can be adjusted based on top-down expectations regarding the nature and/or difficulty of the tasks.

In the Introduction we have relied on the serial-processing model as proposed, for example, by Pashler (1994). Thus, the suggestion made above seems at odds with our assumption. It is important to note though, that the predictions regarding Task 2 are essentially the same. In other words, our conclusions regarding the locus-of-slack hold regardless of the exact model used to explain the PRP effect.

To conclude, valence-laden stimuli, and in particular negative ones, invoke capacity-limited processes. We suggest that these processes are late perceptual ones acting on stimulus categorization. Thus, these stimuli occupy limited capacity for their own prioritized processing. Our interpretation points to a further distinction of the ESE from the classical Stroop effect (Stroop, 1935; which is ascribed to response selection proper) as has been argued previously by Algom et al. (2004), although both variants share the implication of capacity-limited processes.

References

Algom, D., Chajut, E., & Lev, S. (2004). A rational look at the emotional Stroop phenomenon: A generic slowdown, not a Stroop effect. *Journal of Experimental Psychology: General, 133*, 323–338.

Augst, S., Kleinsorge, T., & Kunde, W. 2014. Can we shield ourselves from task disturbance by emotion-laden stimulation? *Cognitive, Affective, & Behavioral*, http://dx.doi.org/10.3758/s13415-013-0243-x (in press).

Bargh, J. A. (2006). What have we been priming all these years? On the development, mechanisms, and ecology of nonconscious social behavior. *European Journal of Social Psychology, 36*, 147–168.

Bertels, J., Kolinsky, R., & Morais, J. (2010). Emotional valence of spoken words influences the spatial orienting of attention. *Acta Psychologica, 134*, 264–278.

Cantor, G. N. (1956). A note on a methodological error commonly committed in medical and psychological research. *American Journal of Mental Deficiency, 61*, 17–18.

Chajut, E., Mama, Y., Levy, L., & Algom, D. (2010). Avoiding the approach trap: A response bias theory of the emotional Stroop effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*, 1567–1572.

Chen, M., & Bargh, J. A. (1999). Consequences of automatic evaluation: Immediate behavioral predispositions to approach or avoid the stimulus. *Personality and Social Psychology Bulletin, 25*, 215–224.

Cohen, N., Henik, A., & Moyal, N. (2012). Executive control attenuates emotional effects — For high reappraisers only? *Emotion, 12*, 970–979.

Contreras, D., Megías, A., Maldonado, A., Cándido, A., & Catena, A. (2012). Facilitation and interference of behavioral responses by task-irrelevant affect-laden stimuli. *Motivation and Emotion, 1–12*.

De Houwer, J., & Tibboel, H. (2010). Stop what you are not doing! Emotional pictures interfere with the task not to respond. *Psychonomic Bulletin & Review, 17*, 699–703.

Dell'Acqua, R., Job, R., Peressotti, F., & Pascali, A. (2007). The picture–word interference effect is not a Stroop effect. *Psychonomic Bulletin & Review, 14*, 717–722.

Dijksterhuis, A., & Aarts, H. (2003). On wildebeests and humans. The preferential detection of negative stimuli. *Psychological Science, 14*, 14–18.

Dresler, T., Mériau, K., Heekeren, H. R., & van der Meer, E. (2009). Emotional Stroop task: Effects of word arousal and subject anxiety on emotional interference. *Psychological Research, 73*, 364–371.

Eastwood, J.D., Smilek, D., & Merikle, P.M. (2003). Negative facial expression captures attention and disrupts performance. *Perception & Psychophysics, 65*, 352–358.

Eimer, M., & Holmes, A. (2002). An ERP study on the time course of emotional face processing. *Neuroreport, 13*, 427–431.

Erthal, F. S., De Oliveira, L., Mocaiber, I., Pereira, M. G., Machado-Pinheiro, W., Volchan, E., et al. (2005). Load-dependent modulation of affective picture processing. *Cognitive, Affective, & Behavioral Neuroscience, 5*, 388–395.

Fagot, C., & Pashler, H. (1992). Making two responses to a single object: Implications for the central attentional bottleneck. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 1058–1059.

Fischer, R., & Schubert, T. (2008). Valence processing bypassing the response selection bottleneck? Evidence from the psychological refractory period paradigm. *Experimental Psychology, 55*, 203–211.

Frings, C., Englert, J., Wentura, D., & Bermeitinger, C. (2010). Decomposing the emotional Stroop effect. *Quarterly Journal of Experimental Psychology, 63*, 42–49.

Garner, W. R. (1978). Selective attention to attributes and to stimuli. *Journal of Experimental Psychology: General, 107*, 287.

Gupta, R., & Raymond, J. E. (2012). Emotional distraction unbalances visual processing. *Psychonomic Bulletin & Review, 19*, 184–189.

Huang, Y. M., Baddeley, A., & Young, A. W. (2008). Attentional capture by emotional stimuli is modulated by semantic processing. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 328–339.

Janczyk, M. (2013). Level 2 perspective taking entails two processes: Evidence from PRP experiments. *Journal of Experimental Psychology Learning Memory and Cognition, 39*, 1878–1887.

Janczyk, M., Dambacher, M., Bieleke, M., & Gollwitzer, P.M. (2014). The benefit of no choice: Goal-directed plans enhance perceptual processing. *Psychological Research*, http://dx.doi.org/10.1007/s00426-014-0549-5.

Janczyk, M., Franz, V. H., & Kunde, W. (2010). Grasping for parsimony: Do some motor actions escape dorsal processing? *Neuropsychologia, 48*, 3405–3415.

Janczyk, M., & Kunde, W. (2010). Does dorsal processing require central capacity? More evidence from the PRP paradigm. *Experimental Brain Research, 203*, 89–100.

Janczyk, M., Pfister, R., Wallmeier, G., & Kunde, W. (2014). Exceptions from the PRP effect? A comparison of prepared and unconditioned reflexes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, http://dx.doi.org/10.1037/a0035548.

Johnston, J. J., & McCann, R. S. (2006). On the locus of dual-task interference: Is there a bottleneck at the stimulus classification stage? *The Quarterly Journal of Experimental Psychology, 59*, 694–719.

Jolicoeur, P., & Dell'Acqua, R. (1998). The demonstration of short-term consolidation. *Cognitive Psychology, 36*, 138–202.

Kleinsorge, T. (2007). Anticipatory modulation of interference induced by unpleasant pictures. *Cognition and Emotion, 21*, 404–421.

Kleinsorge, T. (2009). Anticipation selectively enhances interference exerted by pictures of negative valence. *Experimental Psychology, 56*, 228–235.

Kunde, W., Augst, S., & Kleinsorge, T. (2012). Adaptation to (non-) valent task disturbance. *Cognitive, Affective, & Behavioral Neuroscience, 12*, 644–660.

Kunde, W., Landgraf, F., Paelecke, M., & Kiesel, A. (2007). Dorsal and ventral processing under dual-task conditions. *Psychological Science, 18*, 100–104.

Kunde, W., & Mauer, N. (2008). Sequential modulations of valence processing in the Emotional Stroop Task. *Experimental Psychology, 55*, 151–156.

Kunde, W., Pfister, R., & Janczyk, M. (2012). The locus of tool-transformation costs. *Journal of Experimental Psychology: Human Perception and Performance, 38*, 703–714.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1995). *International affective picture system (IAPS): Technical manual and affective ratings*. Gainesville, FL: University of Florida.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109*, 163–203.

Mathews, A., & MacLeod, C. (1985). Selective processing of threat cues in anxiety states. *Behaviour Research and Therapy, 23*, 563–569.

McKenna, F. P., & Sharma, D. (2004). Reversing the emotional Stroop effect reveals that it is not what it seems: The role of fast and slow components. *Journal of Experimental Psychology Learning Memory and Cognition, 30*, 382–392.

Melcher, T., Born, C., & Gruber, O. (2011). How negative affect influences neural control processes underlying the resolution of cognitive interference: An event-related fMRI study. *Neuroscience Research, 70*, 415–427.

Miller, J., & Reynolds, A. (2003). The locus of redundant-targets and non-targets effects: Evidence from the psychological refractory period paradigm. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 1126–1142.

Murphy, F. C., Hill, E. L, Ramponi, C., Calder, A. J., & Barnard, P. J. (2010). Paying attention to emotional images with impact. *Emotion, 10*, 605–614.

Müsseler, J., & Wühr, P. (2002). Response-evoked interference in visual encoding. In W. Prinz, & B. Hommel (Eds.), *Attention and performance XIX: Common mechanisms in perception and action* (pp. 520–537). Oxford, UK: Oxford University Press.

Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General, 130*, 466–478.

Okon-Singer, H., Tzelgov, J., & Henik, A. (2007). Distinguishing between automaticity and attention in the processing of emotionally significant stimuli. *Emotion, 7*, 147–157.

Paelecke, M., & Kunde, W. (2007). Action-effect codes in and before the central bottleneck: Evidence from the PRP paradigm. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 627–644.

Pashler, H. (1984). Processing stages in overlapping tasks: Evidence for a central bottleneck. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 358–377.

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116*, 220–244.

Pashler, H., & Johnston, J. C. (1989). Chronometric evidence for central postponement in temporally overlapping tasks. *The Quarterly Journal of Experimental Psychology, 41A*, 19–45.

Pereira, M. G., Volchan, E., de Souza, G. G., Oliveira, L., Campagnoli, R. R., Pinheiro, W. M., et al. (2006). Sustained and transient modulation of performance induced by emotional picture viewing. *Emotion, 6*, 622–634.

Pessoa, L., Padmala, S., & Morland, T. (2005). Fate of unattended fearful faces in the amygdala is determined by both attentional resources and cognitive modulation. *NeuroImage, 28*, 249–255.

Pratto, F., & John, O. P. (1991). Automatic vigilance: The attention-grabbing power of negative social information. *Journal of Personality and Social Psychology, 61*, 380–391.

Ruthruff, E., Miller, J., & Lachmann, T. (1995). Does mental rotation require central mechanisms? *Journal of Experimental Psychology: Human Perception and Performance, 21*, 552–570.

Schimmack, U. (2005). Attentional interference effects of emotional pictures: Threat, negativity, or arousal? *Emotion, 5*, 55–66.

Schweickert, R. (1978). A critical path generalization of the additive factor method: Analysis of a Stroop task. *Journal of Mathematical Psychology, 18*, 105–139.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643–662.

Telford, C. W. (1931). The refractory phase of voluntary and associative responses. *Journal of Experimental Psychology, 14*, 1–36.

Tombu, M., & Jolicoeur, P. (2003). A central capacity sharing model of dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 3–18.

Van Dillen, L. F., & Koole, S. L. (2009). How automatic is "automatic vigilance"? The role of working memory in attentional interference of negative information. *Cognition and Emotion, 23*, 1106–1117.

Van Maanen, L., van Rijn, H., & Borst, J. P. (2009). Stroop and picture–word interference are two sides of the same coin. *Psychonomic Bulletin & Review, 16*, 987–999.

Verbruggen, F., & De Houwer, J. (2007). Do emotional stimuli interfere with response inhibition? Evidence from the stop signal paradigm. *Cognition & Emotion, 21*, 391–403.

Williams, J. M. G., Mathews, A., & MacLeod, C. (1996). The emotional Stroop task and psychopathology. *Psychological Bulletin, 120*, 3–24.