Sequential Modulations of Valence Processing in the Emotional Stroop Task

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Abstract. This study investigated trial-to-trial modulations of the processing of irrelevant valence information. Participants (N = 126) responded to the frame color of pictures with positive, neutral, or negative affective content – a procedure known as an emotional Stroop task (EST). As is typically found, positive and negative pictures delayed responses as compared to neutral pictures. However, the type and extent of this valence-based interference depended on the irrelevant picture valence in the preceding trial. Whereas preceding exposure to negative valence prompted interference from positive and negative pictures, such interference was removed after neutral trials. Following positive pictures, interference from negative but not from positive pictures was observed. We suggest that these sequential modulations reflect automatic self-regulatory selection processes that help to keep the balance between attending to task-relevant information and task-irrelevant information that signals important changes in the environment.

Keywords: emotion, affect, attention

For biological organisms stimuli of certain valence (i.e., stimuli that can be classified as positive or negative) are of primary importance. Such stimuli often signal danger or opportunities to gain something and it would, therefore, be functional that organisms posses a high sensitivity for them. There is considerable evidence showing that valent stimuli have the power to interrupt ongoing information processing even when stimulus valence is nominally task-irrelevant (e.g., Hansen & Hansen, 1988; Pratto & John, 1991; Öhmann, Flykt, & Esteves, 2001).

A widely acknowledged example of the impact of irrelevant valence information is the emotional Stroop task (EST; Schimmack, 2005; Williams, Matthews, & MacLeod, 1996). In a typical EST experiment participants respond to some relevant stimulus aspect, such as the color of a word or the frame color of a picture and have to ignore the word or picture itself. The words or pictures are either positive (e.g., baby), negative (e.g., snake), or neutral (e.g., table). The emotional Stroop effect denotes the slowdown of response with affective compared to neutral stimuli. The widely acknowledged explanation of this slowdown holds that affective stimuli automatically capture the observer's attention and, thus, interfere with the processing of task-relevant information. Thus, information processing is hampered when a valent stimulus is present (Pratto & John, 1991).

Although this explanation almost suggests itself, it might portray an incorrect or at least incomplete picture of valence effects in the EST. Specifically, there is reason to believe that the affect of valent stimuli has its greatest impact at some time later than the actual presentation. That is, a valent stimulus might not directly impact performance in the trial in which it is presented, but at least one trial later. Some evidence for this view comes from paradigms closely related to the EST. For example, in the affective priming paradigm, participants name a target picture that is preceded by an irrelevant prime picture some hundred milliseconds before. Although the valence of these stimuli is task-irrelevant, responding to the target is often faster when the target is preceded by an affectively congruent rather than incongruent prime (e.g., Spruyt, Hermans, De-Houwer, & Eelen, 2002). Basically, a sequence of two trials in the EST resembles the structure of events in the affective priming paradigm. There is a stimulus with irrelevant valence (and a response to it) in trial n–1, which is followed, a few hundred milliseconds later, by another valent stimulus in trial n. Thus, a valent stimulus in trial n–1 might exert effects similar to a prime in the affective priming paradigm. In this case one would predict a sequential congruency effect, that is, processing is facilitated when the valence in trial n–1 matches that of trial n.

Another indication of the possibility of sequential effects in the EST comes from effects of brief affective states on the processing of valence information. It has been shown that stimuli that are affectively congruent to the observer's current affective state exert less interference than affectively incongruent stimuli. For example, words are classified more quickly as adjective or noun when the valence of the word is congruent to performance feedback from an immediately preceding trial. Thus, the word "faithful" is classified more quickly as an adjective after a trial

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with positive rather than negative feedback (Experiment 4, Rothermund, 2003; Rothermund, Wentura, & Bak, 2001). This suggests that the task-irrelevant valence of words causes less interference when congruent to the feedback-induced affective state of the observer. Such a rejection of affect-congruent information might be part of a counterregulatory mechanism that prevents an escalation of affective states. It does not seems too far-fetched to assume that valent stimuli in the EST (e.g., a gun) induce brief affective states as well. If a valent stimulus in trial *n*–1 does briefly induce a corresponding affective state, this might consequently reduce the interference from stimuli of state-congruent valence in trial *n*, in a similar way as feedback from a previous trial does so.

Finally, there is also evidence from the EST itself that points to the possibility of valence effects on subsequent trials. For example, if the emotional Stroop effect occurs exclusively at the individual trial level it should not matter whether valent and neutral stimuli are mixed or blocked. In other words, the effect should emerge independent of the preceding trial history. However, the response-time difference between valent and neutral stimuli is larger when these stimuli are blocked rather than mixed (Algom, Chajut, & Lev, 2004; Richards, French, Johnson, Naparstek, & Williams, 1992). This suggests that valent stimuli delay responses some trials after their actual presentation, which would inflate the valent-neutral difference when valent trials are blocked but attenuate it when they are mixed with neutral trials. In line with this idea, McKenna and Sharma (2005) observed that a negative word in a sequence of neutral words delays responses one trial later than its actual presentation.

To summarize, there is preliminary evidence from the EST and from related paradigms which suggests that emotional stimuli extend to affect information processing in trials after their presentation. The purpose of the present study was to explore such sequential trial effects in more detail. We asked whether the emotional quality of a picture in trial *n* of the EST affects the way an emotional picture in trial *n*+1 impacts performance. From the foregoing review of the literature it should become clear that different types of sequential effects might ensue. First, valent stimuli, particularly negative ones, might delay responses in the subsequent trial compared to neutral stimuli (McKenna & Sharma, 2005). Second, content-specific sequential effects might occur as well, that is, the impact of a positive or negative stimulus might depend on the valence of the previous stimulus. If the previous-trial valence has effects similar to a prime in the affective priming paradigm, faster responding is predicted when stimulus valence repeats from trial *n*–1 to trial *n* (Spruyt et al., 2002). The same result is predicted if we assume that stimuli in trial *n*–1 induce a brief affective state, which then prompts less interference from stimuli with affect-congruent valence in trial *n* (Rothermund, 2003).

To study the impact of previous-trial valence we employed a standard EST paradigm with pictures as the irrelevant carrier of valence. Pictures were used because they appear to produce more robust affective-priming effects than words (e.g., Spruyt et al., 2002).

Method

Participants

Participants were 126 students (77 women, mean age 23.18 years, *SD* = 4.29) with normal or corrected-to-normal vision.

Apparatus and Materials

Participants were tested individually. They were seated in front of a 15 in. (38 cm) monitor with a resolution of 1024 × 768 pixels that was connected to a personal computer. Each trial started with a 500 ms white cross at screen center on a gray background. Following 500 ms after fixation-cross offset, a picture (240 × 183 pixel) with one of the four colored frames appeared until the participant responded or 3,000 ms had elapsed. Participants responded with the keys 4, 5, 6, and 8 on the number block of a standard PC keyboard, which were pressed with the index finger of the right hand. Following a 1000 ms intertrial interval the next trial started.

Emotional Picture Stroop Tasks

Forty-five pictures from the International Affective Picture system (IAPS; Lang, Bradley, & Cuthbert, 1999) served as stimuli. Fifteen pleasant (number 1463, 1710, 2040, 2091, 2150, 2170, 2340, 2360, 2550, 2660, 4599, 4641, 5001, 5260, 8162 from the IAPS), 15 unpleasant (1050, 1930, 2750, 2900, 3030, 3160, 3280, 3350, 6260, 6510, 6530, 9290, 9300, 9560, 9911), and 15 neutral (2190, 2210, 2250, 2840, 7000, 7002, 7006, 7010, 7030, 7050, 7080, 7090, 7100, 7217, 7550) pictures were used. Valence was estimated by 10 independent judges using the valence dimension of the Self-Assessment Manikin (SAM; Bradley, Greenwald, & Hamm, 1993), which is a 9-point visual rating scale with the endpoints 1 (*very unpleasant*) and 9 (*very pleasant*). The inter-rater consistency for the selected pictures was high ($\alpha = .98$) and the mean of the ratings was 7.43 for pleasant pictures, 4.84 for neutral pictures, and 2.05 for unpleasant pictures. Thus, the selected pictures differed significantly in valence, $F(2, 42) = 1306$, $p < .001$.

Each picture was presented four times with a colored frame (each picture with a red, yellow, green, and blue frame), resulting in 180 test trials. A random order of test trials was created, which was constant across participants. Test trials were presented in three test-blocks with 60 trials each. Participants were allowed to take a break after each block. Prior to the test trials, each participant received a

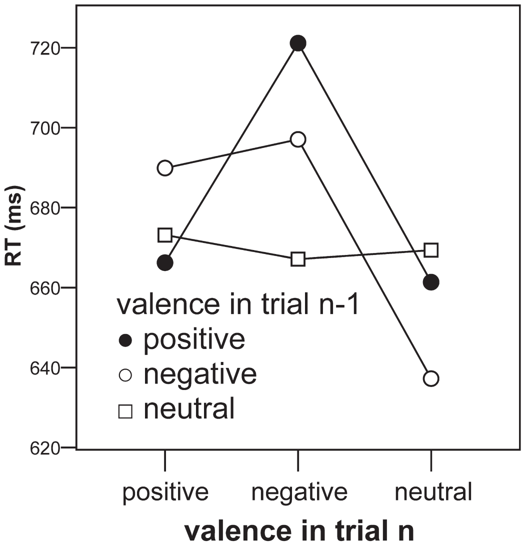

Figure 1. Mean reaction times as a function of picture valence in trial n and trial n–1.

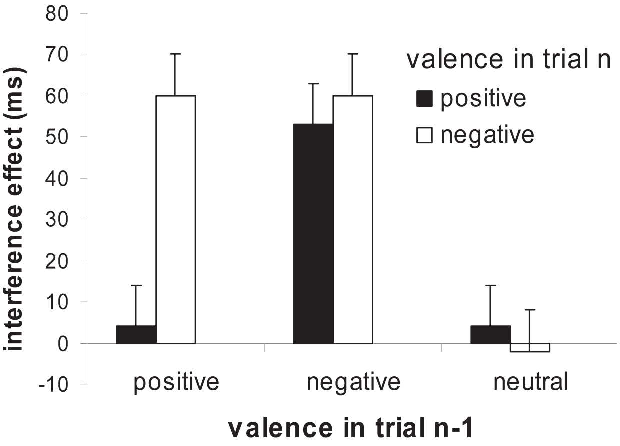

Figure 2. Mean interference effect (RT with positive/negative stimuli minus RT for the corresponding neutral condition) as a function of picture valence in trial n–1 and trial n. Errors bars represent 95% confidence intervals of the means.

practice block with 20 trials. Participants were told to react as fast but also as accurately as possible to the frame color by pressing one of the four response keys.

Results

The first trial in each block, trials following incorrect responses, and trials with response times below 100 ms or above 1500 ms were discarded. These criteria applied to 9% of the data. For each participant mean reaction times (RT) were calculated for all possible combinations of stimulus valence in trial n and stimulus valence in trial n–1. Mean reaction times for these nine combinations of valence in trial n and trial n–1 are shown in Figure 1.

Participants' mean RTs were entered into a 3 × 3 analysis of variance (ANOVA) with the within-subjects factors stimulus valence in trial n (pleasant, unpleasant, neutral) and stimulus valence in trial n–1 (pleasant, unpleasant, neutral). The analysis revealed a significant main effect of stimulus valence in trial n, $F(2, 250) = 107.10$, $p < .01$. Responding to negative pictures (695 ms) was, on average, slower than to positive pictures (676 ms), which was slower than to neutral pictures (656 ms). Single comparisons revealed that all three pairwise differences were significant, all t values (125) values > 6.1; all p values < .001. Additionally there was a main effect of stimulus valence in trial n–1, $F(2, 250) = 12.91$, $p < .01$. Responding was slower when the previous trial was positive (683 ms) than when it was negative (675 ms) or neutral (670 ms). Single comparisons revealed that the difference between previous positive and negative pictures, $t(125) = 3.24$; $p < .01$, as well as the difference between previous positive and neutral pictures in trial n–1 were significant, $t(125) = 5.13$; $p < .001$. The difference between negative and neutral pictures in trial n–1 just missed significance, $t(125) = 1.85$, $p < .07$.

Most importantly, there was a significant interaction of valence in trial n and trial n–1, $F(4, 500) = 42.73$, $p < .01$. When the previous trial contained a neutral picture, the picture valence in the present trial had no effect. When the previous trial contained a negative picture, both positive as well as negative pictures delayed responses compared to a neutral stimulus in trial n. When the previous trial contained a positive picture, negative but not positive pictures delayed responses in trial n[1].

To analyze the interaction of n × n–1 valence in more detail, we computed the size of the emotional Stroop effect in the present trial for each type of valence in the previous trial; that is, we subtracted from RTs to positive and negative pictures the RTs to neutral pictures separately for each type of valence in the preceding trial. The interference effect for positive and negative pictures as a function of the valence in the previous trial is shown in Figure 2. There was no interference when the preceding trial was neutral (both p values > .28 for a one-sample t-test against zero). Negative pictures caused significant interference independent of whether the preceding trial contained a positive or negative picture (both p values < .001), whereas positive pictures interfered when the preceding trial contained a

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[1] To estimate the robustness of this complex and somewhat unpredicted interaction we created several random samples of participants (e.g., odd vs. even numbered participants). The data pattern for RTs as well as for error rates was identical in these random samples, and subgroup (e.g., whether a participant was odd or even numbered) caused no effects or interactions whatsoever when entered as factor in the above analysis ($F < 1$). Thus, the interaction found in the whole sample was replicable in random subsamples of participants as well. We thank a reviewer for the suggestion of this analysis.

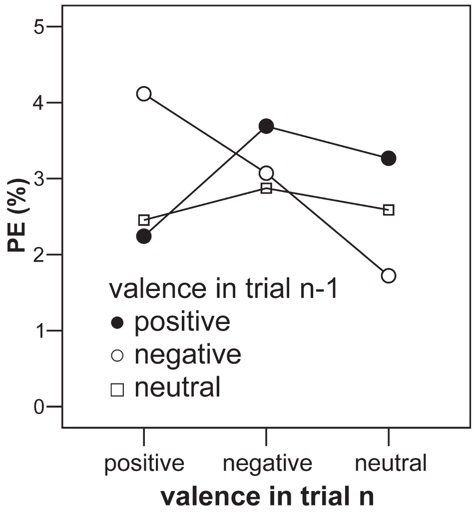

Figure 3. Percentage of errors as a function of picture valence in trial *n* and trial *n*–1.

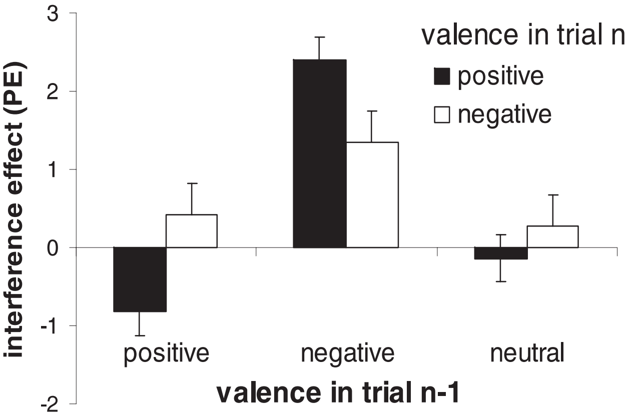

Figure 4. Mean interference effect (PE with positive/negative stimuli minus PE for the corresponding neutral condition) as a function of picture valence in trial *n*–1 and trial n. Errors bars represent 95% confidence intervals of the means.

negative picture ($p < .001$), but not when it contained a positive picture ($p > .38$)[2].

The mean error rate was 2.9%. The only significant effect in the analysis of error rates was the interaction of valence in trial *n* and trial *n*–1, $F(4, 500) = 7.50$, $p < .001$. As can be seen in Figure 3, this interaction was very similar to the one found in RTs. The interference effect in error rates for positive and negative pictures as a function of the valence in the previous trial is shown in Figure 4.

Discussion

The present study investigated whether the impact of task-irrelevant valence information changes as a function of the valence of previous irrelevant stimulation in the Emotional Stroop task. The answer is clear-cut: Yes, it does. Yet, the specific form of this sequential modulation is complex and does not comply with a simple model of irrelevant valence processing. When the preceding trial was neutral, a subsequent valent stimulus left essentially no trace in behavior. This result accords with the idea that the behavioral effects of valence take time to evolve and do not show up right away in the trial where they are presented but at least one trial later. Yet, the effect of a previous valent stimulus was not to simply delay responses (McKenna & Sharma, 2005). Rather a valent stimulus seemed to set the stage for the impact of subsequent valence information. Following a positive stimulus only negative stimuli interfered with responding whereas positive stimuli did not. Yet, after negative stimuli, positive as well as negative stimuli caused interference.

What model explains these sequential valence interference effects? If one confined the discussion of the data to those conditions where positive/negative stimuli were presented in subsequent trials, the results would accord well with previous reports of decreased interference from stimuli with valence congruent rather than incongruent to preceding events (cf. Figure 1): With a positive stimulus, performance was worse when a negative rather than a positive stimulus preceded, and with a negative stimulus, performance was worse when a positive rather than a negative stimulus preceded. Such reduced interference from stimuli with valence congruent to previous events might either reflect processes of affective counterregulation (Rothermund, 2003) or a spread of inhibition of previous distracting valence to subsequent valence-congruent distracting stimuli (Pratto, 1994). Yet, things become a bit more complicated when interference is expressed as the performance difference between positive/negative stimuli and corresponding neutral stimuli, as is usually done in the EST (cf. Figure 2). Then it would have to be explained why there was interference from negative stimuli following negative ones, and why there was little interference from valent stimuli following neutral stimuli.

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[2] The pictures might differ in other dimensions as valence, such as arousal. To obtain a quantitative estimate of such arousal differences we used the normative arousal scores supplied with the IAPS picture set (Lang et al., 1999). The mean arousal scores for positive, negative, and neutral pictures were 4.8, 5.8, and 2.5 on a rating scale from 1 to 9. To test if the present sequential effects were affected by differences in arousal we spilt each valence set into high and low arousing pictures (according the median of arousal scores). Low arousing pictures had an average arousal score of 4.0 and high arousing pictures of 5.0. Thus, differences between low and high arousing pictures were at least in the range of the arousal differences between positive and negative pictures. We then entered arousal in the previous trial (high or low) as an additional factor into the ANOVA reported above. This left the interaction of valence in trial *n* and trial *n*–1 almost unaffected, $F(4, 500) = 1.32$, $p > .26$ for the interaction of previous arousal × current valence × previous valence. Thus, it seems unlikely that the present sequential effects of stimulus valence are mediated by differences in arousal.

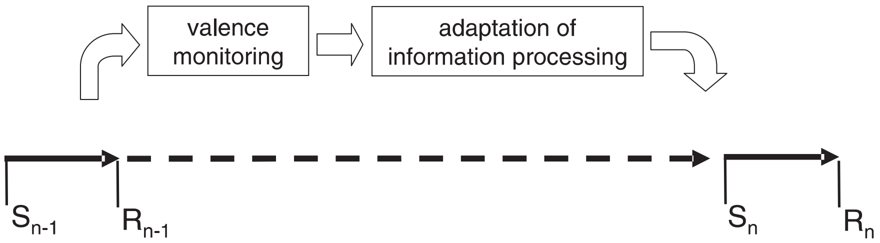

Figure 5. A two-process model of sequential effects in the emotional Stroop task.

We, therefore, suggest an explanation of these results in a slightly different framework, the sequential evaluation check (SEC) model (Scherer, 2001). The SEC model assumes an initial relevance check of stimuli, the outcome of which determines subsequent regulation of information processing. The function of the relevance check is the "detection of stimulus characteristics that require attention deployment" (p. 99). Thus, the model contains two stages of valence processing, an afferent stage mediating valence registration and an efferent stage that causes changes in subsequent information processing (cf. Figure 5). The important aspect of such a two-stage model is that valence information does not interfere with cognition unconditionally, but only when previously experienced valence information has calibrated the system to encounter such information.

Even though such a model is admittedly speculative, its adaptive value is easy to see. Neutral stimuli normally indicate that nothing "important" has occurred in the environment and the organism can, thus, afford to continue to focus on task-relevant information (color in our study). Yet, a positive or negative event signals that something important outside the present task is going on and should be attended to. In this case, negative and possibly threatening events should have privileged access. In addition, positive information is particularly welcome when a negative event has occurred in order to attenuate a negative and potentially dysfunctional affective state. In this case "looking at the bright side of life" might help to cope with the consequences of having experienced a negative event. Stated inversely, attending to positive events is dispensable when already in good mood (Derryberry, 1993; Rothermund, 2003).

Further research is certainly necessary to test this model in more detail. For example, which stages of information processing are changed after exposure to valence information in the EST? These might be relatively early processes, such as changes in attention to, or perceptual suppression of, certain valent information (e.g., Derryberry, 1993; Rothermund & Wentura, 1998) or late process such as the suppression of motor responses (Wilkowski & Robinson, 2006). Another important point to be scrutinized is the generalizability of the present sequential effects. Do the same sequential effects occur with other stimuli such as words? This need not necessarily be so, because words and pictures differ in several important respects. Pictures have a higher ecological validity than words (Kindt & Brosschot, 1999), and their semantic processing is more efficient than that of words (DeHouwer & Hermans, 1994; Glaser, 1992). In fact, in another experiment with words as the carrier of valence, we found little interference from affective words at all, and not surprisingly, little evidence for sequential effects as well.

Beyond these more or less speculative theoretical implications, the present results have methodological consequences as well. These concern the use of the EST as a tool to study interference from affective stimuli. Obviously, the impact of distractive evaluative information, which the Stroop task intends to measure, is not independent of the preceding trial history. Researchers employing the EST should, thus, be aware of such sequential dependencies. Specifically, we found that the distracting impact of positive information was reduced when the previous trial contained positive or neutral information. This is important when the valence of the distracting information is presented in a blocked manner (Brosschot, de Ruiter, & Kindt, 1999; Egloff & Hock, 2001). In particular, with a blocked positive valence all current and previous trials contain positive information. With such blocking the distracting impact of positive (but not of negative) information might be smaller compared to a trial-by-trial manipulation of affective content (Richards et al., 1992).

To conclude, the present study shows that irrelevant affective stimuli determine how subsequent affective stimuli affect performance. The way they do so is in line with a two-stage model with a valence (or arousal) monitoring mechanism, the outcome of which determines how the processing of subsequent valence information is changed. It seems plausible to us that such processes have evolved to solve a notorious problem of biological organisms, namely to attend to relevant information when possible, and to attend to irrelevant information when necessary.

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