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Automatic response activation in sequential affective priming: an ERP study

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Affective priming effects denote faster responses when two successively presented affective stimuli match in valence than when they mismatch. Two mechanisms have been proposed for their explanation: (i) Priming of affective information within a semantic network or distributed memory system (semantic priming). (ii) Automatic activation of the evaluative response through the affective prime (response priming). In this experiment, we sought more direct evidence for prime-induced response activations with measurement of the lateralized readiness potential (LRP). Onset of the stimulus-locked LRP was earlier in affectively congruent trials than in incongruent trials. In addition, priming modulated the LRP-amplitude of slow responses, indicating greater activation of the incorrect response hand in affectively incongruent trials. Onset of the response-locked LRP and peak latency of the P300 component were not modulated by priming but the amplitude of the N400 component was. In combination, these results suggest that both, semantic priming and response priming constitute affective priming effects in the evaluative categorization task.

Keywords: sequential affective priming; response activation; semantic priming; lateralized readiness potential; event-related potential

Automatic evaluations of incoming stimuli direct subsequent behaviour and judgments (Fazio, 2001; De Houwer, 2009). A frequently used method to measure automatic evaluations is 'sequential affective priming' that presents two affective stimuli in rapid succession. In the evaluative decision task, participants are to evaluate the second stimulus (the target) but to ignore the first one (the prime). Typical findings are faster and less error-prone responses when prime and target are affectively congruent (i.e. positive–positive, negative–negative) than when they are incongruent (i.e. positive–negative, negative–positive). This affective priming effect is assumed to reflect automatic evaluations of the primes that facilitate responding in congruent trials and delay responses in incongruent trials (Fazio *et al.*, 1986; for reviews see Klauer and Musch, 2003; De Houwer *et al.*, 2009).

To explain affective priming effects in the evaluative decision task, two accounts have been proposed. (i) A 'semantic priming account' that explains affective priming with a pre-activation of evaluatively congruent targets via spreading activation in a semantic network or via semantic pattern priming in a distributed memory system (e.g. Bargh *et al.*, 1996; Fazio, 2001; Spruyt *et al.*, 2007). (2) A 'response priming account' that proposes that affective primes automatically activate the corresponding evaluative response that is the correct one in congruent trials but the incorrect one in incongruent trials (e.g. Klinger *et al.*, 2000; De Houwer *et al.*, 2002). Whereas evidence from some behavioural studies supported the semantic priming account, evidence for the response priming account has also been obtained in other studies.

Evidence supporting the semantic priming account comes from affective priming studies that demand naming the target or lexical decision. In these tasks, affective prime-target congruency is unrelated to the response to the target, ruling out response priming as an alternative account. Several studies observed affective priming effects in lexical decision and naming tasks (e.g. Hermans *et al.*, 1994; Bargh *et al.*, 1996), but others failed to replicate these results (Klauer and Musch, 2001; Spruyt *et al.*, 2004) or yielded even opposite results (i.e. an incongruency advantage; Glaser and Banaji, 1999). Recent research has revealed that affective priming effects in naming tasks are robust only when attention is paid to the evaluative meaning of the primes (e.g. De Houwer and Randell, 2002; Spruyt *et al.*, 2009). Thus, affective priming effects were found to be conditional upon a distal evaluation goal that warrants affective processing of the primes.

Evidence favouring the response priming account comes from studies that show an influence of response-related factors on affective priming effects. When participants' task is to judge the valence of the target (i.e. to make a binary evaluative decision), prime-target congruency is confounded with a correspondence relation between the evaluative response and the prime, because the evaluative response to the target corresponds with the valence of the prime in congruent trials but not in incongruent trials. Provided that affective primes automatically activate the corresponding

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evaluative classification response, affective priming effects can then be explained with a response synergy in congruent trials and with a time-consuming response conflict in affectively incongruent trials. In line with this hypothesis, several studies showed that affectively related prime-target pairs engender affective priming effects in the evaluative decision task but not in other semantic decision tasks (Klinger *et al.*, 2000; De Houwer *et al.*, 2002; Klauer and Musch, 2002). This evaluative task-goal dependency is at odds with a semantic priming account that predicts affective priming irrespective of the judgment task as long as the prime-target pairs are sufficiently (i.e. semantically) processed, and supports a response competition account of affective priming effects.

In summary, the extant literature provides mixed support for a locus of affective priming effects in semantic priming and response priming. Rather than being exclusive, however, both processes might underlie affective priming effects in the evaluative decision task. To determine their relative contribution, Klauer *et al.* (2005) randomly mixed two semantic decision tasks to separate semantic priming from response-related priming effects. Their data revealed both semantically and response-mediated priming effects, though response-related priming effects were much larger than semantically mediated priming effects. Thus, both priming processes might mediate affective congruency effects in the evaluative decision task.

Distinguishing semantic from response-related processes in affective priming, however, is difficult with behavioural data alone, because behavioural performance represents the combined output of both of these processes (and others). In contrast, event-related potentials (ERPs) provide a continuous window to the neural processes from stimulus presentation to response. Moreover, certain components of the ERP are known to be specifically related to different subprocesses. For the present purposes, complementing behavioural data with specific components of the ERP may therefore elucidate the relative contribution of semantic priming and response priming more directly. To date, two studies have investigated electrophysiological correlates of affective priming in an evaluative categorization task. Zhang *et al.* (2006; see also Zhang *et al.*, 2010) recorded ERPs while participants evaluated words that were preceded either by affective words or by affective pictures. Affective congruency modulated the N400 component, with incongruent trials eliciting larger N400 amplitudes than congruent trials. The authors interpreted the underlying mechanisms for this N400 priming effect in terms of spreading of activation within an evaluative-semantic network or integration of affective information. However, an electrophysiological index of response priming was not assessed in this study.

The role of response competition in affective priming was more closely examined by Bartholow *et al.* (2009). In their study, an activation of the prime-related response was evident even before target onset in the lateralized readiness potential (LRP), indexing relative response activation in the motor cortex (Coles, 1989). In addition, the proportion of affectively congruent prime-target pairs was varied between 80, 50 and 20% of the trials (cf. Klauer *et al.*, 1997). Significant LRP effects indicating an automatic activation of the prime-related response were observed only if the primes predicted the valence of the target above chance. Furthermore, the amplitude of the N2-component, which is thought to index the magnitude of response conflict detected by the anterior cingulate cortex (e.g. van Veen and Carter, 2002), was increased in affectively incongruent trials even when target valence was not predictable from the prime (50% congruent trials), whereas congruent trials evoked a larger N2-response when the consistency proportion was low (20% congruent trials). Onset and amplitude of the P300 component, indexing the ease or speed of evaluative target categorization (e.g. Kutas *et al.*, 1977; but see Verleger, 1997), were not modulated by affective congruency. The authors concluded from this pattern of electrophysiological data a locus of affective priming effects in response-related conflict rather than in the ease of target categorization (see also Bartholow, 2010).

To sum up, electrophysiological studies disagree about the relative involvement of response-related and semantic processes in sequential affective priming. This inconsistency might in part be due to differences in procedure, material and electrophysiological measures across studies. Furthermore, no study has provided positive evidence to date that the behavioural classification response is automatically activated by the evaluative category of the prime alone. In the present research, we therefore conducted a standard affective priming experiment that included separate electrophysiological measures of response-related and semantic priming processes. We reasoned that, when keeping material and procedure constant while measuring ERPs, the relative contribution of response priming and semantic priming to affective congruency effects in the evaluative decision task can be more accurately assessed.

THE PRESENT STUDY

In the present experiment, response priming was assessed with measurement of the LRP which is an online marker of relative response activation (for an introduction and overview see Coles, 1989 or Eimer, 1998) that is mainly generated within M1 (Leuthold and Jentzsch, 2002). The LRP is based on the readiness potential (RP), which exhibits greater negativity over the motor cortex contralateral than ipsilateral to the responding hand as soon as a specific (left *vs* right) hand response is activated (Kutas and Donchin, 1980). This RP characteristic is used in the calculation of the LRP (see 'Method' section). Basically, it is assumed that the LRP reflects the relative activation of left and right responses, with the LRP beginning to deviate from baseline as soon as task-configured information about the specific response is available. Thus, in tasks in which a target stimulus is preceded by a precue or prime, the LRP can be used to determine whether and to what extent a response is activated by the prime prior to or shortly after the onset of the target (Gratton *et al.*, 1988; Eimer, 1995; Leuthold and Kopp, 1998). In the evaluative categorization task with two evaluative categories (good *vs* bad) mapped onto opposite hands, the amplitude and the polarity of the LRP can hence be used to determine whether a response is activated by the evaluative category of the prime. Furthermore, the onset of the LRP can be analysed to determine the point in time at which response-hand selection is completed and motor programming starts (Masaki *et al.*, 2004). For this chronometric analysis, an important characteristic of the LRP is its onset in waveforms time-locked to the onset of either the stimulus or the overt response (Leuthold *et al.*, 1996). The interval from stimulus onset to the onset of the LRP (stimulus-locked LRP interval) indicates the duration of those processes occurring before start of the LRP, including perception and at least some aspects of response selection. The interval between onset of the LRP and the overt response (response-locked LRP interval) indicates the duration of those processes that occur after LRP onset. In short, the S-LRP and the LRP-R intervals could be analysed as chronometric markers for the duration of premotoric and motoric processing stages in affective priming, respectively.

In addition to LRP, ERPs were measured that are primarily sensitive to categorization-related processes. First, the latency of the P300 (or P3) component was analysed to index the speed or ease at which evaluative target categorization occurs. Several studies have shown that the amplitude and latency at which the P300 component peaks increases as stimulus evaluation becomes more difficult (e.g. Johnston *et al.*, 1986; Liu *et al.*, 2010). On the basis of the hypothesis that congruent primes facilitate target encoding, P300 should peak earlier when prime and target share an evaluative category (i.e. when target evaluation is easy) than when they belong to opposite evaluative categories.

Second, the N400 response was used to index processing of affective mismatches between primes and targets. The N400 component is a broad negative deflection of the ERP that is sensitive to semantic violations and to manipulations of the context in which linguistic stimuli are processed (e.g. Kutas and Hillyard, 1980). Considerable research has demonstrated that semantically incongruent prime-target pairs evoke a larger N400 response than semantically congruent pairs, irrespective of response requirements (for an overview see Lau *et al.*, 2008). This N400 effect has been interpreted in terms of spreading of activation within a semantic network (e.g. Kiefer, 2002) or integration of semantic information (e.g. Chwilla *et al.*, 1998). Thus, the amplitude of the N400 should be greater in affectively incongruent trials than in affectively congruent trials.

ERPs were recorded during a standard affective priming experiment, with affective pictures as primes and words as targets. A picture–word variant was favoured for several reasons: (i) The different representational format of words and pictures eliminates any confusion of primes with targets that might alternatively explain response tendencies towards the primes. (ii) Evidence is available that an affective congruency relation between word pairs is often confounded with a perceptual overlap on a word-fragment or letter level (e.g. Abrams and Greenwald, 2000; Abrams, 2008). The different perceptual format of pictures and words rules out any systematic correspondence relation other than the affective one. (iii) Research has shown that affective pictures are evaluated faster than words, suggesting that pictures have a privileged access to a semantic network containing affective information (De Houwer and Hermans, 1994). Thus, affective pictures should prime evaluative decisions more effectively than affective words.

METHOD

Participants

A total of 24 students (21 women) aged between 18 and 27 years ($M = 21.7$) participated in exchange for payment or for partial course credit. All participants were right-handers and had German as first language.

Apparatus and stimuli

Participants were seated at a distance of ~100 cm from a 17 VGA colour monitor. A constant viewing distance was provided by a fixed chin rest. Participants entered the responses into the keyboard with a press of the spacebar using their left hand and with a press of the enter key of the numerical board using their right hand.

Targets were 30 positive and 30 negative adjectives that were selected from a standardized word pool according to their evaluative norms (Schwibbe *et al.*, 1981; see Appendix 1). The subsets of positive and negative adjectives did not differ in extremity of valence, frequency of usage and number of letters (range: 4–9), with P's > 0.30. Affective primes were 30 positive and 30 negative pictures selected from the International Affective Picture System (Lang *et al.*, 2005; see Appendix 1). Additional sets of 16 words and 16 pictures (8 positive, 8 negative) were used for task practice and warm-up trials. Pictures were displayed in full resolution (1024×768 pixel) at the screen. Words were shown in red colour (Courier New, point size 14) on a white background at the screen centre.

Design

The experimental design was a 2 (prime valence: positive *vs* negative) $\times$ 2 (target valence: positive *vs* negative) repeated-measures design. Each block consisted of 30 trials from each of the four conditions of the design, resulting in 120 trials per block that were presented in random order. Each participant worked through four experimental blocks, resulting in 240 affectively congruent (positive–positive, negative–negative) and 240 affectively incongruent (positive–negative, negative–positive) prime-target combinations. Each stimulus was shown twice in each block, with random prime-target pairing. In the list construction, assignment of the stimuli to affectively congruent and incongruent trials was balanced in each block [i.e. each picture (word) was paired once with an affectively congruent and once with an affectively incongruent word (picture)], to keep the material constant across the priming conditions. Assignment of the left and right response keys to target valence was counterbalanced across participants.

Procedure

Participants were seated in a dimly lit, electrically shielded and sound-attenuated chamber. To familiarize the participants with the task, each experimental session started with two practice blocks that consisted of 16 trials each. In the first practice block, each trial started with the presentation of a white fixation cross (300 ms), a picture (150 ms) and a red word that remained on the screen for 1 s. Thus, SOA was set to 150 ms. Participants were instructed to evaluate the word as quickly and accurately as possible but to ignore the picture. Correct responses were signalled to the participant with a green exclamation mark that stayed on the screen for 500 ms. In case of an incorrect response or a response omission, the exclamation mark was coloured red. The next trial started after a random time interval between 600–1200 ms.

In the second practice block, a response window was introduced for the evaluative decision. The word was presented for 200 ms and was replaced immediately with a backward mask (a black string of nine percentage signs presented for 800 ms). Participants had to enter the classification response after appearance of the mask. All other procedural details were identical with those of the first block.

The sequence of events in the experimental blocks was the same as in the second practice block. Each block started with two warm-up trials that were not analysed. To encourage swift and accurate responses, participants were informed that a high number of correct and fast responses in a block would be rewarded with a bonus gratification (50 Eurocents). Response accuracy was high when responses were correct in more than 80% of the block trials. Response speed was high when latencies of more than 40% of the correct responses in a block were below the median latency of correct responses in the preceding block. After each block, a performance summary appeared whether accuracy and response speed in that block had been sufficient to gain the bonus. At the end of the session, participants were debriefed, thanked and paid for participation.

ERP recording and analysis

Electroencephalographic (EEG) activity was continuously recorded from 144 Ag/AgCl electrodes mounted in an elastic cap using a BioSemi ActiveTwo system (BioSemi, Amsterdam, Netherlands). The electrode sites corresponded to the standard BioSemi 128-channel arrangement, with 16 additional electrodes located below the standard positions at inferior occipitotemporal and temporal sites (for details of electrode arrangement see Wiese *et al.*, 2008). EEG signals were sampled at a rate of 256 Hz.

Contributions of blink artefacts were corrected off-line using the adaptive artefact correction method of Brain Electromagnetic Source Analysis (BESA) software (Ille *et al.*, 2002). EEG activity was re-referenced to an average mastoid reference. Trials with any EEG artefacts (exceeding $\pm 60\,\mu V$, drifts, channel blockings) and trials with incorrect behavioural responses were discarded. The analysis epoch for the stimulus-synchronized ERP waveforms started 200 ms before prime onset and lasted until 1050 ms after target onset. For response-locked ERPs, the epoch started from 1000 ms before until 350 ms after response onset. EEG activity was band-pass filtered (0.03–30 Hz), averaged time-locked to prime onset (S-locked data) or to response onset (R-locked data). EEG activity was averaged time-locked to either stimulus or response onset.

In addition, for each participant and each experimental condition the ERP at the recording site over the motor cortex ipsilateral to the response hand was subtracted from the ERP at the homologous contralateral recording site (i.e. ERP[C4′] minus ERP[C3′] for left hand and ERP[C3′] minus ERP[C4′] for right hand responses). In order to eliminate any ERP activity unrelated to hand-specific motor activation, the LRP was calculated by averaging the resulting difference waveform across hands, separately for congruent and incongruent conditions (Coles, 1989; Eimer, 1998). Deviations of the resulting LRP from zero toward increased negativity (positivity) indicated activation of the (in)correct response hand at the level of the motor cortex.

P300 peak latency was measured as the interval between target onset and the time point of maximal positivity at the Pz electrode in a search window from 250 to 500 ms, using a computerized peak-picking procedure. Based on visual inspection of grand mean ERP waveforms, and similar to other ERP priming studies (e.g. Kiefer, 2002; Zhang *et al.*, 2010), mean N400 amplitude was determined at midline electrodes CPz, Pz and POz in the time interval 400–550 ms after target onset. LRP onsets were measured in low-pass filtered (5 Hz, 6 db/octave) waveforms and analysed by applying the jackknife-based procedure suggested by Miller *et al.* (1998) and Ulrich and Miller (2001). Specifically, 24 different grand average LRPs for each of the experimental conditions were computed by omitting from each grand average the data of a different participant. LRP onsets were determined in each of the 24 grand average LRP waveforms of each congruency condition. The stimulus-synchronized LRP waveform (S-LRP) was aligned to a 100-ms baseline before target onset, whereas the response-synchronized LRP waveform (LRP-R) was referred to a 100-ms baseline starting 550 ms before response onset. As recommended (Miller *et al.*, 1998), the S-LRP onset was determined at the point in time when LRP amplitude reached 50% of maximal LRP amplitude in that specific condition, whereas onsets in the LRP-R waveforms were obtained using a relative LRP amplitude criterion of 30%. Additionally, S-LRP and LRP-R onset latencies were determined at the time point when LRP amplitude exceeded $-0.5\ \mu V$ in order to control the stability of LRP onset effects.

Statistical analyses were carried out using repeated-measures analyses of variance (ANOVAs) with degrees of freedom Greenhouse–Geisser corrected where appropriate. LRP onset latency measures were submitted to ANOVAs with F-values corrected as follows: $F_C = F/(n-1)^2$, where F_C denotes the corrected F-value and n the number of participants (Ulrich and Miller, 2001).

RESULTS

Behavioural data

Participants did not respond before the response deadline in 2.2% of the trials. Trials with incorrect responses (7.7% of all trials) were discarded from reaction time analyses. Reaction time was measured from target onset. Affective priming effects were computed by subtracting mean performance (RT, error rate) in the congruent trials from performance in the incongruent trials (i.e. affective priming effect = $M_{incongruent} - M_{congruent}$). Table 1 shows mean RT and error rate within each affective prime-target combination.

An ANOVA of the reaction times with prime valence and target valence as factors yielded no main effect of target valence, $F < 1$. The main effect of prime valence was significant, $F(1, 23) = 29.42$, $P < 0.001$, with slower responses when a negative prime was presented. The interaction between prime and target valence was highly significant, $F(1, 23) = 34.83$, $P < 0.001$. Participants responded on average 17 ms slower in incongruent trials than in congruent trials, yielding a strong affective priming effect (Cohen's $d = 1.22$).

An ANOVA of the error rates with prime and target valence as factors corroborated the reaction time analyses reported above. Incorrect responses were less frequent in congruent trials than in incongruent trials ($\Delta M = 2.2\%$, $d = 0.80$), $F(1, 23) = 15.22$, $P < 0.001$. In addition, errors were more frequent when a negative prime was presented, $F(1, 23) = 7.24$, $P < 0.05$. The main effect of target valence was not significant ($F < 1$).

Event-related potentials

Lateralized readiness potential

Figure 1 depicts the stimulus-locked LRP waveforms for congruent and incongruent conditions. ANOVA results of the S-LRP interval values for the two onset criteria are shown in Table 2. LRP onset measures were submitted to an ANOVA with repeated measures on the factor affective congruency (congruent *vs* incongruent). The ANOVA revealed a shorter S-LRP interval for congruent than for incongruent trials ($M = 455$ *vs* 511 ms; values given for the 50 % criterion), $F_C(1, 23) = 25.1$, $P < 0.001$. An analogous effect was seen for the absolute LRP-onset criterion as well (Table 2). The response-synchronized LRP waveforms are depicted in Figure 2. In contrast to the results for the S-LRP interval there was no reliable effect of affective congruency on the LRP-R interval, $F_C < 1$ (see Figure 2 and Table 2). Motoric processing time was ~176 ms in both congruent and incongruent trials.

Even though the present data show the predicted increase in the S-LRP interval in the incongruent condition, there was no evidence for an activation of the incorrect hand within

Table 1 Mean response time (RT in ms), mean percentage error (PE) as a function of prime and target valence (s.d. in parentheses)

	Target			
	Positive		Negative	
Prime	RT	PE	RT	PE
Positive	634 (55)	6.7 (5.7)	654 (50)	7.6 (6.3)
Negative	661 (58)	10.1 (8.1)	647 (53)	6.6 (4.2)

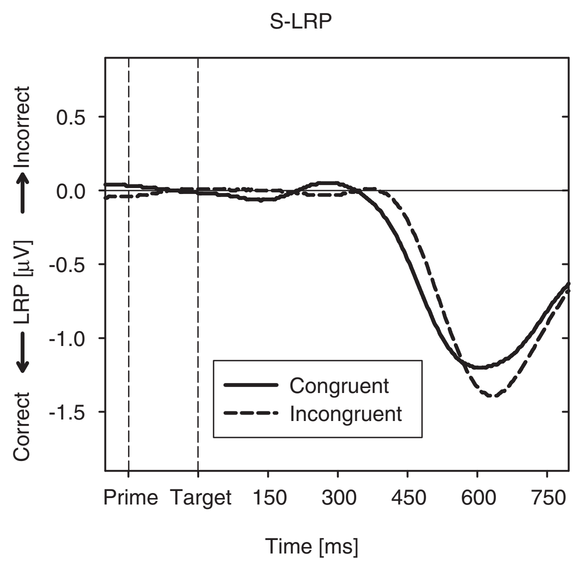

Fig. 1 Grand mean stimulus-locked lateralized readiness potential (S-LRP) waveforms as a function of affective congruency (congruent *vs* incongruent).

Table 2 F_C-values of the ANOVA for the congruency effect on the S-LRP Interval and on the LRP-R interval for relative onset criteria (50 and 30%, respectively) and fixed onset criterion ($-0.5\ \mu V$)

		S-LRP interval		LRP-R interval	
		50%	$-0.5\ \mu V$	30%	$-0.5\ \mu V$
Congruency	$F_C(1, 23)$	14.83***	4.33*	0.0002****	0.018****
Congruent		478	464	176	182
Incongruent		524	502	176	184

Mean S-LRP and LRP-R Intervals (in ms) as a function of congruency.
$^*P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$; $^{****}P > 0.85$ (non-significant).

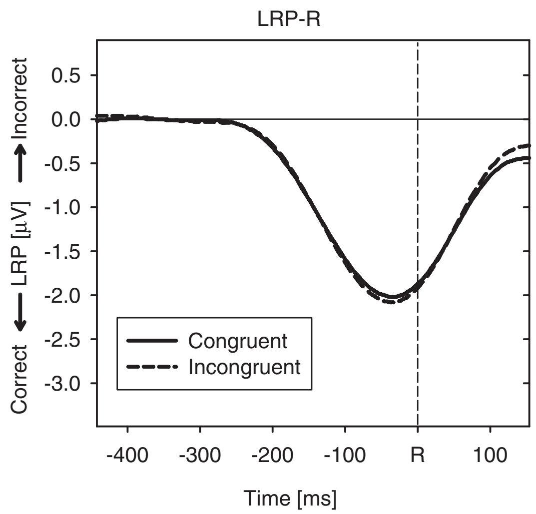

Fig. 2 Grand mean response-locked lateralized readiness potential (LRP-R) waveforms as a function of affective congruency (congruent *vs* incongruent). R = response onset.

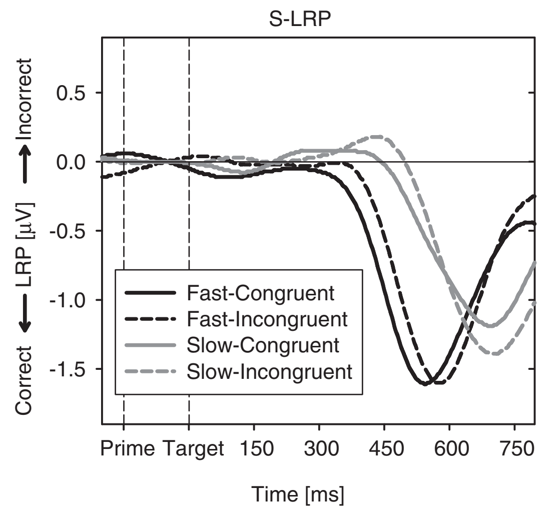

Fig. 3 Grand mean stimulus-locked lateralized readiness potential (S-LRP) waveforms as a function of response speed (fast *vs* slow) and of affective congruency (congruent *vs* incongruent).

the incongruent condition (i.e. a positive going LRP in the incongruent condition). It should be noted, however, that eliminating trials with incorrect responses from analysis might have worked against the response priming hypothesis, because these are arguably the trials in which the incorrect response activation is strongest (Gratton *et al.*, 1988). In order to get a better view of incorrect response tendencies, we therefore decided to run an additional analysis that split the data into fast and slow responses. For this analysis, each behavioural response was classified as either fast or slow by comparing it to the RT median of the respective condition within each participant, and LRPs were separately calculated for fast and slow responses.[1] Given that overlap of prime-related and target-related motor activations is minimized with slow responses, we expected more conclusive evidence for erroneous response tendencies in incongruent trials when the behavioural response was emitted slowly.

As can be seen in stimulus-synchronized LRP waveforms depicted in Figure 3, there was indeed an initial positive LRP (dip) in the incongruent condition for the slow responses, which suggests activation of the incorrect response in this specific condition. In order to determine whether this LRP dip was reliable, mean S-LRP amplitude was measured in three consecutive 50-ms intervals starting 400 ms after target onset. For each time window a two-tailed *t*-test was performed against zero and the LRP was considered to be present if the *t*-test was significant ($P < 0.05$).The *t*-tests indicated a reliable, positive-going LRP between 400-500 ms in the incongruent condition, t's$(23) > 2.75$, P's < 0.05. The negative-going LRP in the congruent condition was reliable in the 500-550 ms interval, $t(23) = -2.15$, $P < 0.05$. Corresponding analyses of the LRP-R interval did not yield any significant effects, with all P's > 0.10.

P300 latency

Figure 4 displays ERP waveforms for congruent and incongruent conditions at the Pz electrode. An ANOVA of P300 peak latency analogous to that of LRP onsets revealed no significant effect of affective congruency, $F < 1$, indicating that congruent and incongruent trials ($M = 399$ *vs* 403 ms) did not reliably differ in categorization time.

N400 amplitude

As can be seen in Figure 4, there was a negative-going difference with a centroparietal maximum in the time interval 400–550 ms after target onset. Based on qualitatively similar semantic and affective priming effects on N400 (e.g. Kiefer, 2002; Zhang *et al.*, 2006; Wiese and Schweinberger, 2011), we conclude that this negative difference reflects an N400 effect. An ANOVA with repeated measures on congruency and eletrode (CPz, PZ, POz) performed on mean ERP amplitudes (400–550 ms) indicated a significant main effect of affective congruency, $F(1, 23) = 9.25$, $P < 0.01$, due to more negative-going ERP amplitude for incongruent than congruent trials ($M = 8.1$ *vs* 8.6 µV). This affective priming effect was not modulated across centroparietal electrodes, $F < 1$.

Regression analyses

To elucidate the utility of the ERP responses for predicting the behavioural priming effect in slow trials, we entered in a multiple regression analysis the S–LRP (i.e. the amplitude in compatible trials subtracted from the amplitude in incompatible trials) and the N400 differences (i.e. the amplitude in incompatible trials subtracted from the amplitude in

[1] ANOVAs with response speed (fast *vs* slow) and affective congruency (congruent *vs* incongruent) as within-subjects factors revealed only trivial effects of response speed on mean RT and on the onset of the S-LRP interval. Importantly, we did not observe any interactions of response speed with affective congruency, with all P's > 0.10.

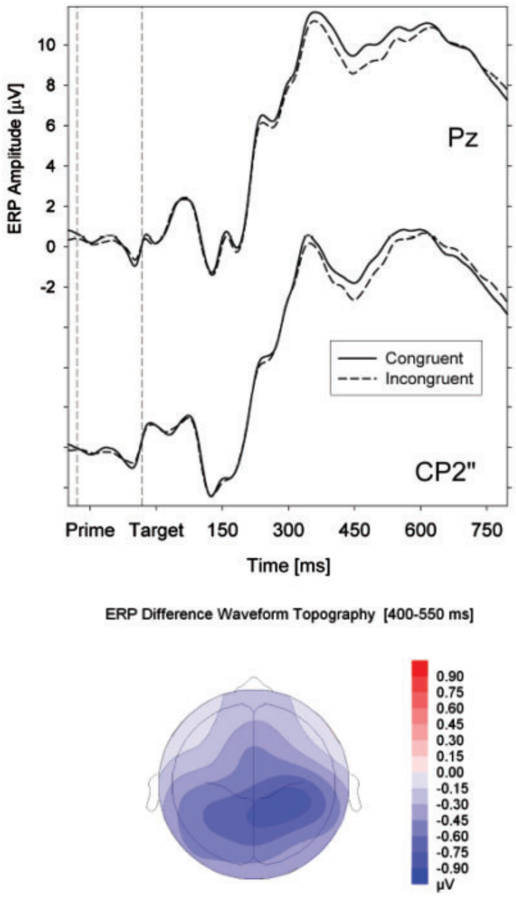

Fig. 4 Top: Grand mean stimulus-locked event-related brain potential (ERP) waveforms at electrodes Pz and CP2" (located in between CP2 and P2) as a function of affective congruency (congruent *vs* incongruent). Bottom: Topographic voltage maps (spherical spline interpolation, 90° projection) of mean ERP difference waveforms reflecting the affective congruency effect (incongruent minus congruent) in the time interval 400–550 ms after target onset. Isopotential line spacing is 0.15 µV.

compatible trials) as predictor variables of the affective priming effect (RT difference).[2] When combined, both ERPs accounted for $R^2 = 36.7\%$ of the total variance of affective priming effects, $F(2, 21) = 6.09$, $P < 0.01$. Standard score partial regression coefficients were significant for the S-LRP ($\beta = 0.57$, $t[23] = 3.21$, $P < 0.05$) and the N400 ($\beta = 0.47$, $t[23] = 2.45$, $P < 0.05$), after partialing out the effect of the other predictor. Furthermore, the regression score of the S–LRP was significantly larger than that of the N400, $\chi(1, N = 24) = 5.41$, $P < 0.05$. In short, the ERPs explained a significant portion of the total variance of the affective priming effects independently from each other, but S-LRP was a better predictor than N400.

[2]An analogous regression analysis was computed for the priming effect in fast trials. For this analysis, the data set of one participant was excluded because of an extreme outlier value in the S-LRP according to Tukey (1977). With the remaining sample ($n = 23$), neither the coefficient of determination ($R^2 = 6.7\%$) nor the standardized regression weights of S-LRP ($\beta = -0.26$) and N400 ($\beta = 0.01$) reached significance (with all P's > 0.10).

DISCUSSION

In speeded evaluative decisions, responses were faster when a to-be-ignored affective picture matched the valence of a target word than when they mismatched. Previous studies have explained such affective priming with (i) either a pre-activation of the evaluative category of the target through the prime ('semantic priming'; e.g. Fazio *et al.*, 1986) or (ii) a pre-activation of the evaluative response that corresponds with the valence of the prime ('response priming'; e.g. De Houwer *et al.*, 2002). By indexing both priming processes with distinctive electrophysiological markers, the present study provides evidence that both processes might be involved in affective priming of evaluative decisions.

Affective response priming was indexed by the LRP, an online-measure of hand-specific response activation (Coles, 1989). Affective prime-target congruency modulated the onset of the S-LRP but not the peak latency of the P300 component that is thought to index the speed of evaluative target categorization. This result pattern is in line with a response priming account that expects faster selection of the prime-corresponding evaluative response, independently of a difference in the ease of target processing. Furthermore, the affective relationship between prime and target had a clear influence on the onset of the S-LRP but not on the LRP-R interval. This dissociation argues for a locus of the priming effect in a pre-motoric processing stage of response selection rather than in motoric stages of response programming and response execution.

Most direct evidence for the response competition account is obtained from the analysis of the amplitude of the LRP that indicates to what extent a response is activated by the evaluative category of the prime. When trials with fast and slow behavioural responses were analysed separately, with minimized overlap of prime-related and target-related motor activations when responses are slow, greater activation of the incorrect response hand was observed in slow incongruent trials. This particular result suggests that in these trials the prime-corresponding response hand was automatically activated by the evaluative category of the prime. Thus, affective primes automatically activate assigned motor responses even when the target valence is not predictable from the prime, lending additional support to Bartholow *et al.*'s (2009) claim of affective response activation. Note that covert activation of a conflicting response should slow down the selection of the correct response, and was thus expected from theory to be most apparent in slow incongruent trials (Gratton *et al.*, 1988). Furthermore, controlled activation of the correct response to the target might have masked or overlaid automatic activation of the (incorrect) response through the prime when the behavioural response is selected quickly (or merely guessed). As a result, a positive dip in the LRP indicating activation of the incorrect response is apparent only in slow incongruent trials, when automatic and controlled response activations do not overlap as much in time.

Semantic priming was indexed by a N400 component with incongruent trials having larger negative amplitudes than congruent trials. Before discussing possible implications of this result, we would like to address a possible complication with the interpretation of the N400 in the priming paradigm (cf. Holcomb and Neville, 1990), which arises from the overlap with the P300 component (see Figure 4). We think that the present congruency effect in ERP amplitude reflects an N400-like effect for two reasons. Firstly, the topography of the ERP difference wave shows a posterior negativity that is slightly larger over the right than the left hemisphere (Figure 4), consistent with similar N400 asymmetries in semantic and affective priming studies (e.g. Holcomb and Neville, 1990; Zhang *et al.*, 2010). In addition, and more importantly, Zhang *et al.* (2010) found the P300 amplitude to be larger for incongruent than congruent prime-target conditions in their affective priming study. Together, we therefore view it most likely that the present ERP congruency effect mirrors an N400 effect rather than a P300-related amplitude modulation.

This N400 effect might then reflect an automatic spread of evaluative activation from prime to target, as Zhang *et al.* (2006) have proposed. Alternatively, it might index the outcome of an automatic affective matching process that follows target evaluation (Klauer and Stern, 1992; Wentura, 2000; Klauer and Musch, 2002). Irrespective of the exact underlying mechanism, the N400-response to affectively (in)congruent picture–word pairs suggests that an affective mismatch relation was detected at a processing level that is independent of stimulus format (cf. Zhang *et al.*, 2010). Accordingly, an overlapping affective system might underlie the processing of evaluative meaning represented by words and pictures.

Overall, then, the electrophysiological data suggest that both semantic priming and response priming underlie affective priming effects in the evaluative decision task. This conclusion is supported by a regression analysis that showed that the behavioural priming difference is predicted best by both processes simultaneously. This analysis additionally revealed that response priming (S-LRP) is a better predictor than semantic priming (N400). The latter observation is in line with behavioural studies that likewise found response-related affective priming effects to be larger than semantically mediated priming effects (e.g. Klauer *et al.*, 2005).

Future studies might manipulate semantic and response-related factors independently to study the underlying priming mechanisms more in detail. For instance, semantic priming, but not response priming, should be influenced when target presentation is degraded (De Houwer *et al.*, 2001); in contrast, response priming, but not semantic priming, should be affected by response practice (Klauer *et al.*, 2005). Dissociating electrophysiological correlates of affective priming mechanisms in experimental tasks might hence be a promising way to disentangle the processes that mediate affective congruency effects in the evaluation task.

Conflict of Interest

None declared.

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APPENDIX 1

MATERIALS

Positive pictures (IAPS)

1440, 1460, 1710, 1750, 1920, 2040, 2050, 2057, 2058, 2070, 2080, 2091, 2150, 2209, 2216, 2260, 2340, 2550, 2660, 5830, 5831, 5910, 7502, 8080, 8170, 8190, 8210, 8370, 8420, 8470.

Negative pictures (IAPS)

2205, 2750, 2800, 3010, 3015, 3064, 3120, 3180, 3230, 3301, 3350, 3530, 6212, 6313, 6350, 6540, 6560, 9007, 9040, 9220, 9252, 9253, 9410, 9433, 9570, 9571, 9800, 9810, 9910, 9921.

Positive words

angenehm [comfortable], anziehend [appealing], begabt [talented], beliebt [popular], dankbar [thankful], ehrlich [honest], engagiert [committed], fair [fair], fleißig [diligent], freimütig [frank], friedlich [peaceful], gebildet [educated], gelassen [calm], gemütlich [comfortable], gerecht [just], gütig [benevolent], human [humane], kreativ [creative], logisch [logical], loyal [loyal], milde [benignant], optimal [ideal], praktisch [convenient], robust [robust], sanft [gentle], schlau [clever], standhaft [firm], tolerant [tolerant], vergnügt [cheery], zart [tender].

Negative words

abhängig [addicted], aggressiv [aggressive], arglistig [dissembling], brutal [brutal], bösartig [malignant], boshaft [malicious], dumm [stupid], entmutigt [crestfallen], fanatisch [fanatic], gehässig [spiteful], gemein [nasty], giftig [noxious], grausam [atrocious], hochnäsig [sniffy], jähzornig [irascible], kaputt [broken], korrupt [corrupt], langsam [tardy], launisch [capricious], monoton [monotonous], nervös [nervous], peinlich [embarrassing], rude [rude], schlampig [sloppy], starr [rigid], schuldig [guilty], tödlich [deathly], traurig [sad], verlogen [dishonest], zänkisch [quarrelsome].