

Mechanisms of masked evaluative priming: task sets modulate behavioral and electrophysiological priming for picture and words differentially

Markus Kiefer,^{1,†} Nathalie Liegel,^{1,†} Monika Zovko,¹ and Dirk Wentura²

¹Department of Psychiatry, Section for Cognitive Electrophysiology, Ulm University, 89075 Ulm, Germany and

²Department of Psychology, General Psychology, Saarland University, 66123 Saarbrücken, Germany

Correspondence should be addressed to Markus Kiefer, Department of Psychiatry, Ulm University, Leimgrubenweg 12, 89075 Ulm, Germany. E-mail: markus.kiefer@uni-ulm.de

[†]These authors contributed equally to this work.

Abstract

Research with the evaluative priming paradigm has shown that affective evaluation processes reliably influence cognition and behavior, even when triggered outside awareness. However, the precise mechanisms underlying such subliminal evaluative priming effects, response activation vs semantic processing, are matter of a debate. In this study, we determined the relative contribution of semantic processing and response activation to masked evaluative priming with pictures and words. To this end, we investigated the modulation of masked pictorial vs verbal priming by previously activated perceptual vs semantic task sets and assessed the electrophysiological correlates of priming using event-related potential (ERP) recordings. Behavioral and electrophysiological effects showed a differential modulation of pictorial and verbal subliminal priming by previously activated task sets: Pictorial priming was only observed during the perceptual but not during the semantic task set. Verbal priming, in contrast, was found when either task set was activated. Furthermore, only verbal priming was associated with a modulation of the N400 ERP component, an index of semantic processing, whereas a priming-related modulation of earlier ERPs, indexing visuo-motor S-R activation, was found for both picture and words. The results thus demonstrate that different neuro-cognitive processes contribute to unconscious evaluative priming depending on the stimulus format.

Key words: evaluative priming; automatic processes; attentional control; unconscious visual processing; event-related potentials

Introduction

Affective evaluation processes have been shown to influence cognition and behavior, even when triggered unintentionally (Fazio, 2001). Such automatic evaluation has been frequently investigated with the evaluative priming paradigm (Fazio et al., 1986): when participants classify a target as emotionally positive or negative in an evaluative decision task (EDT), responses are faster if a preceding prime stimulus has the same affective valence (for a meta-analysis see, Herring et al., 2013). In support of the notion of an automatic evaluation process, evaluative priming is also observed under unconscious viewing conditions,

when the prime stimulus is briefly presented and masked by a visual pattern (e.g. random sequence of letters) (e.g. Greenwald et al., 1996; Klauer et al., 2007; Wentura and Degner, 2010).

In the EDT, primes and targets in the congruent vs incongruent conditions differ not only with regard to evaluative congruency (same vs different emotional valence), but also with regard to response congruency (same vs different response category). The dominant account of evaluative priming in the EDT is therefore the response activation account (Klauer et al., 1997; Wentura, 1999; Klinger et al., 2000): According to this

Received: 23 December 2015; Revised: 11 November 2016; Accepted: 14 November 2016

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mechanism, the prime initiates a specific response tendency which can either be congruent or incongruent with the target response. Response activation can be based on a direct association between the prime and the response based on S-R learning (Klinger et al., 2000; Damian, 2001). Such S-R learning was taken as explanation for evaluative priming effects in particular for subliminal primes, where priming was more robust for familiar primes (i.e. primes also presented as visible targets) compared with unfamiliar primes (Abrams and Greenwald, 2000; Klinger et al., 2000; Kiefer et al., 2015). Response activation might be additionally based on the implicit application of task-control representations ('task sets') (Ansorge et al., 2014) to the prime (Klauer et al., 2007; Wentura and Degner, 2010; Kiefer et al., 2015; Heider et al., 2016). If the prime matches the task set (e.g. 'press left key in response to a positive stimulus'), the task set is executed and the corresponding response is activated. Thus, the task set execution account of evaluative priming requires a semantic analysis of the prime stimulus with regard to its valence (Dehaene et al., 1998).

In semantic activation accounts, evaluative priming is proposed to depend on automatic activation of emotional semantic prime features, which facilitates subsequent processing of valence-congruent targets (Spruyt et al., 2009). In behavioral studies, semantic activation can only be unequivocally demonstrated in tasks such as pronunciation, in which evaluative congruency is independent of response congruency (Spruyt et al., 2002, 2004).

Event-related potentials (ERPs), which allow the online monitoring of cognitive processes, help to disentangle processes underlying evaluative priming. Semantic processes are specifically reflected in a modulation of the N400 ERP component (Kutas and Hillyard, 1980), a broad negative ERP deflection between 300 and 500 ms over the parietal scalp with larger amplitudes for semantically incongruent words and pictures compared with congruent stimuli (e.g. Bentin et al., 1985). S-R activation, a prerequisite for response activation, in contrast, are presumably indexed by an earlier negative potential over the occipito-parietal scalp, which starts already at about 200 ms after target onset, and lasts until about 500 ms in some studies (Martens et al., 2011; Zovko and Kiefer, 2013). Polarity is similar to the N400 with more negative potentials in the response incongruent than in the responses congruent condition. Finally, a frontally distributed N200 component in a time range of 200–300 ms is assumed to reflect response conflict, again with more negative ERPs for incongruent trials (Eimer, 1993; Kopp et al., 1996). Early occipito-parietal ERP effects of S-R activation as well as later emerging N400 effects frequently persist for several hundred milliseconds and partially overlap with the subsequently emerging late positive complex (LPC) within 400–600 ms, possibly related to decisional and/or response execution processes (Kutas et al., 1977; Bartholow et al., 2009).

A few studies using visible primes investigated the electrophysiological correlates of evaluative priming in the EDT. Modulations of the N200 ERP component (Bartholow et al., 2009), of the lateralized readiness potential indexing response activation (Bartholow et al., 2009; Eder et al., 2012), and of the N400 ERP component (Eder et al., 2012; Zhang et al., 2006) suggest that both response-related and semantic processes contribute. The occipito-parietal congruency effect in the N200 time range, indicative of S-R activation, has not been analyzed in these studies. Taken behavioral and ERP findings together, semantic and response activation accounts of affective priming can be

considered as complementary (Klauer and Musch, 2003; Spruyt et al., 2004; Herring et al., 2013).

Although evaluative priming depends on multiple mechanisms, the underlying mechanisms involve unintentionally triggered automatic processes. According to classical theories of automaticity (Posner and Snyder, 1975; Schneider and Shiffrin, 1977), automatic processing is considered to be entirely stimulus-triggered. Revised theories of automaticity (Neumann, 1990; Naccache et al., 2002; Kiefer and Martens, 2010), in contrast, propose attentional top-down influences on unconscious automatic processing. More specifically, the attentional sensitization model (Kiefer and Martens, 2010) as well as the feature-specific attention allocation account (Spruyt et al., 2009) state that automatic processes, which match attentional task representations, are amplified, whereas other processes are attenuated. This idea can be tested with the induction task paradigm (Kiefer and Martens, 2010). In this paradigm, a masked priming task is directly preceded by an induction task to induce a specific task set. Masked semantic priming effects within a lexical decision task, which depend on unconscious semantic prime processing, were only found following a semantic induction task (living/non-living classification), but not following a perceptual induction task (round/elongated classification) (Martens and Kiefer, 2009; Kiefer and Martens, 2010; Martens et al., 2011). In contrast, masked visuo-motor response priming, which requires an arbitrary association of a visual shape with a response, was only obtained subsequent to a perceptual shape, but not subsequent to a semantic (Martens et al., 2011) or a color induction task (Zovko and Kiefer, 2013).

In this study, by using the induction task paradigm, we wanted to determine the relative contribution of semantic activation and response activation processes to masked evaluative priming in the EDT with emotionally valenced pictures and words (see Figure 1). Across two experiments the stimulus format was varied: In Experiment 1, primes and targets were pictures, whereas in Experiment 2 the corresponding names served as stimuli. Although repeated presentation of prime stimuli as visible targets facilitates the formation of stimulus-response associations as a basis for S-R based visuo-motor priming for both pictorial and verbal stimuli (Kiefer et al., 2015), semantic activation processes might differentially contribute to pictorial and verbal evaluative priming. As the selected pictures are composed of distinct visual features, responses in the EDT with repeatedly presented targets could be directly based on visual features of the scene via S-R association, bypassing semantics. Masked evaluative picture priming might therefore resemble visuo-motor priming with shape stimuli at a functional and neuronal level (Martens et al., 2011). This assumption does not contradict demonstrations of a privileged access of pictures to semantics (Glaser, 1992; Spruyt et al., 2002) because our assertion is restricted to repeatedly presented (and categorized) pictures. Words, in contrast, are composed of similar visual features (i.e. letters) and are thus visually less distinct than pictures. With words, responses based on S-R links might therefore be complemented by an at least coarse semantic analysis of emotional valence to execute the corresponding response.

The comparison of semantic and perceptual induction task conditions in combination with ERP measurements previously allowed us to dissociate semantic and response activation (Martens et al., 2011). In this study, prior to the primed EDT a perceptual or a semantic decision task was presented to induce a perceptual and a semantic task set, respectively. In addition,

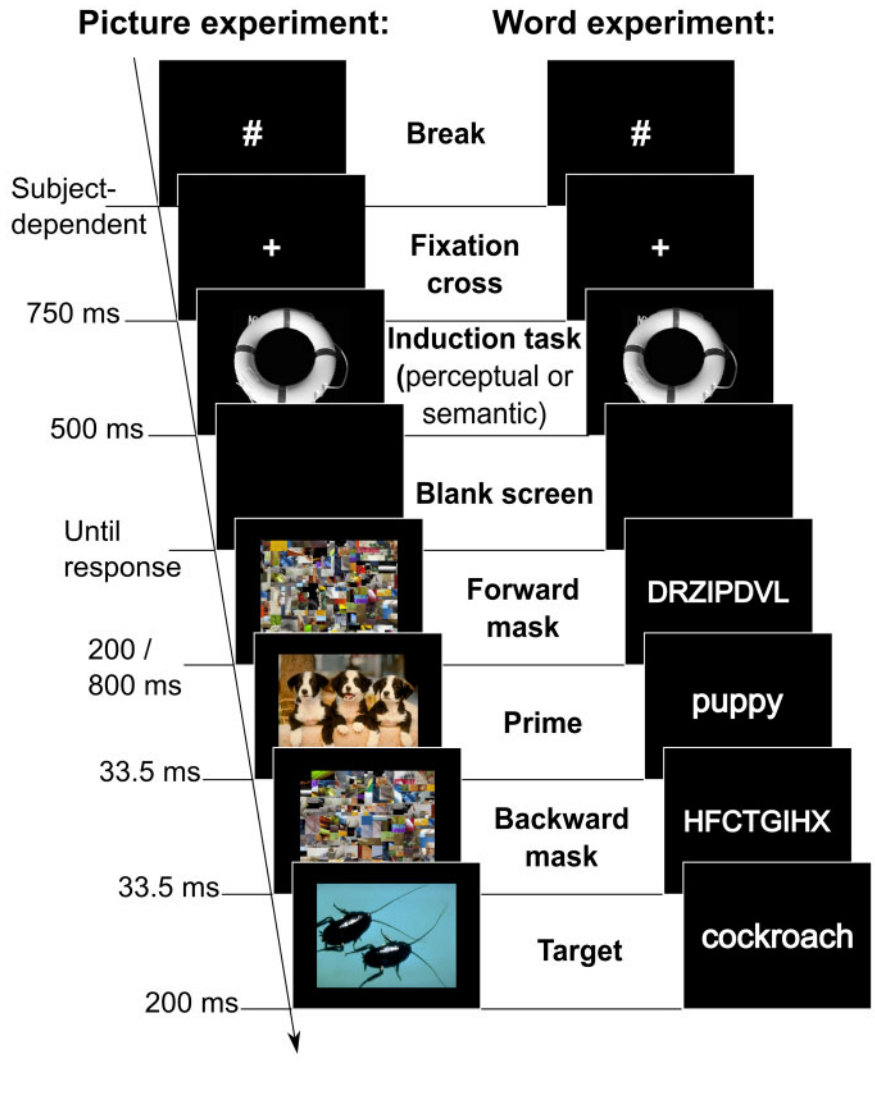


Fig. 1. Temporal sequence of one trial in the picture (Experiment 1) and word experiments (Experiment 2). Both experiments only differed in terms of prime and target modality. The masked prime was presented either 200 or 800 ms after the response to the semantic or perceptual induction task. The semantic induction task demanded a semantic object classification (living/non-living decision) whereas the perceptual induction task required a perceptual classification of object shape (round/elongated shape). The target task was an evaluative decision.

the time interval between the response to the induction task and masked prime presentation (response prime interval, RPI) was varied (short: 200 ms; long 800 ms) to investigate how the induction tasks' influence on subliminal evaluative priming changes over time. Previous research within the area of task switching (e.g. Rogers and Monsell, 1995; Kiesel et al., 2010) and with the induction task paradigm (e.g. Kiefer and Martens, 2010) indicated that task sets are actively suppressed 600 ms after task completion.

We expected to find a differential modulation of unconscious evaluative priming by previously activated task sets for the pictorial and verbal format in particular at the short RPI condition, at which the induced task set is strongly activated. As masked evaluative priming with highly repeated picture targets

is assumed to depend mainly on visuo-motor S-R activation, pictorial priming should only be obtained following a perceptual induction task. Verbal masked evaluative priming; however, should be supported by both visuo-motor and semantic processes. We therefore expected verbal evaluative priming subsequent to both the perceptual and the semantic induction tasks. These functional differences of pictorial and verbal masked evaluative priming should also be visible in their electrophysiological correlates: a modulation of the N400 ERP component indexing semantic priming processes should only be observed for words. As evaluative picture priming (with highly repeated picture targets) might bypass semantics, a modulation of the N400 ERP component should be absent for pictorial priming. In contrast, earlier occipito-parietal ERP priming effects coinciding

with the N200, which index visuo-motor S-R activation or later priming effects on the LPC should be visible for both pictures and words.

Methods

Participants

Twenty-four right-handed healthy volunteers with normal or corrected-to-normal vision contributed data to Experiment 1 (mean age 23.8 years, 12 women) and to Experiment 2 (mean age 23.2 years, 12 women), respectively (see also the Supplementary Materials). Participants were not aware of the purpose of the study and were informed of the presence of the masked primes only after the main experiments. All experiments were approved by the local Ethics Committee.

Material

Induction tasks. The same induction tasks were used in the picture (Experiment 1) and in the word priming (Experiment 2) experiments. In the perceptual induction task, stimuli were 100 grey-scale pictures of round objects, and another 100 pictures of elongated objects. In the semantic induction task, 100 grey-scale pictures of living and non-living objects, respectively, were presented. The same stimuli were previously used to investigate modulation of masked semantic and masked visuo-motor priming by task sets (Martens et al., 2011). Perceptual and semantic inductions showed a comparable difficulty level with regard to reaction times (RTs) and error rate (ER) in earlier studies (Kiefer and Martens, 2010; in the present experiments semantic induction showed a slightly higher level of difficulty, see Supplementary Materials).

Masked evaluative picture and word priming. In Experiment 1, four color pictures with positive and four pictures with negative emotional valence (see the Supplementary Materials), which can be unequivocally named, were selected from the International Affective Picture System (Lang et al., 1999). Eight scrambled pictures composed of small parts of various complex visual scenes served as forward and backward masks. Mask selection occurred randomly.

In Experiment 2, names of the four positive and negative pictures were used as stimuli for the verbal priming condition. Masks were random sequences of 10 capital letters, which were randomly drawn in each trial. Prime and target words were presented according to German spelling norms with the first letter capitalized. Pictorial and verbal stimuli¹ have been validated in a previous study (Kiefer et al., 2015).

Procedure

In both experiments, the total number of 800 trials (768 experimental and 32 filler trials) was divided into eight blocks of 100 trials each. The trials of the induction tasks and the masked priming paradigm were combined such that all conditions of the induction task and the masked priming paradigm co-occurred equally often and were entirely balanced. Four subsequent blocks were assigned to each induction task (semantic vs perceptual). Order of induction task conditions was counterbalanced across participants. Trial order within each block was randomized (evaluative congruency and RPI conditions). Breaks were provided between the blocks. The masked prime and the visible target had either the same valence (congruent condition) or different valences (incongruent condition) in half of the trials. All prime stimuli were also presented as visible targets and

were thus familiar. Primes were combined with the target stimuli with the restriction that in a given trial primes and targets were always different stimuli in order to avoid repetition priming effects. It was ensured that the picture of the induction task was not semantically related to the prime and the target within one trial.

Stimuli were displayed on a cathode ray tube monitor synchronously with the screen refresh rate of 16.67 ms at a viewing distance of 75 cm. Words or symbols were displayed in white font against a black background. The sequence of events within each trial was as following (see Figure 1): After the participant initiated the trial with a key press, there was a fixation cross (750 ms), an induction task picture (500 ms) followed by a blank screen lasting until to the response. In the semantic induction task, participants were instructed to decide whether the object was living or non-living. In the perceptual induction task, participants had to decide whether the object had a round or elongated shape. Responses were given via key presses with left and right index fingers. Then, a forward mask was presented for either 800 ms (long RPI) or 200 ms (short RPI) in half of the experimental trials, respectively, followed by the prime (33.5 ms), the backward mask (33.5 ms) and the target stimulus (200 ms). There was a black screen until the participant responded. The task was to decide whether the target stimulus had positive or negative valence (EDT). Target responses were given via key presses with left and right index fingers. Instructions of induction tasks and EDT stressed both response speed and accuracy. Assignment of the response categories in the EDT to right hand or left hand key presses were counterbalanced across participants. After the response in the EDT, hash marks were presented, which prompted the participant to initiate the next trial by a button press. Thirty-two filler trials with an intermediate RPI of 500 ms were included, in order to render the transitions between the different RPI conditions smoother.

Before the four blocks of a given induction task, participants first received task instructions and practiced the induction task assigned to this block and the EDT separately. Subsequently, they practiced the tasks in the same sequence as in the main experiment. In a debriefing after the main experiment, none of the participants reported subjective awareness of the primes. An objective test of prime visibility, however, led to the exclusion of five participants in the picture experiment due to a classification accuracy of >65% in one of the induction task conditions. Further information regarding the methods, the prime visibility test and control analyses relating prime visibility to priming are given in the Supplementary Materials.

Electrophysiological recordings and statistical analysis

Scalp voltages were continuously recorded (digitization rate = 500 Hz, band-pass = 0.001–100 Hz; BrainAmp, BrainVision-Recorder, Brain Products, Gilching, Germany) using a cap with 64 equidistant Ag/AgCl electrodes (EasyCap, Herrsching, Germany). Eye movements were recorded with supra- and infraorbital electrodes and with electrodes on the external canthi. After filtering (high cutoff: 30 Hz, 24 dB/octave attenuation; low cutoff: 0.1 Hz, 12 dB/octave attenuation, 50 Hz notch filter) ocular blink contributions to the electroencephalogram (EEG) were removed by independent component analysis (Makeig et al., 1997). Continuous EEG was segmented starting 150 ms prior to forward mask presentation, which served for baseline correction, and ended 800 ms after target onset. Artifact-free segments with correct responses were averaged separately for each experimental condition and electrode, and re-referenced to

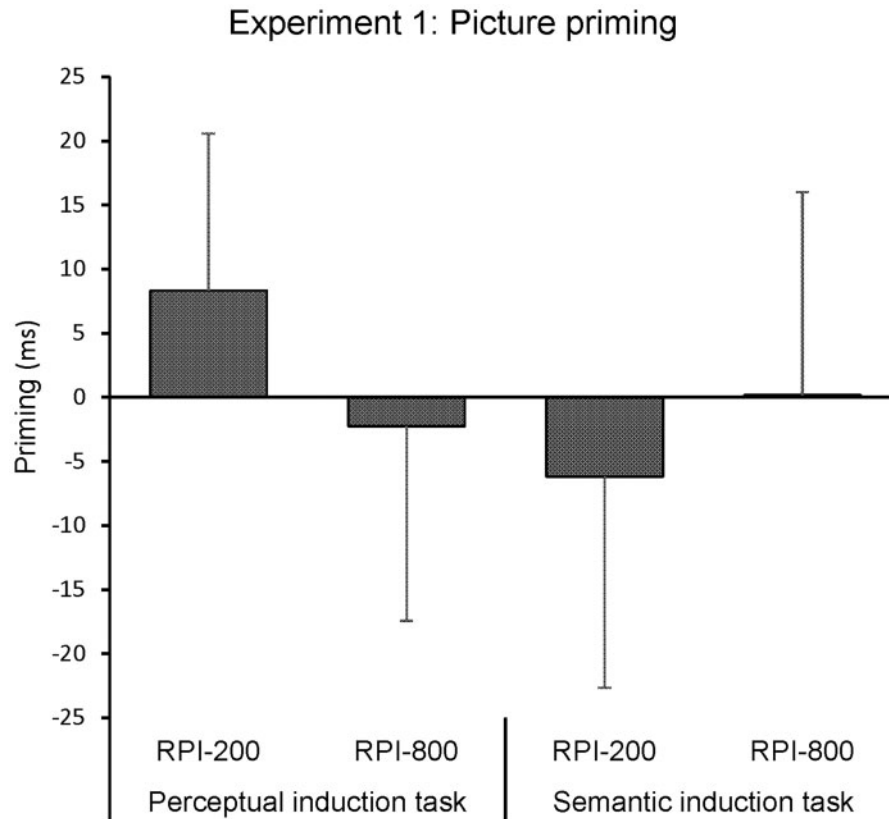


Fig. 2. Experiment 1 (picture priming). Mean RT priming effects (incongruent minus congruent) in the EDT ($n = 24$) in milliseconds as a function of induction task and RPI. In this and the following figures, the vertical lines depict the s.d. of each condition.

average reference (Scherg and von Cramon, 1984; Kiefer et al., 1998). EEG was analyzed with BrainVisionAnalyzer (Brain Products, Gilching, Germany).

Response-related processes have been associated with a frontally distributed N200 as well as an occipito-parietal negativity starting in this time range and extending to the LPC. Semantic priming has been shown to modulate the later parietal N400 ERP component. We therefore selected a frontal (FP1/FP2, AF3/AF4, F5/F6, F1/F2, FC3/FC4) and an occipito-parietal (CP3/CP4, P5/P6, P1/P2, PO3/PO4, P7/P8, PO1/PO2, O1/O2, O9/O10) electrode cluster for statistical analysis. ERPs in these clusters were averaged across electrode sites of each hemisphere. The time course of ERP congruency effects was analyzed in three-time windows (N200: 280–320 ms; N400: 320–420 ms, LPC: 420–520 ms). Statistical analysis involved repeated measures ANOVAs on mean voltages with the within-subject factors RPI, induction task, congruency and hemisphere (P level of 0.05). Purely topographical effects are not reported.

Results

Experiment 1: pictorial evaluative priming

Behavioral results. For reaction time (RT) analysis of the EDT, mean RT of correct responses was calculated for each condition. Trials, in which RT was not in the range of 200–4000 ms and deviated more than two s.d.s from an individual's mean in the remaining trials, were rejected from analysis as outliers (2.82%). A repeated-measures ANOVA with the factors congruency,

induction task and RPI revealed a significant main effect of RPI indicating faster reactions at the long RPIs, $F(1, 23) = 37.70$, $P < 0.001$, $\eta_p^2 = 0.999$. Most importantly, a significant triple interaction between induction task, congruency and RPI was observed, $F(1, 23) = 12.96$, $P = 0.015$, $\eta_p^2 = 0.931$ (see Figure 2). Fisher LSD post hoc tests revealed significant evaluative priming only after perceptual induction at the short RPI ($P = 0.002$): Evaluative decisions were faster in the congruent than in the incongruent condition. An analogous ANOVA on error rates (ERs) only yielded a significant main effect of congruency, $F(1,23) = 4.55$, $P = 0.044$, $\eta_p^2 = 0.165$ (all other F s < 1.48 , P s > 0.24). ER was lower in the congruent than in the incongruent condition (Table 1).

Electrophysiological results. A significant interaction between congruency, induction task and RPI was found in the N200 time window at occipito-parietal electrodes, $F(1,23) = 6.93$, $P = 0.015$, $\eta_p^2 = 0.232$ (Figures 3 and 4). Post-hoc tests revealed more negative potentials to incongruent than to congruent conditions only after perceptual induction at the short RPI ($P < 0.001$). At frontal electrodes, congruency effects were not significant (all F s < 1.32 , P s > 0.26). In the N400 time window, the interaction between induction task, hemisphere and congruency was significant at occipito-parietal electrodes, $F(1, 23) = 6.42$, $P = 0.019$, $\eta_p^2 = 0.218$, but post-hoc tests did not yield significant congruency effects. In the LPC time window, the triple interaction between congruency, induction task and RPI was again significant, now at both occipito-parietal, $F(1,23) = 7.51$, $P = 0.012$, $\eta_p^2 = 0.246$, and frontal electrodes, $F(1,23) = 4.43$, $P = 0.046$, $\eta_p^2 = 0.162$. Post-hoc tests yielded at occipito-parietal electrodes ($P = 0.04$) more negative potentials to incongruent

Table 1 Mean target task ERs and RTs of the different target task conditions in the picture experiment

		P2	P8	S2	S8
ER [%]	congruent	6.5 (5.5)	6.5 (6.2)	5.6 (5.0)	6.5 (5.7)
	incongruent	6.8 (6.4)	8.2 (6.4)	6.3 (5.8)	6.9 (6.5)
RT [ms]	congruent	566 (72)	549 (70)	577 (76)	553 (67)
	incongruent	574 (75)	547(63)	570 (73)	553 (63)

s.d.s are given in brackets. P2, perceptual induction task, short RPI condition; P8, perceptual induction task, long RPI condition; S2, semantic induction task, short RPI condition; S8, semantic induction task, long RPI condition.

than to congruent conditions and a reversed polarity pattern at frontal electrodes ($P = 0.03$), both only after perceptual induction at the short RPI. Hence, pictorial evaluative priming modulated ERPs only in the time range of the N200 and the LPC, but not in the N400 time window.

Experiment 2: verbal evaluative priming

Behavioral results. Trials with outlying responses (3.39% of the data set) were rejected as indicated above. A repeated measures ANOVA on mean correct RT per condition with the within-subject factors congruency, induction task and RPI yielded a significant main effect of congruency, $F(1,23) = 70.86$, $P < 0.001$, $\eta_p^2 = 0.755$: Reactions in the congruent condition were faster than in the incongruent condition (Figure 5). In addition, significant main effects of RPI, $F(1,23) = 17.35$, $P = 0.004$, $\eta_p^2 = 0.43$, and induction task, $F(1, 23) = 11.14$, $P = 0.03$, $\eta_p^2 = 0.326$, were obtained indicating that evaluative decisions were faster in the long vs short RPI conditions and faster subsequent to the perceptual induction task vs the semantic induction task. Although there were significant interactions between RPI and congruency $F(1, 23) = 5.64$, $P = 0.026$, $\eta_p^2 = 0.197$, as well as between induction task and congruency, $F(1, 23) = 6.04$, $P = 0.022$, $\eta_p^2 = 0.208$, due to larger congruency effects following large RPIs than following short RPIs as well as following perceptual induction than following semantic induction, congruency effects were significant in all induction task \times RPI conditions (all P s < 0.001 ; for a joint analysis of the RT of both experiments, see the Supplementary Materials). An analogous analysis of ER (Table 2) only revealed a significant main effect of congruency, $F(1, 23) = 12.63$, $P = 0.002$, $\eta_p^2 = 0.345$ (all other F s < 0.94 , P s > 0.34 in the RT and ER analyses).

Electrophysiological results. ERP data analysis (Figures 6 and 7) revealed significant main effects of congruency at both occipito-parietal and frontal electrodes in the N200 time window, occipito-parietal: $F(1,23) = 4.46$, $P = 0.046$, $\eta_p^2 = 0.162$; frontal: $F(1,23) = 5.28$, $P = 0.031$, $\eta_p^2 = 0.187$, as well as in the N400 time window, occipito-parietal: $F(1, 23) = 25.56$, $P < 0.001$, $\eta_p^2 = 0.998$; frontal: $F(1,23) = 12.00$, $P = 0.002$, $\eta_p^2 = 0.912$, and the LPC time window, occipito-parietal: $F(1,23) = 18.89$, $P < 0.001$, $\eta_p^2 = 0.450$.; frontal: $F(1, 23) = 5.80$, $P = 0.02$, $\eta_p^2 = 0.201$. In all time windows, ERPs were more negative to incongruent than to congruent trials at occipito-parietal electrodes, whereas at frontal electrodes the polarity of the effect was reversed.

For the N200 and N400, there were no further significant effects involving congruency, all F s < 2.11 , P s > 0.16 , although Figure 6 suggests an interaction by RPI and induction task for the N200 analogues to the results for picture priming. Indeed, one-tailed one-sample t -tests revealed a congruency effect in the N200 time window only for perceptual induction at the

short RPI similar to the picture experiment [$t(23) = -3.87$, $P < 0.0004$; all other t s < 0.35 P s > 0.72].

In the LPC time window, a significant interaction between congruency, hemisphere and RPI was observed at frontal electrodes, $F(1, 23) = 4.87$, $P = 0.038$, $\eta_p^2 = 0.174$ (all other F s < 2.11 , P s > 0.16). Post-hoc tests revealed significant congruency effects in the short RPI condition over both hemispheres, left and right: $P < 0.001$, whereas in the long RPI condition congruency effects were confined to the left hemisphere, $P = 0.002$.

Additional ANOVAs with the between-subjects factor experiment compared ERP effects between the word and the picture experiments. For the N400, the interactions between congruency and experiment, $F(1, 46) = 10.62$, $P = 0.002$, $\eta_p^2 = 0.188$, as well as between congruency, induction task, hemisphere, and experiment, $F(1, 46) = 6.25$, $P = 0.02$, $\eta_p^2 = 0.112$, were significant at occipito-parietal electrodes. The interaction between congruency and experiment reached significance for the occipito-parietal LPC, $F(1, 46) = 10.15$, $P = 0.003$, $\eta_p^2 = 0.181$. For the occipito-parietal N200 and for ERPs at frontal electrodes, there were no significant effects involving the congruency \times experiment term, F s < 3.23 , P s > 0.08 . We entered RT priming as covariate (see Supplementary Materials), in order to exclude the possibility that the enhanced modulation of the N400/LPC in the word experiment were related to larger RT priming for this stimulus format. These analyses confirmed the significant interactions between experiment and congruency for the N400, but not for the LPC and, thus, substantiate a specific modulation of the occipito-parietal N400 by verbal priming.

Discussion

In this study, we investigated attentional modulation of masked evaluative priming with pictures and words, in order to infer, to which extent priming depends on response or semantic activation processes. In line with the assumption that pictorial subliminal evaluative priming (with familiar primes) primarily depends on visuo-motor S-R activation, behavioral and electrophysiological priming effects in the picture experiment were only observed following perceptual induction, but were abolished following semantic induction. Furthermore, pictorial priming influenced ERPs at occipito-parietal electrodes in the N200 and LPC time windows (280–320 ms, 420–520), in line with earlier studies on visuo-motor priming (Martens et al., 2011). As pictorial priming did not modulate the N400 ERP component, an electrophysiological index of semantic processing (Kutas and Hillyard, 1980), priming was presumably based on visual features of the pictures, bypassing semantics.

In the word experiment, behavioral and electrophysiological priming effects were found both after perceptual and semantic induction. Electrophysiological priming effects for words emerged in the N200 time window, most pronounced after perceptual induction, similar to the picture experiment suggesting a contribution of visuo-motor processes. However, unlike picture priming, evaluative congruency affected the N400 ERP component somewhat later between 300 and 400 ms after target onset, as found in earlier studies (Zhang et al., 2010; Eder et al., 2012). This indicates that both visuo-motor and semantic processes contribute to subliminal verbal evaluative priming. Visuo-motor processes might outweigh semantic processes, given that the magnitude of behavioral priming was larger following perceptual than following semantic induction, although N400 priming was comparable.

Alternatively, larger behavioral priming following perceptual than following semantic induction in both experiments

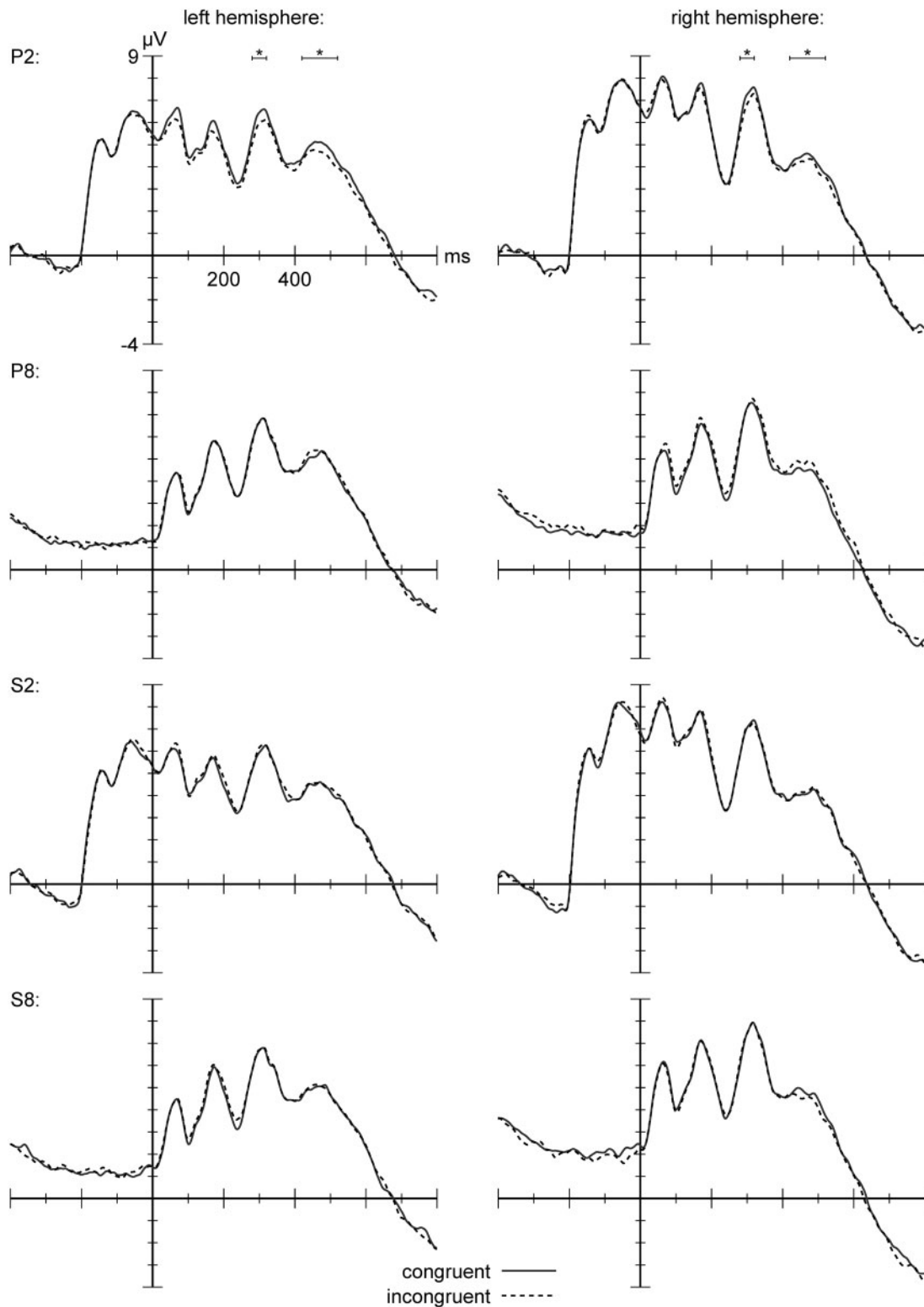


Fig. 3. Experiment 1 (picture priming). Grand-average ERPs of the occipito-parietal electrode cluster as a function of hemisphere, RPI, induction task, and congruency. In this and the upcoming figures showing ERP plots, voltages were collapsed across the electrode sites of the respective hemisphere. The time point of 0 ms represents target onset. To equalize short and long RPI epoch length, long RPI trials are shown without their baseline, which lasted from 1017 to 867 ms before target onset. P2, perceptual induction task, short RPI condition; S2, semantic induction task, short RPI condition; P8, perceptual induction task, long RPI condition; S8, semantic induction task, long RPI condition. Significant priming effects, marked by an asterisk, were only found in the P2 condition (from 280 to 320 ms and from 420 to 520 ms).

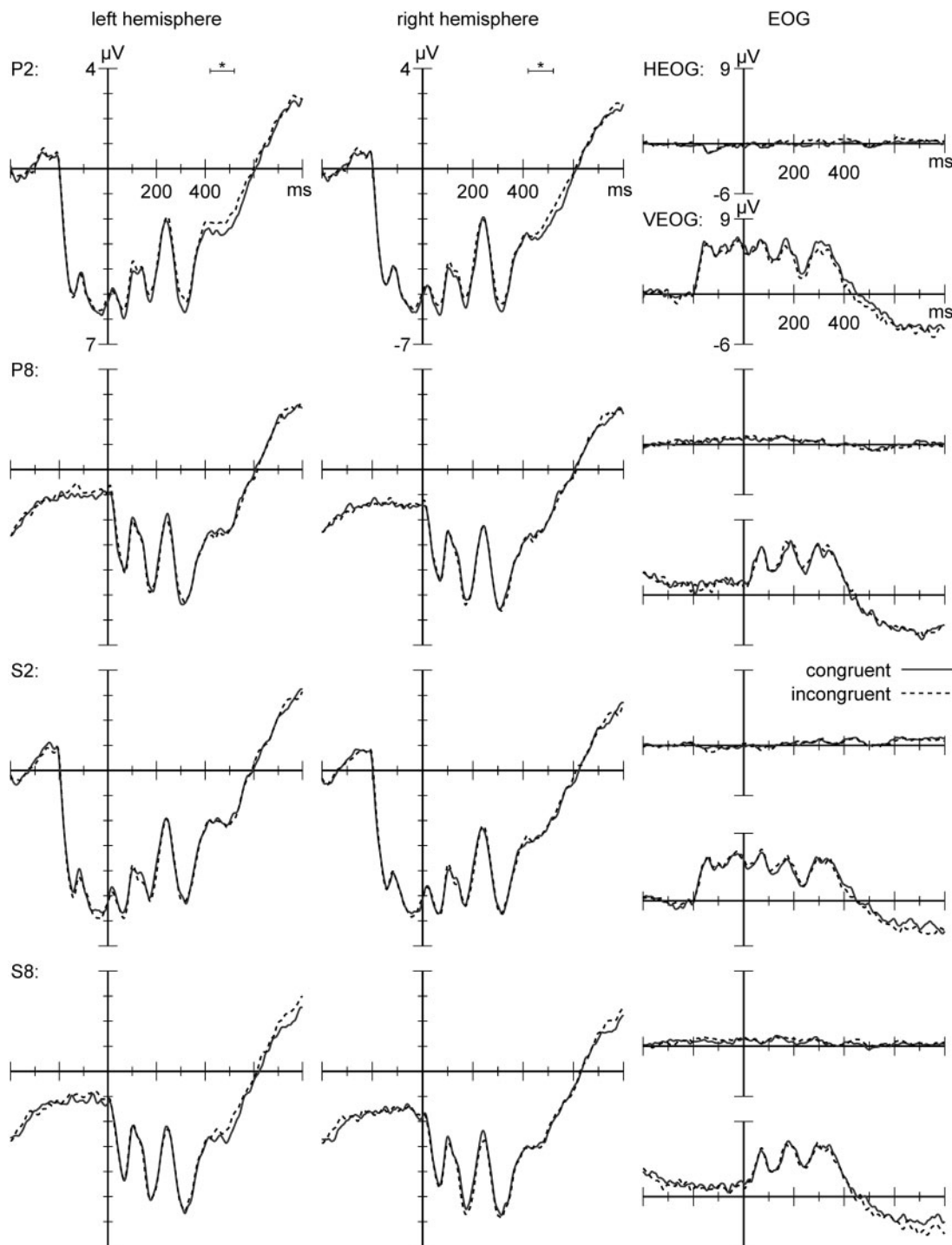


Fig. 4. Experiment 1 (picture priming). Grand-average ERPs of the frontal electrode cluster as a function of hemisphere, induction task, RPI, and congruency. Significant priming effects, marked by an asterisk, were only found in the P2 condition (from 420 to 520 ms).

could reflect an attenuation of evaluative semantic processing by the semantic induction task because it directs attention to non-evaluative semantic features, whereas the perceptual induction task is semantically neutral. However, this explanation fails to account for the pattern of N400 priming effects in the word experiment, which were of similar magnitude following either induction task. Most likely, the EDT performed in each trial activated an evaluative mind set (Spruyt et al., 2009) in addition to the general semantic task

set of the induction task, thereby enhancing evaluative processing.

Induction task effects on verbal priming were not modulated by RPI, because attenuated processing in one pathway (e.g. semantic) can be compensated by enhanced processing in the other pathway (e.g. visuo-motor), when task sets are inhibited at long RPIs. Pictorial and verbal ERP priming effects including those in the N200 time window were largely comparable across the first and second half of the sessions (see Supplementary

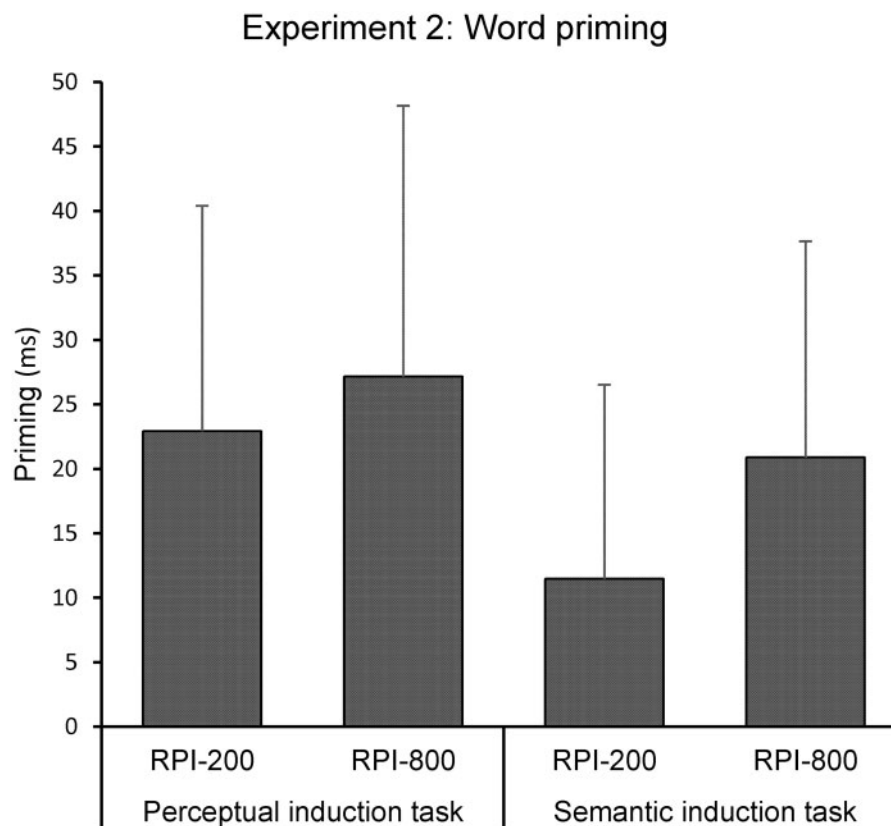


Fig. 5. Experiment 2 (word priming). Mean RT priming effects (incongruent minus congruent) in the EDT ($n = 24$) in milliseconds as a function of induction task and RPI.

Table 2 Mean target task ERs and RTs of the different target task conditions in the word experiment

		P2	P8	S2	S8
ER [%]	congruent	5.6 (4.4)	5.4 (3.6)	5.0 (4.5)	5.2 (3.6)
	incongruent	8.1 (5.7)	8.1 (5.3)	7.6 (4.6)	7.6 (4.9)
RT [ms]	congruent	563 (51)	546 (49)	588 (66)	572 (65)
	incongruent	586 (47)	573 (42)	599 (60)	592 (55)

s.d.s are given in brackets. P2, perceptual induction task, short RPI condition; P8, perceptual induction task, long RPI condition; S2, semantic induction task, short RPI condition; S8, semantic induction task, long RPI condition, all includes P2, P8, S2 and S8 trials.

Materials) suggesting that S-R links were rapidly acquired, presumably already in the training phase.

Response conflict related processes do not seem to contribute to priming in the present experiments due to the absence of the frontal conflict N200 effect with more negative ERPs for incongruent than for congruent trials (Bartholow *et al.*, 2009). Instead, for verbal priming the polarity of the frontal congruency effect in the N200 time range was just reversed with more positive (or less negative) potentials for incongruent trials, while any effect was absent for pictorial priming. Previously, positive ERPs over the frontal scalp in the N200 time range and later have been related to activity within lateral prefrontal cortex reflecting controlled semantic retrieval (Abdullaev and Posner, 1997). It cannot, however, be entirely excluded that occipitoparietal and polarity-reversed frontal congruency effects for

words could represent a bipolar potential field in an averaged-referenced data set, generated from the same brain areas (Scherg and von Cramon, 1984).

With regard to its exclusive sensitivity to perceptual task sets and its electrophysiological signature, pictorial evaluative priming in this study parallels earlier findings on masked visuo-motor priming with geometrical shapes (Martens *et al.*, 2011). This similarity suggests that masked pictorial evaluative priming with highly repeated targets, which are also presented as primes, seems to rely on similar S-R activation processes as shape priming. However, compatible with demonstrations of a privileged access of pictures to semantics (Glaser, 1992; Spruyt *et al.*, 2002), pictorial priming by unfamiliar primes, which require an at least coarse semantic analyses as basis for task set execution (Kiefer *et al.*, 2015), might rely on semantic processing and elicit an N400 (see also, Ortells *et al.*, 2016).

Masked verbal evaluative priming was obtained following both a perceptual and semantic induction task and was associated with early ERP congruency effects in the range of the N200 as well as with a modulation of the N400. Given this result pattern, the mechanisms underlying masked verbal and pictorial evaluative priming (with familiar primes) must be distinct. However, masked verbal evaluative priming also differs from masked semantic priming within a lexical decision task: Masked semantic priming was boosted by a semantic induction task, but was attenuated by perceptual induction tasks (Kiefer and Martens, 2010; Martens *et al.*, 2011). These differential effects of perceptual induction tasks on verbal evaluative vs semantic priming are remarkable because the inductions task in these earlier studies on semantic priming

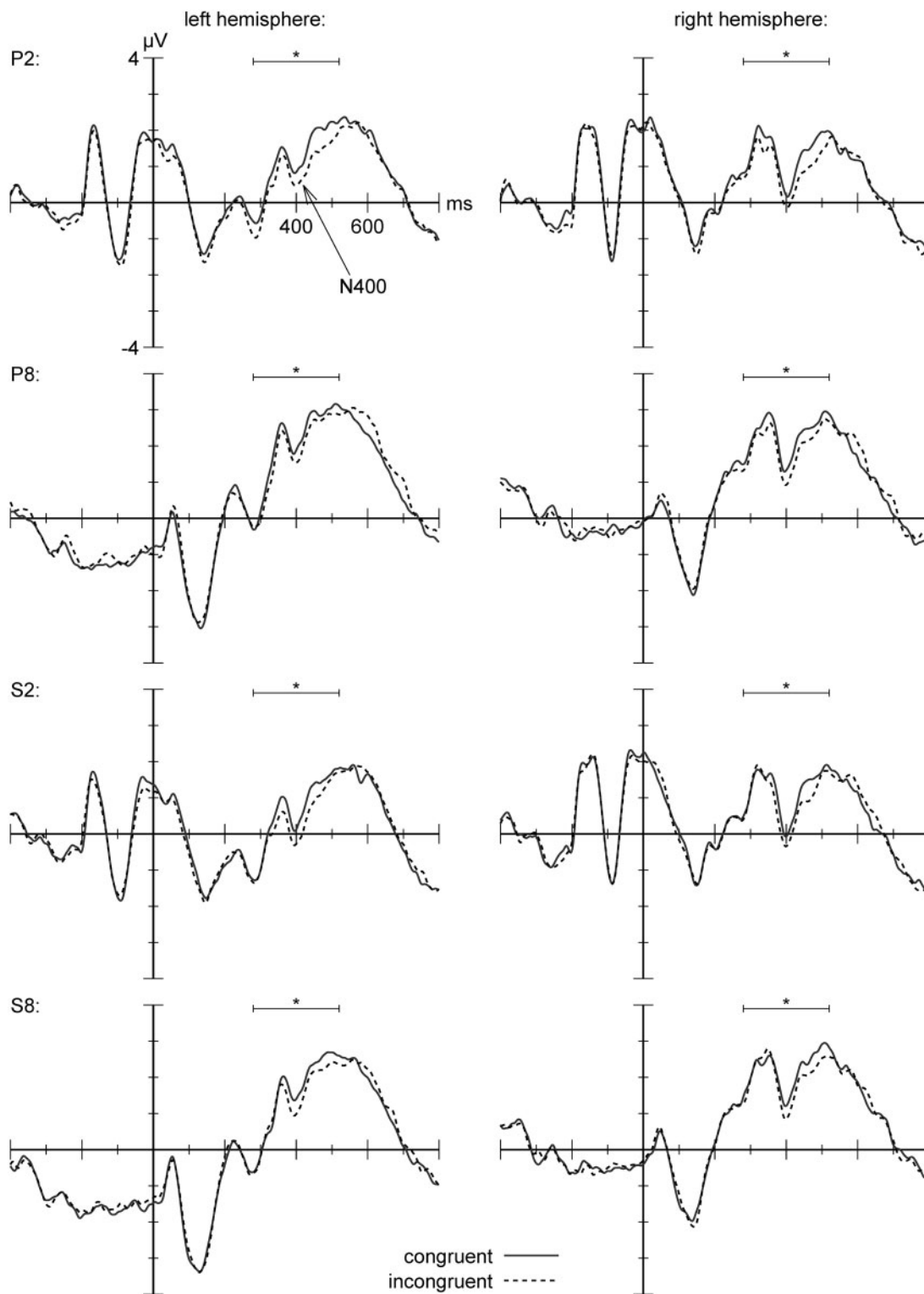


Fig. 6. Experiment 2 (word priming). Grand-average ERPs of the occipito-parietal electrode cluster as a function of hemisphere, induction task, RPI and congruency. Significant priming effects, marked by an asterisk, were found across all conditions, respectively from 280 to 520 ms.

were the same as in the present work. Furthermore, unlike evaluative priming, masked semantic priming specifically modulated the N400, but not ERPs in the N200 time range. Given these differences, verbal priming in the EDT is unlikely the result of pure semantic activation, but also

involves visuo-motor processes in line with earlier findings and theoretical accounts of evaluative priming in the EDT (Klauer et al., 1997; Wentura, 1999; Klinger et al., 2000; Zhang et al., 2006; Eder et al., 2012). In support of this view, source analyses of the present scalp ERP effects at their maximum

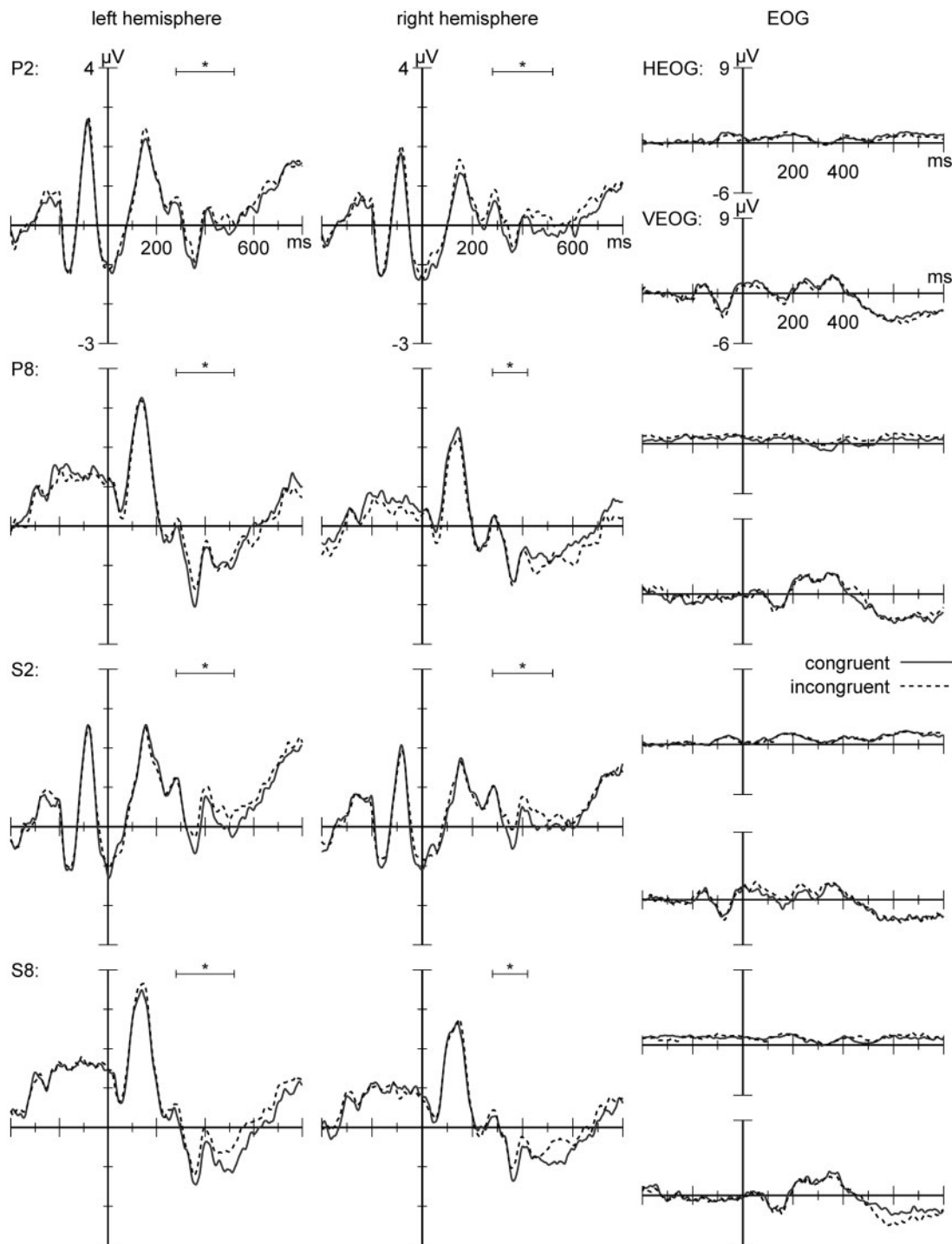


Fig. 7. Experiment 2 (word priming). Grand-average ERPs of the frontal electrode cluster as a function of hemisphere, induction task, RPI and congruency. Significant priming effects, marked by an asterisk, were found across all conditions, respectively from 280 to 420 ms. In the time window from 420 to 520 ms, analysis revealed significant priming for all except for right hemisphere long RPI conditions (data not shown as ERPs were collapsed across hemispheres).

global field power (see Supplementary Materials) suggested for pictorial priming following perceptual induction generators within a visuo-motor network comprising occipital and parietal areas in line with earlier work on visuo-motor priming (Ulrich and Kiefer, 2016). For verbal priming, generators in a similar visuo-motor network were identified after perceptual induction, whereas after both perceptual and

semantic induction sources in semantic regions within anterior temporal and lateral prefrontal cortex (Kiefer *et al.*, 2007), and in emotional regions within orbito-frontal cortex (Erk *et al.*, 2003) were observed.

Our results are generally consistent with earlier studies on evaluative priming in pronunciation tasks revealing a dependency of supraliminal (Gawronski *et al.*, 2010; Spruyt *et al.*, 2007,

2009) and subliminal (Spruyt et al., 2012) evaluative priming on attention to evaluative stimulus features. Our study confirms and extends these findings by showing that even the highly robust evaluative priming effect in the EDT can be influenced by attention. The present results therefore confirm the attentional sensitization model (Kiefer and Martens, 2010) as well as the feature-specific attention allocation account (Spruyt et al., 2009): they show that attentional modulation of unconscious processing is a quite general computational principle that also applies to unconscious processes underlying priming in the EDT.

In conclusion, our results provide important novel evidence regarding the mechanisms underlying unconscious evaluative priming in the EDT: we found picture priming only after the perceptual induction task, but word priming after both perceptual and semantic induction tasks. Furthermore, picture and word priming could be differentiated according to their electrophysiological signature. This pattern of results suggests that masked pictorial priming by familiar primes on repeatedly presented targets is exclusively based on visuo-motor S-R activation, whereas corresponding masked verbal priming is mediated by both visuo-motor and semantic processes. Thus, this study demonstrates that different neuro-cognitive processes contribute to unconscious evaluative priming depending on the stimulus format.

Supplementary data

Supplementary data are available at SCAN online.

Funding

This research was supported by grants of the German Research Foundation (DFG) to MK (Ki 804/3-2) within the research network 'Neuro-cognitive mechanisms of conscious and unconscious visual perception' (PAK 270/2).

Conflict of interest. None declared.

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