

Research Article

MECHANISMS OF PRIMING BY MASKED STIMULI: Inferences From Event-Related Brain Potentials

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Abstract—A metacontrast procedure was combined with the recording of event-related potentials (ERPs) to examine the mechanisms underlying the priming effect exerted by masked visual stimuli (primes) on target processing. Participants performed spatially arranged choice responses to stimulus locations. The relationship between prime and target locations (congruity) and the mapping between target and response locations (compatibility) were factorially manipulated. Although participants were unaware of prime locations, choice responses were faster for congruent than incongruent conditions irrespective of the mapping. Visual ERP components and the onset of the lateralized readiness potential (LRP), an index of specific motor activation, revealed that neither perceptual nor preselection processes contributed to the congruity effect. However, the LRP waveform indicated that primes activated responses that fit the stimulus-response mapping. These results support the view that sensorimotor processing of masked stimuli is functionally distinct from their conscious perception.

Masked stimuli that humans remain unaware of may nevertheless influence their behavior (cf. Kihlstrom, 1987). For example, when a lighted disk is presented by itself and then, after a short time interval, surrounded by a lighted ring, the ring obscures the visibility of the disk, as indicated by subjective judgments of stimulus brightness. This phenomenon is called metacontrast (Stigler, 1910; cf. Breitmeyer, 1984). Further studies have revealed that masked stimuli nonetheless trigger manual responses (e.g., Fehrer & Raab, 1962; Taylor & McCloskey, 1990). This dissociation between subjective reports and motor performance leads to the question of which mechanisms underlie the processing of masked stimuli.

Neumann and Klotz (1994) modified the metacontrast paradigm in several ways to address this question. Participants performed manual choice responses to target stimuli that appeared shortly after a prime. The time interval between the onset of the prime and the onset of the target—stimulus onset asynchrony (SOA)—was 42 ms. Examples of the stimuli are shown in Figure 1. The prime display was composed of horizontally arranged rectangles displayed at fixation and to the left and right of fixation. Either the left or the right rectangle was flanked by horizontal bars defining the prime location (PL). The target display consisted of rectangles arranged so that the outer contours of rectangles in the prime display fit inside the outer contours of the rectangles in the target display, resulting in metacontrast masking of the prime. Target location (TL) was defined by bars flanking one of the rectangles in the target display. Discriminative responses about the presence and absence of the prime revealed null sensitivity ($d' = .024$) of observers, indicating an unawareness of the prime. Nonetheless, the relationship between the prime and target locations (i.e., prime-target congruity)

influenced the processing of target location in two-choice reaction time (RT) tasks. For compatible mappings of target locations to response (R) locations (left TL → left R, right TL → right R), responses were faster when prime and target locations were identical (PL = TL; congruent) than when they were different (PL ≠ TL; incongruent). This congruity effect may be explained by assuming that prime locations activate responses that correspond spatially (e.g., left PL → left R). In this case, the primed response was correct for congruent trials but incorrect for incongruent trials. Interestingly, however, the congruity effect remained unchanged for incompatible stimulus-response (S-R) mappings (left TL → right R, right TL → left R), for which RT was globally increased because of prolonged response selection processes (e.g., Sanders, 1980). According to the response-priming account, one would expect the congruity effect to have been reversed because the correct response should have been primed for incongruent trials (e.g., right PL-left TL → right R) but not for congruent trials (e.g., left PL-left TL → right R). Such a reversal of the congruity effect was clearly not observed. Therefore, Neumann and Klotz (1994) concluded that the parameters of motor responses are directly specified by masked stimuli in a flexible way. In particular, they suggested the direct parameter specification (DPS) hypothesis, according to which responses are mediated by temporary S-R links.

However, different conceptualizations of the DPS hypothesis appear conceivable. For example, motor responses may be specified on an abstract level by selecting the appropriate parameters with no actual activation of the response; this activation would occur only after the correct response is identified at the response selection stage. We refer to this possibility as the *preselection hypothesis*. Alternatively, pre-specified motor responses may become activated immediately at the level of motor preparation (*motor activation hypothesis*). The experimental results just described also agree with the assumption that congruity has an influence on perceptual processing. Note that in congruent trials, prime and target locations are repeated, but in incongruent trials, they are alternated, regardless of the S-R mapping. Accordingly, the prime-target congruity effect might be attributed, at least partially, to priming at a perceptual stage (*perceptual hypothesis*).

The present study was aimed at discriminating among these hypotheses by measuring components of the event-related brain potential (ERP) that provide indices of perceptual and motor processing. Visual information processing is assumed to be reflected in early visual ERP components (cf. Regan, 1989). Activation of specific motor responses in choice RT tasks is indexed by the lateralized readiness potential (LRP). The LRP is computed from the ERP recorded above the motor cortices of the hemispheres contralateral and ipsilateral to the responding hand (cf. Coles, 1989; and Experiment 2, Method). The direction of the LRP indicates whether the correct or incorrect hand is activated, and the onset of LRP activity provides a chronometric index of selective motor activation (e.g., Coles, 1989; Leuthold, Sommer, & Ulrich, 1996; Miller & Hackley, 1992).

The three hypotheses about the origin of the congruity effect make different predictions about ERP measures. The preselection hypothesis

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Fig. 1. Stimuli and temporal sequence of events in congruent and incongruent trials with compatible stimulus-response mapping. Prime onset on the time scale is at 0 ms (see the text for details). Location of the target square flanked by bars calls for a spatially corresponding key press. The insert shows the stimuli used by Neumann and Klotz (1994). SOA = stimulus onset asynchrony.

suggests that prime processing results in the preselection of response parameters according to task-appropriate S-R mapping rules. In the case of incongruity, response parameters are preselected incorrectly. Because their correct reselection is time-consuming, onset of the LRP should occur later for incongruent than congruent trials. Only correct LRP activity should be observed in either case, because responses are assumed to be activated only after the correct response has been determined. The motor activation hypothesis assumes immediate activation of preselected responses. Consequently, in congruent trials, only correct LRP activity should be observed, but in incongruent trials, the LRP should reveal an initial prime-related phase of incorrect response activation followed by a second target-related phase of correct LRP activation. Finally, the perceptual hypothesis predicts that onset of the LRP and latencies of ERP components related to perceptual processing are affected by congruity.

EXPERIMENT 1

In this pilot RT experiment, we attempted to replicate and extend Neumann and Klotz's (1994) metacontrast choice RT task employing

a modified vertical S-R arrangement¹ and prime-target SOAs of 34, 51, and 68 ms. In addition, to examine awareness of prime location, we asked participants to perform forced-choice responses to the position of the prime. Unlike in the choice RT task, prime location was relevant, and it was masked for various SOAs by the stimulus that was the target in the RT task.

Method

Participants

Sixteen right-handed volunteers (19–31 years, $M = 24$ years; 1 male) participated. Their mean handedness score was 77 (Oldfield, 1971), and all had normal or corrected-to-normal vision.

1. A problem with the use of the LRP concerns the possibility that lateralized targets, as in Neumann and Klotz's study, elicit asymmetric ERP activity related to the stimulus, which may be picked up at the electrodes over the motor cortices (C3 and C4) and indistinguishably overlap with the LRP. This problem can be avoided by using vertical S-R arrangements (cf. De Jong, Liang, & Lauber, 1994).

Procedure, stimuli, and apparatus

The stimuli and event sequence are depicted in Figure 1. Participants were tested in a shielded chamber where ambient light was kept at a low level. A room ventilator produced a constant background noise of 38 dB. The viewing distance was 1 m. A fixation cross subtending 5×5 mm was presented at the center of the computer screen (60-Hz refresh rate) throughout the experiment. Each trial started with the presentation of a warning tone (1000 Hz, 45 dB[A], 10 ms duration) followed 720 ms later by a faint rectangle (11×11 mm, 25 cd/m², 17 ms duration)² at fixation, to capture attention as in Neumann and Klotz's study (1994). After a blank 17-ms interval, the prime display appeared. It consisted of the outer contours (white lines) of two rectangles (10×12 mm, 3 cd/m², 17 ms duration) with centers placed 27 mm above and below fixation. Either the upper or the lower rectangle was flanked by vertical bars located 7 mm from the center on the left and right sides. The target display followed onset of the prime display at an SOA of either 34, 51, or 68 ms. It consisted of the outer contours of two rectangles (16×16 cm, 7 cd/m², 136 ms duration), one of which was flanked by two bars, each 10 mm from the center. As a means to prevent premature responding and to keep attention at fixation, a no-go signal was presented on randomly selected trials, with a probability of 10%. This signal consisted of the outer contours of a small square (5×5 mm) displayed at fixation simultaneously with the target. Subjects were instructed to indicate the location of the target as quickly as possible. If the response was correct, the next trial started 2,000 ms after target onset. If the response was incorrect, a feedback tone (1500 Hz, 55 dB[A], 100 ms duration) was presented immediately after the response, and the next trial started 2,000 ms later.

A computer keyboard was used for registering the responses. Participants used their right and left index fingers to press the "T" and the "V" keys to indicate the target location. The spatial S-R mapping was either compatible (upper target → "T" key; lower target → "V" key) or incompatible (upper target → "V" key; lower target → "T" key). Mapping changed after eight experimental blocks. The order of S-R mappings, as well as the assignment of response fingers to response keys, was balanced across participants. The relationship between prime location and target location defined prime-target congruity. Congruity was randomized from trial to trial. Bars appeared at the same position for primes and targets in congruent trials and in opposite positions in incongruent trials. For the prime, the rectangle flanked by bars defined prime location. For the target, it defined target location requiring spatially corresponding responses (e.g., upper TL → upper R) and noncorresponding responses (e.g., upper TL → lower R) for compatible and incompatible S-R mappings, respectively.

After 10 min of dark adaptation, participants began with a preliminary practice block that was followed by 16 experimental blocks of 60 trials each. Blocks were separated by a short rest controlled by the participant. Subjects were asked to keep their eyes on the fixation cross, not to blink as long as it was visible, and to respond quickly and accurately. After the RT experiment, participants performed the forced-choice localization task, in which they had to identify prime location. The SOA between prime and target was adaptively shortened or lengthened using a weighted up-down method (Kaernbach, 1991) in order to determine the threshold of perception without awareness. This task started with a 442-ms SOA to allow for correct prime localization. Over the course of 60 trials, the SOA was adaptively shortened (mini-

mum of 34 ms) until a stable plateau of either 50% or 75% correct decisions was reached (predefined performance levels in separate blocks of trials).

Data analysis and design

In the choice RT task, all trials with incorrect responses and trials with RTs of less than 100 ms or more than 1,200 ms were discarded. Statistical analyses were performed by means of Huynh-Feldt corrected repeated measures analyses of variance (ANOVA) with variables of SOA (34 vs. 51 vs. 68 ms), congruity (congruent vs. incongruent), and mapping (compatible vs. incompatible).

Results and Discussion

Prime localization task

As can be seen in Figure 2a, asymptotic performance levels of 75% and 50% correct decisions were reached after about 30 to 40 trials at SOAs of about 200 ms and 85 ms, respectively. This result suggests that participants were unable to determine the prime location at SOAs below 85 ms. Furthermore, participants did not report any introspective awareness of the prime after the RT experiment. Thus, these results are in accord with Neumann and Klotz's (1994) signal detection findings.

Choice RT task

In no-go trials, 79.4% of responses were successfully withheld, indicating that participants attended fixation. An explanation of RTs based on a speed-accuracy trade-off can be excluded because accuracy and RT were negatively correlated (cf. Fig. 2b). Using a vertical S-R arrangement in Experiment 1, we successfully replicated the RT effects of congruity and mapping reported by Neumann and Klotz (1994). RTs were shorter in congruent (478 ms) than incongruent (519 ms) conditions, $F(1, 15) = 49.0, p < .001$, and shorter in compatible (473 ms) than incompatible (521 ms) mappings, $F(1, 15) = 20.4, p < .001$. The results for the three different SOAs extend their study: There was an increase of the congruity effect from the 34-ms to the 68-ms SOA, $F(2, 30) = 40.4, p < .001$, and this increase was larger for the incompatible mapping (13 vs. 45 vs. 76 ms) than for the compatible mapping (25 vs. 41 vs. 62 ms), $F(2, 30) = 5.8, p < .01$.

EXPERIMENT 2

To examine the mechanisms underlying the congruity effect more directly, we recorded ERPs in a second experiment that was identical to the first, except that SOA was held constant at 51 ms to provide a sufficient number of trials for ERP analysis. After the RT experiment, participants performed both a forced-choice localization task and a prime detection task.

Method

Participants

Ten females and 4 males (20–29 years, $M = 22.9$ years) participated. All were right-handed (mean handedness score of 84; Oldfield, 1971) and had normal or corrected-to-normal vision.

Procedure

After the RT task, participants performed the prime localization task of Experiment 1 but using only the condition with a predefined

2. The actual stimulus duration (d) can be calculated as follows: $d = [(n - 1)/f] + p$, where n is the number of scans, f is the refresh rate, and p is phosphor persistence (about 4 ms).

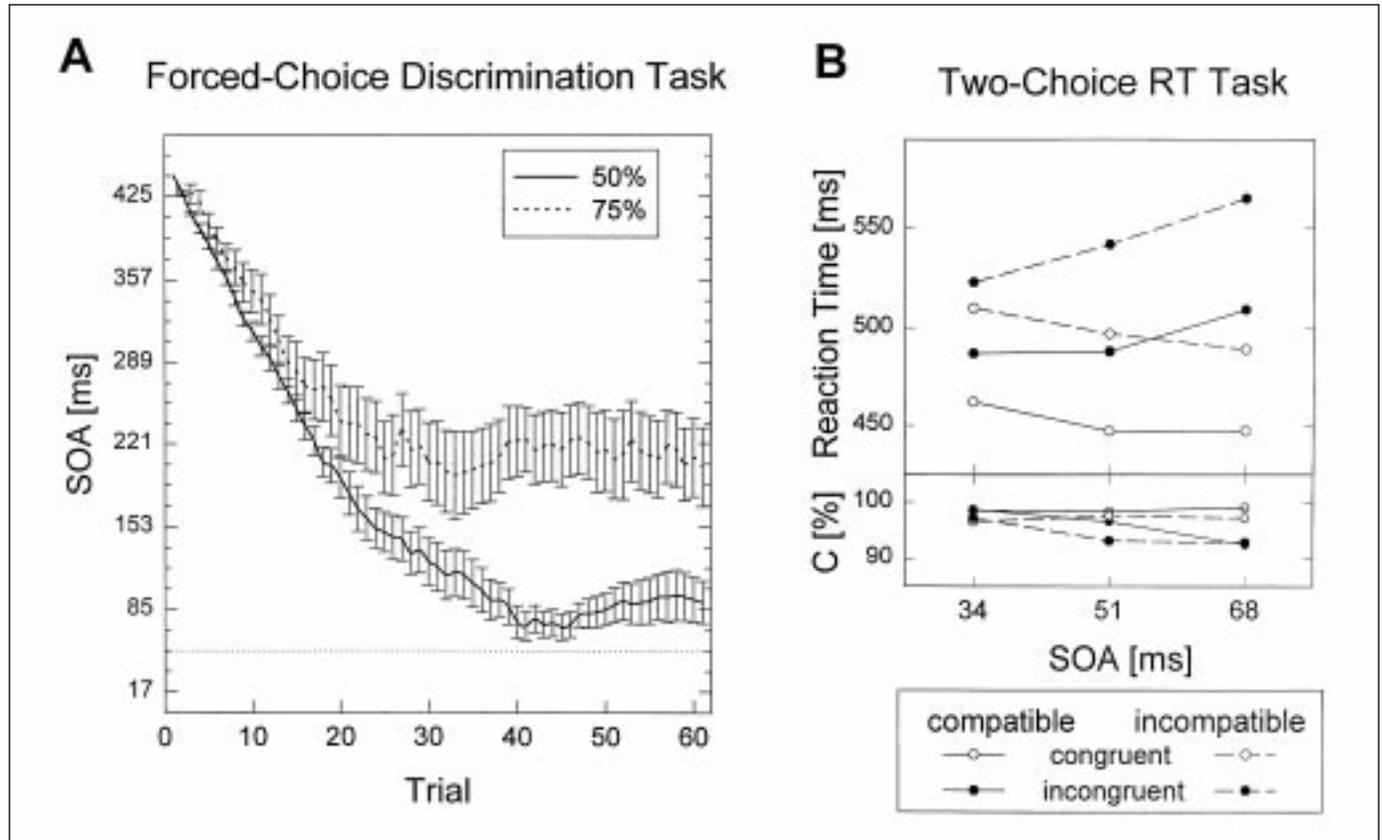


Fig. 2. Behavioral results of Experiment 1. Forced-choice discrimination performance is shown in (a). Error bars denote standard errors, and the horizontal line indicates the 51-ms stimulus onset asynchrony (SOA). Reaction time (RT) and percentage of correct responses are shown in (b). Results are shown separately for congruent and incongruent prime and target locations when stimulus-response mappings were compatible and incompatible.

performance level of 50% correct decisions. The prime detection task consisted of another block of 60 trials in which prime bars were present on half of the trials. Participants judged whether prime bars were present or not, and the SOA was adaptively shortened, as in the forced-choice localization task, until a performance level of 50% correct was reached.

Electrophysiological recording

The electroencephalogram (EEG) was recorded from Fz, Cz, Pz, O1, and O2 (International 10-20 System) and from C'3 and C'4, located 4 cm to the left and right of Cz along the interaural line, respectively (Kutas & Donchin, 1980). Unipolar recordings of the vertical electrooculogram (vEOG) and of the horizontal electrooculogram (hEOG) were obtained from electrodes affixed above and below the left eye and to the outer canthus of each eye, respectively. All electrodes were referenced to linked mastoids. Tin electrodes mounted in an Electro-Cap International (ECI) Electro-Cap and ECI Electro-Gel were used. Electrode impedance was below 5 k Ω .

The EEG and EOG were continuously digitized at 1000 Hz. Offline, C'3 and C'4, O1 and O2, and hEOG recordings were recalculated

to bipolar derivations. Signals at ipsilateral recording sites were subtracted from signals at homologous contralateral recording sites for each hand separately (e.g., in trials calling for a right-hand response, the signal recorded at C'4 was subtracted from the signal recorded at C'3). Separate mean difference waveforms were computed for trials signaling left- and right-hand responses. These difference waveforms were averaged separately for each subject and each experimental condition, thereby eliminating any ERP asymmetries unrelated to motor activation. The difference wave obtained from electrodes over the motor cortices reflects the LRP, with negative and positive LRP deviations from the zero line indicating, respectively, correct and incorrect response activation.

Data analysis

We discarded all trials with incorrect responses, trials with RTs less than 100 ms or more than 1,200 ms, and all trials in which hEOG or vEOG activity exceeded a range of 25 μ V. ERP waveforms were digitally low-pass filtered (10-Hz cutoff) and aligned to a 100-ms baseline prior to the prime. A computerized peak-picking procedure was employed to measure the latencies and amplitudes of ERP components in average waveforms at the time point, relative to prime onset, of

maximal negativity or positivity within specific time intervals and at specific electrodes.³ The magnitude of early LRP activation was examined using average amplitude measures for four successive 50-ms time intervals starting 100 ms after prime onset. The presence of incorrect LRP activation was tested by one-tailed *t* tests. LRP onset latency was measured with the jackknife method proposed by Miller, Patterson, and Ulrich (1998), and the null hypotheses were tested using two-tailed *t* tests.⁴

Results and Discussion

Performance

The prime localization task replicated the results of Experiment 1, with correct decisions reaching a stable plateau after about 30 trials at an SOA of about 80 ms. In the prime detection task, the threshold for 50% correct presence/absence judgments was at a higher SOA of about 100 ms, and the threshold was interindividually more variable than in the prime localization task. Data for the choice RT task were analyzed by two-way ANOVAs with repeated measures of congruity and mapping. In go trials, the error rate of about 5% was due to misses (RTs > 1,200 ms) on 0.5% of the trials, anticipatory responses (RTs < 100 ms) on 0.03% of the trials, and incorrect key presses on 4.8% of the trials. The rate of incorrect key presses was lower for congruent (2.8%) than incongruent (6.8%) conditions, $F(1, 13) = 22.8, p < .01$, and lower for compatible (3.8%) than incompatible (5.7%) S-R mappings, $F(1, 13) = 8.2, p < .05$.

An explanation of RT findings based on a speed-accuracy trade-off can be excluded because the conditions with the shortest RTs were also the most accurate. RTs were shorter for congruent stimuli (444 ms) than incongruent stimuli (491 ms), $F(1, 13) = 99.1, p < .001$, and shorter for compatible (449 ms) than incompatible (487 ms) S-R mappings, $F(1, 13) = 13.3, p < .01$. Replicating the results reported by Neumann and Klotz (1994), congruity and mapping produced additive effects, as indicated by the nonsignificant Congruity \times Mapping interaction, $F < 1$. Although this result disagrees with the view that prime locations inflexibly prime spatially corresponding responses, it is impossible to discriminate among the perceptual, preselection, and motor activation hypotheses on the basis of this additive effect.

Electrophysiology

The ERP findings rule out the perceptual and preselection hypotheses and point strongly to a set-dependent response activation mechanism

as underlying the congruity effect (Neumann & Klotz, 1994). Most important, the LRP revealed the presence of two consecutive response activations in the incongruent conditions (Fig. 3, left panel). An early LRP phase starting about 200 ms after prime onset indicates an incorrect response activation that depended on prime location. A late LRP phase indicating correct response activation started after 350 ms and apparently depended on target location. This sequence of prime-related and target-related response activation occurred for both the compatible and the incompatible S-R mapping. Two LRP phases may also be present in the congruent condition. However, because of the overlap of equidirectional early and late response activations, they cannot be disentangled. A two-way repeated measures ANOVA of LRP amplitudes with variables of congruity and mapping revealed LRP amplitude to be more negative for congruent than incongruent trials for all 50-ms amplitude areas starting with the 100- to 150-ms interval, $F_s(1, 13) > 6, p_s < .05$.⁵ Incorrect LRP activity induced by incongruent primes attained statistical significance for the compatible mapping from 200 to 250 ms after prime onset, $t(13) = 2.0, p < .05$, but the incorrect LRP activity of the incompatible mapping, appearing slightly later, from 250 to 300 ms, was not significant, $t(13) = 0.9, p > .19$. However, inspection of individual waveforms revealed interindividual variability at the onset and throughout the incorrect LRP activity. Because the use of fixed 50-ms areas to measure incorrect LRP activity might not have been ideal for this incongruity condition, we computed latency-adjusted LRP amplitudes individually.⁶ This analysis also yielded incorrect LRP activity for the incompatible S-R mapping, $t(13) = 1.8, p = .05$. The appearance of prime-related incorrect LRP activity in incongruent trials for both S-R mappings contradicts the perceptual and preselection hypotheses, whereas it is consistent with the motor activation hypothesis of the congruity effect.

Further support for the motor activation hypothesis is provided by the huge congruity effect on correct LRP onset latency (295 vs. 378 ms), $t(13) = 4.0, p < .05$, which appeared to be even larger than the congruity effect on RT (447 vs. 491 ms). This result can be explained by the overlap of prime-related and target-related response activations. That is, in congruent trials, correct LRP onset occurred relatively early because of equidirectional prime- and target-related response activation phases. In contrast, in incongruent trials, correct LRP onset occurred relatively late because prime-related activation counteracted target-related response activation. Hence, any premotoric (preselection or perceptual) hypothesis would be supported only if the onset of prime-related response activation were influenced by congruity. However, it appears that early LRP activation began at the same time following prime onset for congruent as for incongruent trials (cf. Fig. 3, left panel).⁷

3. ERPs were measured during the following intervals: at occipital electrodes, from 60 to 100 ms (P80), 120 to 170 ms (N140), 150 to 200 ms (P180), and 200 to 270 ms (N230); at Cz, from 270 to 330 ms (P310) and 300 to 400 ms (N360); and at Pz, from 300 to 1,000 ms (P480). Average amplitude measures of N360 and P480 were taken between 300 and 400 ms and 400 and 600 ms, respectively.

4. For each condition, grand mean LRP waveforms were calculated by averaging across all subjects. In each LRP waveform, the onset of correct LRP activation was determined relative to prime onset as the time point when a relative threshold of 50% of LRP peak amplitude was exceeded. Latency differences were calculated for congruity, mapping, and interaction terms. Then, 14 subsamples of grand average LRPs for each of the four conditions were computed by omitting from each subsample the ERP data of another participant. LRP onsets were measured in the waveforms of the subsamples, and standard error of the difference was determined as outlined by Miller et al. (1998).

5. To assess whether LRP effects could have been due to eye movements or asymmetric activity within visual brain areas, we analyzed the hEOG and lateralized occipital activity in exactly the same way as the LRP. Lateralized occipital activity and hEOG activity were not influenced by the experimental variables, $F_s < 1.2$, and cannot account for the LRP findings.

6. A computerized peak-picking procedure was used to determine the time point of the most positive LRP value between 150 and 350 ms after prime onset for participants showing incorrect LRP activity. Aligned to this time point was the center of a 50-ms area across which mean LRP amplitude was measured.

7. A statistical test cannot be provided for this null result because the small amount of incorrect LRP activity meant that the onset of the early LRP phase could not be measured.

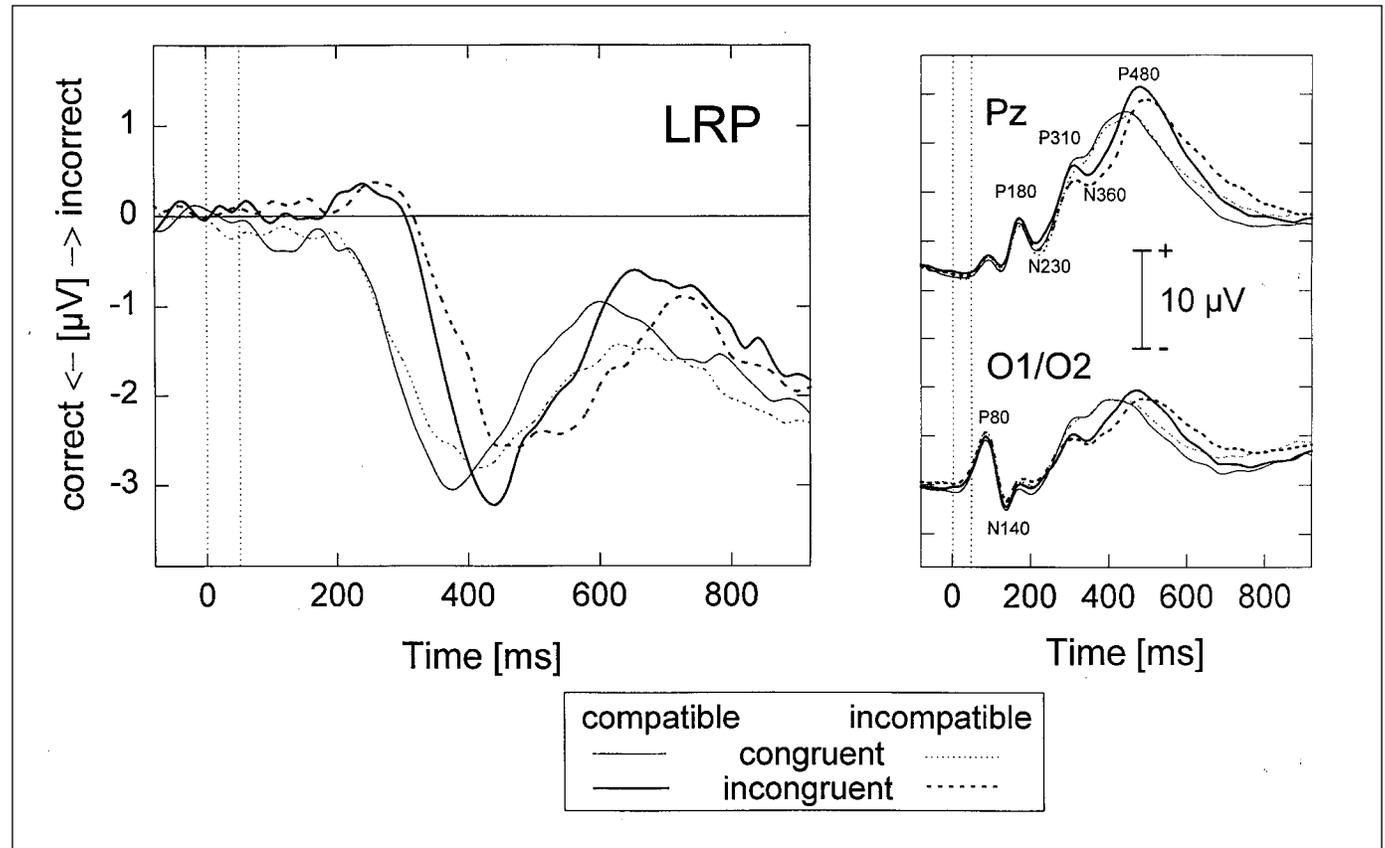


Fig. 3. Grand mean wavelshapes of the lateralized readiness potential (LRP; left panel) and of the event-related potential (ERP; right panel) at parietal sites (Pz) and occipital sites (O1/O2; average of the ERP recorded at O1 and O2 electrodes). Results are shown separately for congruent and incongruent prime and target locations when stimulus-response mappings were compatible and incompatible. Vertical dotted lines indicate onset of the prime (at 0 ms) and target (at 51 ms), respectively.

The perceptual hypothesis is further disconfirmed by the finding that early visual ERP components were largely uninfluenced by congruity (Fig. 3, right panel), except for a significant 2-ms congruity effect in P180 latency, $F(1, 13) = 6.0, p < .05$. However, the small effect size makes it questionable whether this P180 effect is reliable. P480 peaked earlier for congruent (452 ms) than incongruent (504 ms) conditions, $F(1, 13) = 48.6, p < .001$, suggesting an influence of congruity on a late perceptual categorization process (cf. Regan, 1989). However, because response conflicts may delay the latency of the P300 component (Leuthold & Sommer, 1998), which we take the P480 to reflect, the congruity effect on P480 latency cannot be conceived as evidence against the motor activation hypothesis.

Finally, in line with the motor activation hypothesis is the finding of a negative-going deflection appearing at about 360 ms (N360) for incongruent conditions (Fig. 3, right panel). A three-way repeated measures ANOVA with the variables of electrode (Fz, Cz, Pz), mapping, and congruity revealed N360 amplitude to be significantly less positive for incongruent (8.3 μV) than congruent (11.1 μV) trials, $F(1, 13) = 20.6, p < .001$; this effect was more pronounced over centroparietal than over frontal and occipital electrodes, $F(2, 26) = 20.5, \epsilon = 1.0, p < .001$. In the flanker-compatibility studies of Kopp and

colleagues (Kopp, Goertz, Mattler, & Rist, 1996; Kopp, Rist, & Mattler, 1996), flanker-induced response conflicts were associated with the presence of a similar negative-going deflection. Therefore, N360 may be related to the resolution of response conflicts induced in the incongruent trials.

CONCLUSION

We used a metacontrast procedure to test different conceptualizations of Neumann and Klotz's (1994) DPS hypothesis, according to which masked stimuli directly specify response parameters via temporary S-R links. The preselection hypothesis assumes that processing of the prime leads to the advance selection of response parameters. In contrast, the motor activation hypothesis assumes that preselected responses are activated immediately. Alternatively, the perceptual hypothesis points to a possible perceptual locus of the priming effect.

The present ERP results provide strong evidence for the motor activation hypothesis. They suggest that response selection receives perceptual information about the masked prime and the target and, on this basis, determines the assigned response, which is activated

immediately. A response may be initiated whenever the activation difference between the left and right hand exceeds a critical threshold; the LRP reflects the time course of this activation difference. Because of the SOA, prime processing finishes before target processing begins, leading to prime-related early activation of the correct response in congruent trials and of the incorrect response in incongruent trials (see also Eimer & Schlaghecken, in press). In the latter case, target-related response activation must overcome incorrect preactivation to achieve the response execution threshold; as a result, the response is delayed. This is true for both compatible and incompatible S-R mappings, indicating that preconscious stimulus processing results in task-appropriate motor activation via prespecified S-R links, as postulated by Neumann and Klotz's (1994) DPS hypothesis. It is worth mentioning that in agreement with the DPS hypothesis, Klotz and Wolff (1995) found an influence on RT when congruity was defined by prime and target shapes and not, as in our experiments, by location information.

More generally, the present findings relate to the question of nonconscious and conscious cognitive processing (cf. Kihlstrom, 1987; Velmans, 1991). We assume that both masked and unmasked stimuli are processed along the same sensorimotor route leading to action; masking of visual stimuli affects their conscious identification but spares their sensorimotor processing. Consistent with this view are studies indicating an influence of illusory spatial information on cognitive verbal judgments but not on sensorimotor behavior (Bridgeman, Lewis, Heit, & Nagle, 1979; Bridgeman, Perry, & Anand, 1997; Wong & Mack, 1981). A dissociation between conscious perception and sensorimotor functions is also suggested by neurological studies (cf. Milner & Goodale, 1995).

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