

Locus of Inhibition in the Masked Priming of Response Alternatives

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ABSTRACT. Masked prime stimuli presented immediately before target stimuli in a choice reaction task give rise to behavioral costs when the primes and the target stimuli are mapped to the same response and result in benefits when they are mapped to opposite responses. Researchers assume that this negative compatibility effect reflects inhibitory processes in the control of perceptuomotor links. The authors investigated whether the inhibition operates at the level of abstract central codes or at effector-specific motor stages. In 2 experiments ($N = 8$ participants in each), left or right hand or foot responses were required to target stimuli that were preceded by masked arrow primes mapped to the same response side as the target stimuli in compatible trials and to the opposite response side in incompatible trials; the primes were irrelevant in neutral trials. In Experiment 1, when the masked primes determined both response side and modality, there was no transfer of negative compatibility effects across response modalities. That finding is inconsistent with a central abstract locus of inhibition and suggests that inhibition operates at effector-specific motor stages. In Experiment 2, primes conveyed only response side information but left response modality uncertain, and negative compatibility effects were elicited for both hand and foot responses, suggesting that partially informative masked primes can trigger a parallel activation and subsequent inhibition of response processes within separate effector systems.

Key words: perceptuomotor links, priming, response activation, response inhibition

From all the information continuously reaching the sense organs, only a few aspects are relevant for the on-line control of behavior. Inhibitory mechanisms play an important role in the process of selecting those objects and events that guide current behavior. Inhibitory control operates at different levels, and evidence for cognitive inhibition has been found at sensory-perceptual and central semantic levels and at motor stages of information processing. Inhibitory processes affect the perception of repeated items (*repetition blindness*; Kanwisher, 1987) and successive targets (*attentional blink*; Raymond, Shapiro, & Arnell, 1992) as well as the control of visual-spatial attention (*inhibition of return*; Maylor, 1985). In the negative priming paradigm

(Tipper, 1985; see, for reviews, Fox, 1995; May, Kane, & Hasher, 1995), the inhibition of irrelevant objects during target selection has been found to interfere with subsequent responses to previously ignored objects. Researchers have assumed that the inhibitory processes underlying negative priming are neither perceptual nor motor but operate at central semantic levels (e.g., Tipper & Driver, 1988; Tipper, MacQueen, & Brehaut, 1988). In studies of response inhibition in which stop signal tasks (Logan & Cowan, 1984) have been used, inhibitory motor control has been shown to operate both peripheral to the motor cortex as well as at cortical motor levels (De Jong, Coles, & Logan, 1995). However, in a recent review of neurophysiological and psychophysiological data, Band and van Boxtel (1999) concluded that response inhibition is always controlled centrally, although it can affect both central as well as more peripheral stages of response-related processing.

Although researchers have usually used suprathreshold stimuli in investigating cognitive inhibition at perceptual, central, and motor levels, inhibitory processes may also be elicited by events that are not accessible to conscious awareness. Eimer and colleagues (Eimer, 1999; Eimer & Schlaghecken, 1998; Schlaghecken & Eimer, 1997, 2000) found evidence for subconscious elicitation of inhibition in studies in which they used the masked priming paradigm; in their studies, responses were required to simple visual target stimuli that were preceded by masked primes. The primes were identical to the target on compatible trials, were mapped to a different response on incompatible trials, and were irrelevant on neutral trials. Although the masking procedure prevented the conscious detection of the primes,¹ prime-target compatibility had systematic effects on per-

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formance in response to the targets. When stimulus onset asynchrony (SOA) between prime and target was short, performance costs were found in incompatible trials, whereas benefits were present in compatible trials (positive compatibility effect; Eimer, 1999; Schlaghecken & Eimer, 1997; 2000; see also Klotz & Wolff, 1995; Neumann & Klotz, 1994). That effect reversed with increasing prime–target SOAs, however, because costs gradually turned into benefits for incompatible trials, whereas costs emerged on compatible trials (negative compatibility effect).

Eimer and Schlaghecken (Eimer, 1999; Eimer & Schlaghecken, 1998, 2000; Schlaghecken & Eimer, 2000) have previously argued that the reversal of prime–target compatibility effects with increased SOA reflects inhibitory processes involved in the control of perceptuomotor links. Studies in which the lateralized readiness potential (LRP), an electrophysiological measure of response activation, was recorded (Coles, 1989; Eimer, 1998) have provided evidence for those inhibitory processes. Initially, the LRP showed a partial activation of the response assigned to the prime. Later, the partial activation was replaced by a relative activation of the contralateral response, which was interpreted as reflecting an active inhibition of the response that was initially activated (Eimer, 1999; Eimer & Schlaghecken, 1998). Although the negative compatibility effects and the response activation pattern observed in the LRP study suggested the presence of an inhibitory component in the control of perceptuomotor links, the effect site of that inhibition is still unknown. Like the inhibitory processes elicited by suprathreshold stimuli, inhibition, as observed in the masked prime paradigm, may operate at sensory–perceptual or central stages or at effector-specific motor stages. Although evidence for response inhibition was obtained in the LRP study, one cannot necessarily conclude that those effects operate solely at motor levels. Inhibition in the masked prime paradigm may be located at perceptual or central stages and may only subsequently affect motor activation processes.

In a previous study, Eimer (1999, Experiment 1) demonstrated that negative compatibility effects are not stimulus specific, thereby ruling out the idea that inhibition operates at sensory–perceptual levels. In that experiment, negative compatibility effects of equal size were found for target stimuli that were physically identical to the primes and for target stimuli that were dissimilar and were presented at a different location. Because the perceptual similarity of primes and targets was not necessary to obtain inhibition, Eimer concluded that the inhibitory processes responsible for negative compatibility effects are not located at sensory–perceptual stages (see Tipper & Driver, 1988, for analogous arguments related to the locus of negative priming). Having ruled out perceptual processes as the locus of inhibition in masked priming, the question remains whether inhibition operates at effector-specific motor stages or at a more abstract central level prior to the channeling of information into different effector systems.

Evidence for effector-unspecific abstract motor programs has been found for different motor tasks (Klapp, 1977; Zelaznik, Shapiro, & Carter, 1982), and abstract generalized motor programs are assumed to be responsible for the fact that the same unique handwritten signature can be generated with the muscles of either the fingers or the arm (Wright, 1990). If inhibition in the masked priming task occurs at a central level (i.e., by affecting abstract left and right codes), those effects should transfer across response modalities (see Tipper et al., 1988, for analogous arguments related to the locus of negative priming). In contrast, if inhibition is located at effector-specific stages, negative compatibility effects should be strictly modality specific. We conducted Experiment 1 to test those alternatives.

EXPERIMENT 1

To test whether inhibition in masked priming operates at central or at effector-specific motor stages, in Experiment 1 we investigated whether prime–target compatibility effects transfer across response modalities (manual button presses and foot pedal-press responses). The experimental procedure was identical to the procedure previously used by Eimer (1999, Experiment 1), except for the inclusion of a second response modality. Two types of target stimuli (central arrows and lateral letter Xs) were presented, whereas only one type of prime stimuli (central arrows) was used. On any given trial, prime and target could come either from the same set (arrow prime followed by arrow target) or from different sets (arrow prime followed by lateral target). Masked primes were presented at fixation; the prime–target SOA was 116 ms; and compatible, incompatible, and neutral trials were equiprobable. In Eimer's 1999 study, both target sets were mapped to the same response set (left and right manual responses) and negative compatibility effects were obtained for both sets, demonstrating that inhibition is not stimulus specific (see previous discussion). In the present experiment, each target set was mapped to a different response modality. Half of the participants responded with a left or right hand button press to left- or right-pointing central target arrows and with a left or right foot pedal press to lateral targets presented to the left or right of fixation. For the remaining participants, the response assignments were reversed (hand responses to lateral targets and foot responses to central arrows). We varied the mapping between central and lateral targets and response effector between participants to prevent transfer effects from previous mappings.

Given those response assignments, the masked primes were mapped to the same response modality as the central arrow targets. Negative compatibility effects were expected for hand and foot responses to central targets, reflecting the inhibition of the response activations triggered by the primes. The critical question was whether similar effects would also be present for responses to peripheral targets. For example, if a masked prime was assigned to a left hand response, would performance costs arise when the target stimulus required a left foot response? The absence of such a transfer of negative

compatibility effects across response modalities would suggest that those effects do not result from an inhibition of abstract left or right codes but are located at effector-specific motor levels. The presence of transfer would be consistent with a central locus of inhibition.

Method

Participants

Eight paid volunteers, 4 men and 4 women, aged 21–29 years (mean age = 24.1 years) participated in the experiment. All participants were right-handed and had normal or corrected-to-normal vision.

Stimuli and Apparatus

Outward-pointing arrows (<>) and left- and right-pointing double arrows (<< and >>) served as prime stimuli. We constructed the mask by superimposing left- and right-pointing double arrows upon one another. Central targets consisted of a left- or a right-pointing double arrow. The stimuli subtended a visual angle of approximately $0.9^\circ \times 0.4^\circ$. Lateral targets were uppercase letter-X stimuli that subtended a visual angle of approximately $0.6^\circ \times 0.6^\circ$. All stimuli were presented in black on a light-gray background on a 17-in. computer screen. Primes, masks, and arrow targets were presented at fixation. Lateral targets were presented 2.9° to the left or right of fixation.

Procedure

Participants were seated in a dimly lit, sound-attenuated chamber, with response buttons under their left and right index fingers and response pedals under their left and right feet. A computer screen was placed 100 cm in front of the participants' eyes so that the screen center was in the center of the participants' horizontal straight-ahead line of sight. Participants were instructed to maintain central eye fixation and to respond as fast and accurately as possible. Half of the participants had to respond with a left or right manual button press to a left- or right-pointing central target and with a left or right foot pedal press to a lateral target appearing to the left or right of fixation. The other half of the participants had to respond with a foot pedal press to central targets and with a manual button press to lateral targets. All target types were equiprobable and were randomized within each block.

The experiment consisted of two sessions of 15 blocks each. Experimental blocks consisted of 60 trials, each starting with the presentation of a prime stimulus (16 ms duration), immediately followed by a mask (100 ms duration) that in turn was immediately followed by a target stimulus (100 ms duration). The intertrial interval was 1,500 ms. Trials were termed *compatible* when the prime and target were mapped to the same response side (e.g., a left-pointing prime arrow followed by a left-pointing target arrow or by a lateral target on the left side), *incompatible* when they were mapped to opposite response sides, and *neutral* when the prime was an outward-pointing double arrow. The three

compatibility conditions were equiprobable and were randomized within each block.²

Data Analysis

Repeated measures analyses of variance (ANOVAs) were performed on mean RTs and error rates for the between-participants variable response mapping (central–hands/lateral–feet vs. central–feet/lateral–hands) and the within-participant variables target type (central and lateral), compatibility (compatible, neutral, and incompatible), and session (1 and 2). Note that the Response Mapping \times Target Type interaction was equivalent to the (implicit) variable response modality (hand vs. foot). In follow-up analyses, we investigated specific interactions between those variables.

Results and Discussion

Mean RTs and error rates (collapsed across both experimental sessions) in compatible, neutral, and incompatible trials are shown in Figure 1 for responses to central and peripheral targets for participants who responded manually to central targets and with foot responses to lateral targets (left) and for participants with the opposite response mapping (right). Hand responses were faster and more accurate than foot responses (481 ms, 4.2% errors vs. 516 ms, 6.25% errors), although the effect was significant only for RTs: Response Mapping \times Target Type, $F(1, 6) = 12.69$, $p < .012$. No other interactions containing the response mapping variable reached significance, there was no effect of session on RTs, and none of the experimental variables had any effect on error rates.

Most important, a main effect of compatibility on RTs, $F(2, 12) = 40.69$, $p < .001$, Greenhouse–Geisser $\epsilon = .769$, was accompanied by a Compatibility \times Target Type interaction, $F(2, 12) = 39.69$, $p < .001$, $\epsilon = .966$. As can be seen in Figure 1, prime–target compatibility effects were clearly present for central targets but were absent for lateral targets. Follow-up ANOVAs conducted separately for both target types (collapsed across sessions and containing response modality as a between-participants variable) revealed a highly significant effect of compatibility for central targets, $F(2, 12) = 56.05$, $p < .001$, $\epsilon = .815$. No Response Mapping \times Target Type \times Compatibility interaction (corresponding to a Response Modality \times Compatibility interaction) was present, indicating that equivalent negative compatibility effects were elicited in response to central targets for hand and foot responses. Subsequent paired t tests conducted separately for responses to central targets (collapsed across both response modalities) revealed both RT costs for compatible trials (26 ms), $t(7) = 6.73$, $p < .001$, and RT benefits for incompatible trials (15 ms), $t(7) = 4.78$, $p < .002$. No effect of compatibility was obtained for lateral targets.

In Experiment 1, masked primes were drawn from the same set as were central targets, whereas peripheral targets were mapped to a different response modality. Although reliable negative compatibility effects were observed for both hand and foot responses to central arrow targets, those

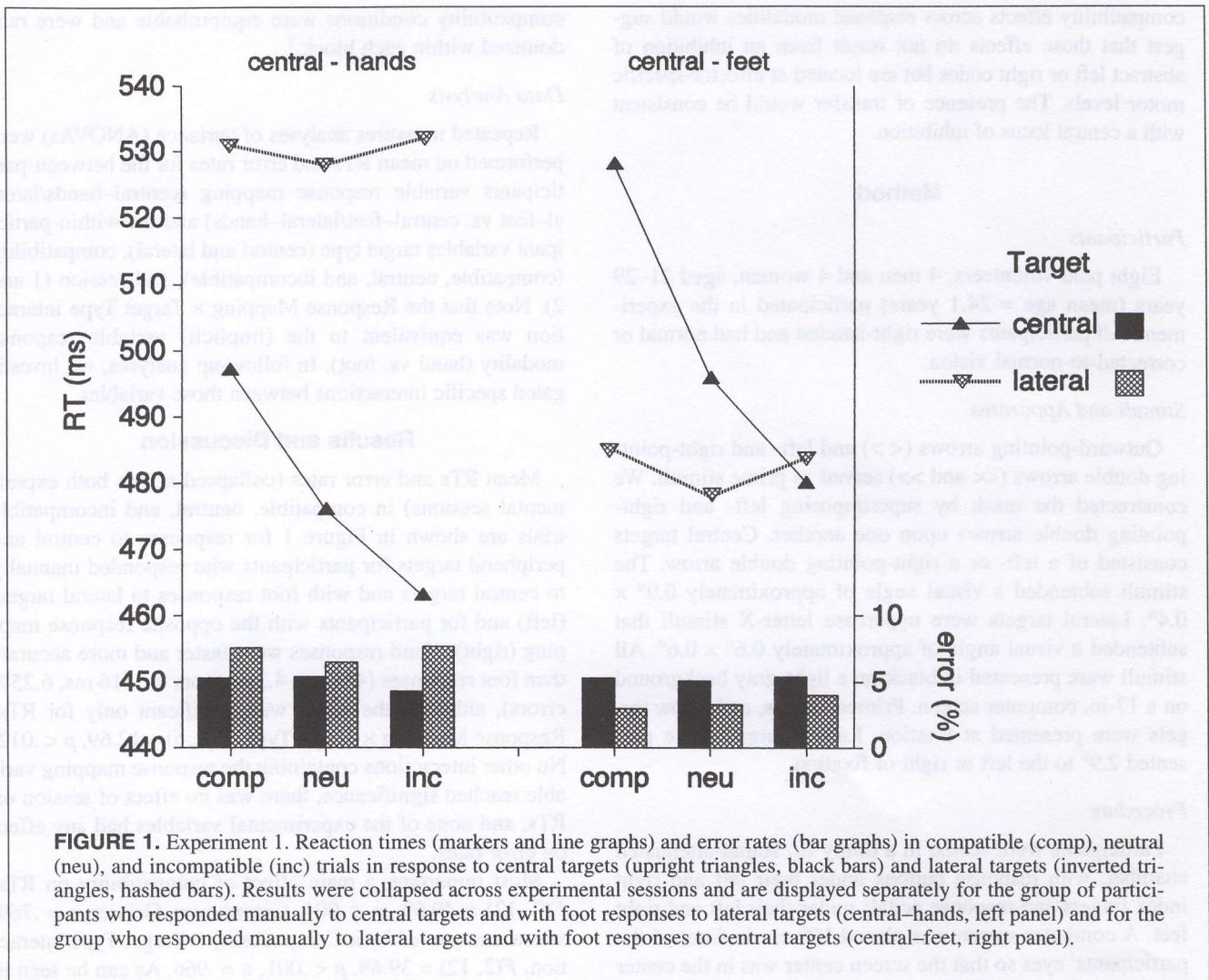


FIGURE 1. Experiment 1. Reaction times (markers and line graphs) and error rates (bar graphs) in compatible (comp), neutral (neu), and incompatible (inc) trials in response to central targets (upright triangles, black bars) and lateral targets (inverted triangles, hashed bars). Results were collapsed across experimental sessions and are displayed separately for the group of participants who responded manually to central targets and with foot responses to lateral targets (central-hands, left panel) and for the group who responded manually to lateral targets and with foot responses to central targets (central-feet, right panel).

effects were entirely absent for responses to peripheral targets. In other words, there was no sign of any transfer of negative compatibility effects across response modalities. If the masked primes had triggered an activation and a subsequent inhibition of an abstract effector-unspecific left or right code, both hand and foot responses should have been affected. The finding that effects were restricted to responses to central arrow targets is inconsistent with the hypothesis that inhibition in the masked priming task operates at central levels and strongly suggests that those inhibitory processes affect effector-specific motor stages.

If inhibition in masked priming operates at motor stages, one may further ask whether the masked prime has to fully specify a response alternative in order for response inhibition to be elicited. Electrophysiological studies have shown that responses can be partially activated by movement precues that indicate response side but leave the effector unspecified (De Jong, Wierda, Mulder, & Mulder, 1988; Ulrich, Leuthold, & Sommer, 1998), indicating that partial response information is sufficient to elicit response activation (see Eimer & Coles, in press, for a discussion of the im-

plications of those studies). In Experiment 1, masked primes delivered full response information because they specified both response modality (hand or foot) and response side. In Experiment 2, we tested whether negative compatibility effects can be observed with partially informative masked primes that leave response modality uncertain.

EXPERIMENT 2

In Experiment 2, we investigated whether behavioral evidence for the inhibition of hand and foot responses can be obtained with masked primes that specify response side but are uninformative with respect to response modality. Stimuli and procedure were similar to those used in Experiment 1, except that only central arrow targets were employed and those target stimuli were either blue or purple. Response side was specified by the direction of the target arrows, whereas response modality (hand vs. foot) was indicated by their color. The black arrow primes were therefore neutral with respect to response modality. If partial information about response side is sufficient to elicit response activation followed by inhibition, negative compatibility effects

should be found in this experiment for both response modalities. If negative compatibility effects are elicited exclusively when a motor response is completely determined by a prime, no such effects should be present for either response modality.

Method

Participants

Eight paid volunteers, 3 men and 5 women, aged 19–26 years (mean age = 22.2 years) participated in the experiment. All participants but 1 were right-handed, and all had normal or corrected-to-normal vision.

Stimuli and Apparatus

The stimuli and apparatus were similar to those used in Experiment 1, except that targets were presented in one of two colors (blue and purple) and no lateral targets were used.

Procedure

The procedure was similar to that used in Experiment 1, except that response modality was indicated by target color. Half of the participants had to respond with a left or right manual button press to a left- or right-pointing blue target

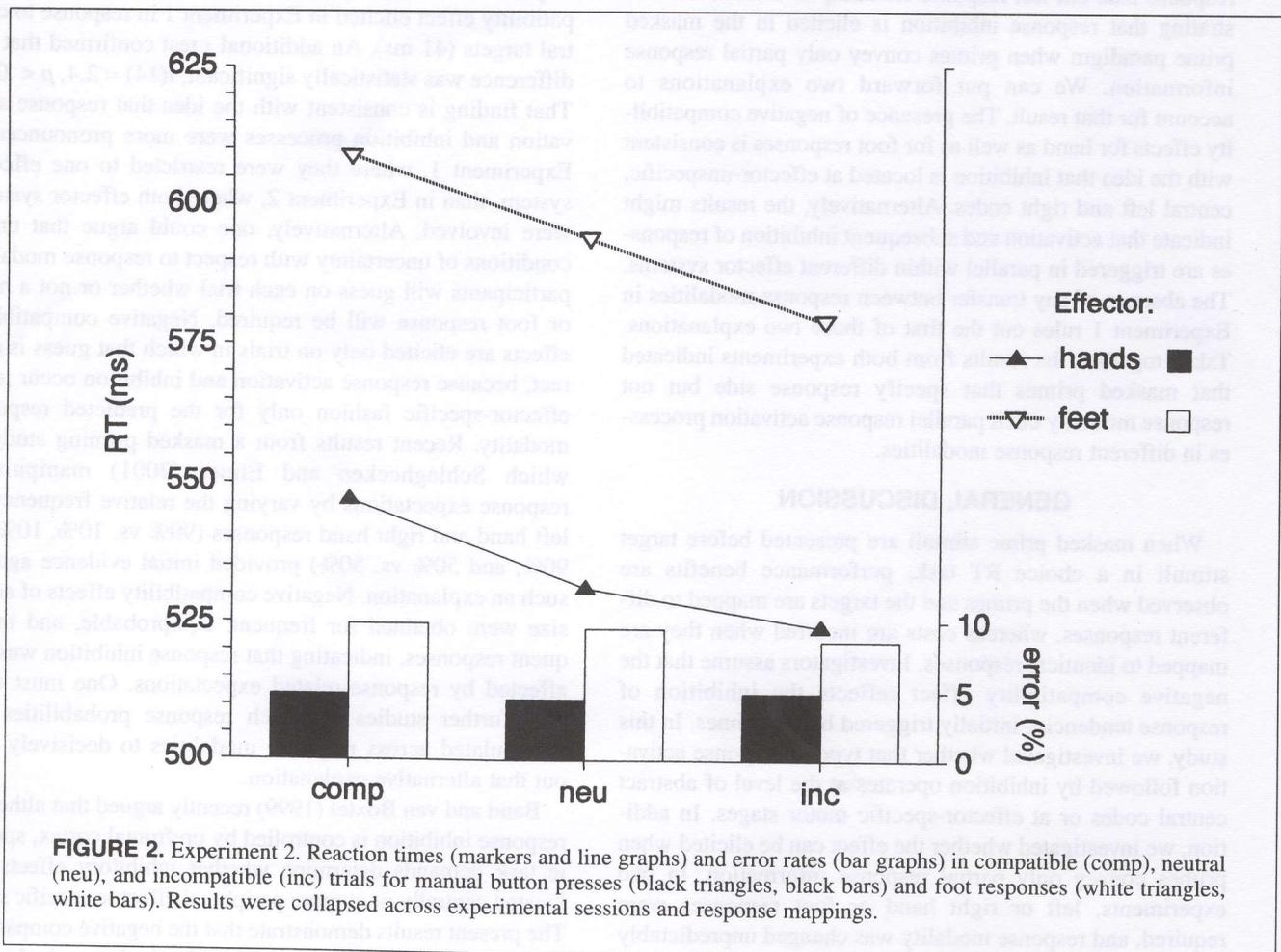
and with a left or right pedal press to a left- or right-pointing purple target. For the other participants, those response assignments were reversed. All target types were equiprobable and were randomized within each block.

Data Analysis

Repeated measures ANOVAs were performed on mean RTs and error rates for the between-participants variable response mapping (blue–hand/purple–foot vs. purple–hand/blue–foot) and the within-participant variables response modality, compatibility, and session.

Results and Discussion

Mean RTs and error rates in compatible, neutral, and incompatible trials for hand and foot responses, collapsed across both response mapping and experimental session, are shown in Figure 2. Manual responses were faster and more accurate than foot responses (534 ms, 4.7% errors vs. 594 ms, 9.3% errors), both $F(1, 6) > 8.9$, both $ps < .024$. Although the RT difference between hand and foot responses was larger for the blue–hand group than for the purple–hand group, $F(1, 6) = 8.66$, $p < .026$, neither the main effects of response mapping on RTs or error rates nor any



other interactions with that variable were significant. Responses tended to be faster and more accurate in the second session than in the first (first session, 571 ms, 9.5% errors; second session, 555 ms, 4.4% errors), although only the main effect of session or the error rate reached statistical significance, $F(1, 6) = 8.08, p < .029$.

More important, there was a main effect of compatibility on RTs, $F(2, 12) = 58.37, p < .001$; responses were fastest in incompatible trials and slowest in compatible trials (Figure 2). No Compatibility \times Response Modality interaction was obtained, indicating that the negative compatibility effects were equivalent for hand and foot responses. Subsequent paired t tests, collapsed across sessions and conducted separately for hand and foot responses, revealed RT costs on compatible trials and RT benefits on incompatible trials in comparison with neutral trials for both response modalities, all $t(7) > 2.47$, all p s $< .042$. No effects of compatibility were present for error rates.

The results from Experiment 2 were clear-cut. Negative compatibility effects were present for both response modalities in a situation in which the masked primes specified response side but left response modality uncertain, demonstrating that response inhibition is elicited in the masked prime paradigm when primes convey only partial response information. We can put forward two explanations to account for that result. The presence of negative compatibility effects for hand as well as for foot responses is consistent with the idea that inhibition is located at effector-unspecific, central left and right codes. Alternatively, the results might indicate that activation and subsequent inhibition of responses are triggered in parallel within different effector systems. The absence of any transfer between response modalities in Experiment 1 rules out the first of those two explanations. Taken together, the results from both experiments indicated that masked primes that specify response side but not response modality elicit parallel response activation processes in different response modalities.

GENERAL DISCUSSION

When masked prime stimuli are presented before target stimuli in a choice RT task, performance benefits are observed when the primes and the targets are mapped to different responses, whereas costs are incurred when they are mapped to identical responses. Investigators assume that the negative compatibility effect reflects the inhibition of response tendencies initially triggered by the primes. In this study, we investigated whether that type of response activation followed by inhibition operates at the level of abstract central codes or at effector-specific motor stages. In addition, we investigated whether the effect can be elicited when primes convey only partial response information. In two experiments, left or right hand or foot responses were required, and response modality was changed unpredictably between trials. Targets were preceded by masked arrow primes mapped to the same response side in compatible trials or to the opposite response side in incompatible trials. In

Experiment 1, hand and foot responses were mapped to central arrow targets and lateral X targets, or vice versa, and negative compatibility effects were elicited for hand and foot responses to central arrow targets but not in response to peripheral targets. If inhibition operates at the level of abstract central left or right codes, a transfer of prime-target compatibility effects across response modalities should have been observed. The finding that no such transfer occurred demonstrates that negative compatibility effects are not generated centrally but at effector-specific motor levels.

In Experiment 2, we tested whether response inhibition processes are elicited under conditions in which masked primes specify only response side but leave response modality uncertain. Both hand and foot responses were mapped to central arrow targets, with target color determining response modality. Negative compatibility effects were observed both for hand and for foot responses, indicating that partially informative masked primes can trigger a parallel activation and subsequent inhibition of responses within separate effector systems. One should note that the overall size of the negative compatibility effect obtained in Experiment 2 (26 ms) was smaller than the negative compatibility effect elicited in Experiment 1 in response to central targets (41 ms). An additional t test confirmed that the difference was statistically significant, $t(14) = 2.4, p < .031$. That finding is consistent with the idea that response activation and inhibition processes were more pronounced in Experiment 1, where they were restricted to one effector system, than in Experiment 2, where both effector systems were involved. Alternatively, one could argue that under conditions of uncertainty with respect to response modality, participants will guess on each trial whether or not a hand or foot response will be required. Negative compatibility effects are elicited only on trials in which that guess is correct, because response activation and inhibition occur in an effector-specific fashion only for the predicted response modality. Recent results from a masked priming study in which Schlaghecken and Eimer (2001) manipulated response expectations by varying the relative frequency of left hand and right hand responses (90% vs. 10%, 10% vs. 90%, and 50% vs. 50%) provided initial evidence against such an explanation. Negative compatibility effects of equal size were obtained for frequent, equiprobable, and infrequent responses, indicating that response inhibition was not affected by response-related expectations. One must conduct further studies in which response probabilities are manipulated across response modalities to decisively rule out that alternative explanation.

Band and van Boxtel (1999) recently argued that although response inhibition is controlled by prefrontal cortex, specific task demands determine whether inhibitory effects are located centrally or at more peripheral effector-specific sites. The present results demonstrate that the negative compatibility effects caused by response inhibition in the masked priming paradigm operate at effector-specific levels; the findings also suggest that when masked primes convey only partial

response information, inhibition can be elicited in parallel within different response systems. The conclusion that inhibitory processes in masked priming operate at effector-specific motor stages rather than centrally seems to distinguish that type of inhibitory control from inhibition mechanisms responsible for negative priming. Because negative priming can transfer across effector systems (Tipper et al., 1988), researchers widely assume that the underlying processes operate at central levels rather than at more peripheral motor stages. One should, however, be cautious in drawing such general conclusions: In most negative priming studies, semantic tasks requiring verbal stimulus identification have been used. If the locus of inhibition is determined by current task demands (Band & van Boxtel, 1999; May et al., 1995; Neill, Valdes, & Terry, 1995), it is hardly surprising to find central inhibition with verbal-semantic tasks, such as those used in negative priming studies, but effector-specific motor inhibition in the masked priming paradigm, where speeded response selection and execution are emphasized.

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NOTES

1. Participants' ability to consciously perceive the mask was tested in forced choice performance blocks; participants had to detect the presence of a prime or to identify masked primes presented either with (Schlaghecken & Eimer, 1997) or without (Eimer & Schlaghecken, 1998) subsequent targets. Detection and identification performance was generally at chance level, and participants consistently reported their inability to respond discriminatively. Although the masks clearly prevented any subjective awareness of the primes, those results do not completely rule out the possibility of some residual perceptual sensitivity to the prime stimuli (see Cheesman & Merikle, 1986, for a distinction between subjective and objective detection thresholds).

2. To test whether the masked primes were accessible to awareness, we ran a forced choice performance block at the end of Experiment 1. On each trial, a left-pointing or right-pointing arrow prime was presented with equal probability for 48, 32, 16, or 0 ms (no prime) and was immediately followed by a mask (100 ms duration). Participants were informed that primes were present on 75% of all trials and were instructed to respond with the right hand when they detected a prime and with the left hand when they did not. Detection accuracy was above chance (86% and 73%, respectively) when primes were presented for 48 or 32 ms. In contrast, only 20% of all primes presented for 16 ms were detected. That performance did not differ significantly from the false alarm rate in trials in which no prime was presented (13%), indicating that the masking procedure was effective in preventing subjective awareness of the primes.

REFERENCES

Band, G. P., & van Boxtel, G. J. (1999). Inhibitory motor control in stop paradigms: Review and reinterpretation of neural mechanisms. *Acta Psychologica, 101*, 179–211.

- Cheesman, J., & Merikle, P. M. (1986). Distinguishing conscious from unconscious perceptual processes. *Canadian Journal of Psychology, 40*, 343–367.
- Coles, M. G. H. (1989). Modern mind-brain reading: Psychophysiology, physiology, and cognition. *Psychophysiology, 26*, 251–269.
- De Jong, R., Coles, M. G. H., & Logan, G. D. (1995). Strategies and mechanisms in nonselective and selective inhibitory motor control. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 498–511.
- De Jong, R., Wierda, M., Mulder, G., & Mulder, L. J. M. (1988). Use of partial stimulus information in response processing. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 682–692.
- Eimer, M. (1998). The lateralized readiness potential as an online measure of central response activation processes. *Behavioural Research Methods, Instruments, & Computers, 30*, 146–156.
- Eimer, M. (1999). Facilitatory and inhibitory effects of masked prime stimuli on motor activation and behavioral performance. *Acta Psychologica, 101*, 293–313.
- Eimer, M., & Coles, M. G. H. (in press). The lateralized readiness potential. In M. Jahanshahi & M. Hallett (Eds.), *The Bereitschaftspotential [Readiness Potential]: In honour of Professors Deecke and Kornhuber*. New York: Kluwer Academic.
- Eimer, M., & Schlaghecken, F. (1998). Effects of masked stimuli on motor activation: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1737–1747.
- Eimer, M., & Schlaghecken, F. (2001). Response facilitation and inhibition in manual, vocal, and oculomotor performance: Evidence for a modality-unspecific mechanism. *Journal of Motor Behavior, 33*, 16–26.
- Fox, E. (1995). Negative priming from ignored distractors in visual selection: A review. *Psychonomic Bulletin & Review, 2*, 145–173.
- Kanwisher, N. (1987). Repetition blindness: Type recognition without token identification. *Cognition, 27*, 117–143.
- Klapp, S. T. (1977). Response programming, as assessed by reaction time, does not establish commands for particular muscles. *Journal of Motor Behavior, 9*, 301–312.
- Klotz, W., & Wolff, P. (1995). The effect of masked stimulus on the response to the masking stimulus. *Psychological Research, 58*, 92–101.
- Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review, 91*, 295–327.
- May, C. P., Kane, M. J., & Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin, 118*, 35–54.
- Maylor, E. A. (1985). Facilitatory and inhibitory components of orienting in visual space. In M. I. Posner & O. S. M. Morin (Eds.), *Attention and performance XI* (pp. 189–204). Hillsdale, NJ: Erlbaum.
- Neill, W. T., Valdes, L. A., & Terry, K. M. (1995). Selective attention and the inhibitory control of cognition. In F. N. Dempster & C. J. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 207–261). San Diego, CA: Academic Press.
- Neumann, O., & Klotz, W. (1994). Motor responses to non-reportable, masked stimuli: Where is the limit of direct parameter specification? In C. Umiltà & M. Moskvitch (Eds.), *Attention and performance XV* (pp. 123–150). Cambridge, MA: MIT Press.
- Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporal suppression and visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18*, 849–860.
- Schlaghecken, F., & Eimer, M. (1997). The influence of subliminally presented primes on response preparation. *Sprache & Kognition, 16*, 166–175.

Schlaghecken, F., & Eimer, M. (2000). A central/peripheral asymmetry in subliminal priming. *Perception & Psychophysics*, 62, 1367-1382.

Schlaghecken, F., & Eimer, M. (2001). Partial response activation to masked primes is not dependent on response readiness. *Perceptual and Motor Skills*, 92, 208-222.

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *The Quarterly Journal of Experimental Psychology*, 37A, 571-590.

Tipper, S. P., & Driver, J. (1988). Negative priming between pictures and words in a selective attention task: Evidence for semantic processing of ignored stimuli. *Memory & Cognition*, 16, 64-70.

Tipper, S. P., MacQueen, G. M., & Brehaut, J. M. (1988). Negative priming between response modalities: Evidence for a cen-

tral locus of inhibition in selective attention. *Perception & Psychophysics*, 43, 45-52.

Ulrich, R., Leuthold, H., & Sommer, W. (1998). Motor programming of response force and movement direction. *Psychophysiology*, 35, 721-728.

Wright, C. E. (1990). Generalized motor programs: Reexamining claims of effector independence in writing. In M. Jeannerod (Ed.), *Attention and performance XIII: Motor representation and control* (pp. 294-329). Hillsdale, NJ: Erlbaum.

Zelaznik, H. N., Shapiro, D. C., & Carter, M. C. (1982). The specification of digit and duration during motor programming: A new method of precueing. *Journal of Motor Behavior*, 14, 57-68.

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NOTES

1. Participants' ability to consistently generate the mask was tested in a forced choice performance block at the end of each session. On each trial, a left-pointing or right-pointing arrow was presented with equal probability for 48, 32, 16, or 0 ms (no prime) and was immediately followed by a mask (400 ms duration). Participants were informed that primes were present on 75% of all trials and were instructed to respond with the right hand when they detected a prime and with the left hand when they did not. Detection accuracy was above chance (50%) and 73% respectively when primes were presented for 48 or 32 ms. In contrast, only 50% of all primes presented for 16 or 0 ms were detected. This performance did not differ significantly from the false alarm rate (chance) in which no prime was presented (15%), indicating that the masking procedure was effective in preventing subjective awareness of the primes.
2. To test whether the masked primes were accessible to awareness we ran a forced choice performance block at the end of each session. On each trial, a left-pointing or right-pointing arrow was presented with equal probability for 48, 32, 16, or 0 ms (no prime) and was immediately followed by a mask (400 ms duration). Participants were informed that primes were present on 75% of all trials and were instructed to respond with the right hand when they detected a prime and with the left hand when they did not. Detection accuracy was above chance (50%) and 73% respectively when primes were presented for 48 or 32 ms. In contrast, only 50% of all primes presented for 16 or 0 ms were detected. This performance did not differ significantly from the false alarm rate (chance) in which no prime was presented (15%), indicating that the masking procedure was effective in preventing subjective awareness of the primes.

REFERENCES

Band, G. R., & van Bavel, O. J. (1990). Inhibitory motor control in stop paradigms: Review and re-interpretation of single-trial studies. *Acta Psychologica*, 101, 179-211.