

## PARTIAL RESPONSE ACTIVATION TO MASKED PRIMES IS NOT DEPENDENT ON RESPONSE READINESS<sup>1</sup>

FRIEDERIKE SCHLAGHECKEN AND MARTIN EIMER

*Department of Experimental Psychology  
Birkbeck College, London*

*Summary.*—Masked primes presented foveally prior to a target trigger an initial partial activation of their corresponding response, followed by an inhibition of the same response. The latter phase results in performance costs on compatible trials and performance benefits on incompatible trials relative to neutral trials (negative compatibility effect). The present study investigated whether this activation-follow-by-inhibition process depends on the overall or specific state of response readiness. In two masked priming experiments, response readiness was manipulated by varying the relative frequency of Go-trials in a Go/NoGo task (Exp. 1) and the relative frequency of left- and right-hand responses in a 2-alternative choice reaction time task (Exp. 2). In both experiments, mean reaction times were longer for infrequent responses than for frequent responses. However, negative compatibility effects were not affected by response frequency. This result indicates that neither the general ability of masked primes to elicit a partial motor activation nor the specific time course of this process is dependent on response readiness. It is concluded that response readiness affects the execution of an overt response rather than the initial activation of this response.

A recent series of studies has shown that overt motor responses on a choice reaction time (RT) task are influenced by successfully masked primes immediately preceding each target (e.g., Neumann & Klotz, 1994; Klotz & Wolff, 1995; Schlaghecken & Eimer, 1997, 2000; Eimer & Schlaghecken, 1998; Dehaene, Naccache, Le Clec'H, Koechlin, Mueller, Dehaene-Lambertz, van de Moortele, & Le Bihan, 1999; Eimer, 1999). On a typical task, target stimuli, e.g., arrows, geometrical shapes, letter strings, digits, are assigned to right-hand and left-hand responses. Prior to the presentation of each target, a masked prime is presented which consists of a stimulus either mapped onto the same response as the target (Compatible trial), onto the opposite response as the target (Incompatible trial), or to no response (Neutral trial). Although participants cannot consciously detect or discriminate the primes, as evidenced by various forced-choice tests (see Schlaghecken & Eimer, 1997; Eimer & Schlaghecken, 1998; Dehaene, *et al.*, 1999; Eimer, 1999), responses to targets are systematically affected by the identity of the prime.

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Electrophysiological and haemodynamic measures (Eimer & Schlaghecken, 1998; Dehaene, *et al.*, 1999; Eimer, 1999) indicate that these effects originate from processes at the response stage, as the masked primes trigger a partial activation of their corresponding motor response. Consequently, responses are usually faster and more accurate on compatible trials than on incompatible trials (*positive compatibility effect*) because on compatible trials the correct response is already partially activated, while on incompatible trials the incorrect response is partially activated. Under specific circumstances, however, the opposite pattern of results can be found. If stimuli like arrows or simple geometrical shapes are employed, a positive compatibility effect only occurs when the interval between prime and target is very short, i.e., less than approximately 60 msec. (e.g., Neumann & Klotz, 1994; Klotz & Wolff, 1995; Schlaghecken & Eimer, 1997, 2000). With longer prime-target intervals, this initial effect decreases and eventually reverses with intervals of about 80 msec. and more (Schlaghecken & Eimer, 1997, 2000). This *negative compatibility effect* comprises performance costs on compatible trials (slower responses and more errors than on neutral trials) and performance benefits on incompatible trials (faster responses and fewer errors than on neutral trials) of approximately equal size (Eimer & Schlaghecken, 1998; Eimer, 1999; Schlaghecken & Eimer, 2000).

Inspection of the Lateralized Readiness Potential, an electrophysiological measure of unimanual response activation, showed the following pattern (Eimer & Schlaghecken, 1998; Eimer, 1999): Around 200 msec. after prime onset, a partial activation of the response assigned to the prime stimulus was found. About 100 msec. later, in the time range where responses to the target stimulus were selected and activated, this initial activation was replaced by a relative activation of the opposite response. It was argued that the reversal phase reflects active inhibition of the initial response tendency. This was confirmed in an experiment in which only a single overt response had to be executed in a Go/NoGo task (Eimer & Schlaghecken, 1998, Exp. 3). Responses to Go-targets were slower and False Alarms to NoGo stimuli were less frequent when the Go stimulus served as prime than when the NoGo stimulus served as prime, suggesting that the response assigned to the Go prime was actively inhibited. Replication of the negative compatibility effect with different types of masks (Eimer & Schlaghecken, 1998; Eimer, 1999), as well as under conditions in which prime and target were physically dissimilar and appeared at different locations (Eimer, 1999; Schlaghecken & Eimer, 2000), seems to rule out a perceptual basis of the negative compatibility effect like Repetition Blindness (e.g., Kanwisher, 1987) or a confusion of prime, mask, and subsequent target. Therefore, these results further corroborated the motor account of the negative compatibility effect.

Although the neural mechanisms underlying partial motor activation

and inhibition elicited by masked primes are as yet not fully understood, one might assume that these processes are affected by response readiness. Response readiness has generally been identified as an anticipatory pre-activation of response structures induced and modified by internal factors like intention or motivation as well as by external factors like task demands. Gratton, Coles, Sirevaag, Eriksen, and Donchin (1988), for example, define response readiness as "an energizing phenomenon [...] by which response structures are activated at a subthreshold level" (p. 331). Similarly, the 'thalamic gating' model proposed by Brunia (1997) equates response readiness with an increase in the excitability of the relevant motor structures brought about by an opening of pathways from the thalamus to the motor cortex. In a state of high response readiness, motor responses are assumed to "require less stimulus-related activation for their evocation" (Coles, Gratton, Bashore, Eriksen, & Donchin, 1985, p. 531). Therefore, it seems reasonable to assume that perceptually extremely weak stimuli like successfully masked primes will be able to trigger their corresponding motor activations only if the motor system is already in a pre-activated, highly unstable state of dynamic equilibrium. In other words, the motor system should be in a state of *optimal response readiness*, i.e., maximally prepared to execute either one of the to-be-expected responses for the masked primes to have any effect.

This assumption, however, has never been tested directly. In most of the studies cited above, experimental conditions inevitably led to high response readiness: A response had to be given on each trial, the time of target onset was known in advance, and the two alternative responses were equiprobable. Therefore, at the beginning of each trial the motor system was likely to be in the required unstable state of highly pre-activated dynamic equilibrium. The results from the NoGo task in Eimer and Schlaghecken (1998) might be taken as an exception, providing initial evidence that the ability of masked primes to trigger a corresponding motor activation does not depend on optimal response readiness. However, in this experiment there was only one Go stimulus, requiring a response with only one finger, and Go and NoGo stimuli were equiprobable. Therefore, it might be argued that Go and NoGo stimuli were actually assigned to two alternative responses, i.e., "perform key-press" and "withhold key-press," thus again allowing for an optimal response readiness.

The present study directly addressed the question of whether conditions of optimal response readiness are necessary for the occurrence of compatibility effects elicited by masked primes. To test whether partial response activation triggered by masked primes depends on the *general* level of response readiness (high vs low), the relative frequency of Go-trials in a modified Go/NoGo task was varied (Exp. 1). To test whether it depends on *specific* response expectancies (equilibrium vs biased preparation), the relative fre-

quency of left- and right-hand responses in a 2-alternative choice RT task was varied (Exp. 2). If optimal response readiness is necessary for a perceptually weak stimulus to trigger a motor activation at all, then masked primes should fail to elicit an initial response activation under conditions of reduced or biased response readiness (*Absent Activation* hypothesis). However, one might assume that the onset of the masked primes increases the general level of motor activation sufficiently for a hand-specific partial response activation to occur (cf. Gratton, *et al.*, 1988; Miller, 1998). If this would be the case, masked primes might trigger a partial motor activation under conditions of reduced or biased response readiness, but the onset of this activation should be delayed relative to a condition where no initial increase in general motor activation is necessary (*Delayed Activation* hypothesis).

To distinguish between these two hypotheses, the experiments were designed in a way that under conditions of optimal response readiness a negative compatibility effect was to be expected. Since this effect exhibits a distinctive time-course of activation-followed-by-inhibition (see above), distinguishing between Delayed Activation and Absent Activation should be possible without the need for additional manipulations like varying the prime-target interval. According to the Absent Activation hypothesis, no compatibility effects should be found under conditions of reduced response readiness. A delayed activation, in contrast, should result in positive compatibility effects, as motor activation in response to the target would occur during the (delayed) initial activation phase rather than during the subsequent inhibition phase. Of course, partial motor activation triggered by masked primes might just be reduced rather than delayed under conditions of reduced response readiness. According to a threshold model of motor inhibition outlined by Schlaghecken and Eimer (2000), this could also result in positive compatibility effects, as no inhibition process would be elicited if the initial activation remains below threshold. However, a simple analysis of RT distributions could distinguish between this *Reduced Activation* hypothesis and the Delayed Activation hypothesis: If activation was delayed, positive compatibility effects should be small for fast responses and larger for slower responses. If, on the other hand, activation was reduced, but not delayed, compatibility effects should be evenly distributed across RT latencies. If manipulations of response readiness did not affect the size or direction of compatibility effects, this would indicate that partial motor activation triggered by a masked prime does not depend on response readiness.

#### EXP. 1: VARYING RELATIVE FREQUENCIES OF GO AND NOGO TRIALS

In this experiment, the overall response readiness was manipulated by varying the probability of Go trials in a choice reaction Go/NoGo task. It

was assumed that response readiness would be high when the probability of Go trials was high (80%), while a very low probability of Go trials (20%) should reduce response readiness (see Low & Miller, 1999). As a consequence, RTs should be shorter in the high Go-probability condition than in the low Go-probability condition. More importantly, prime-target compatibility effects should differ between these conditions if the primes' ability to trigger a partial motor response was dependent on response readiness. Negative compatibility effects similar to those observed in previous studies (Schlaghecken & Eimer, 1997, 2000; Eimer & Schlaghecken, 1998; Eimer, 1999) should be found in the high Go-probability condition. In the low Go-probability condition, no compatibility effects should occur if the Absent Activation hypothesis holds, but positive compatibility effects should be obtained if the Delayed Activation or the Reduced Activation hypotheses hold.

### *Method*

*Participants.*—Eight paid volunteers (2 men), aged 21–41 years ( $M: 31.3$ ) participated in the experiment. According to self-report, all were right-handed and had normal or corrected-to-normal vision.

*Stimuli and apparatus.*—Left-pointing, right-pointing, and inward-pointing double arrows (<<, >>, ><) served as primes and targets. The mask was constructed by superimposing left-pointing and right-pointing double arrows upon one another. All stimuli subtended a visual angle of approximately  $0.9^\circ \times 0.3^\circ$  and were presented in black on a white background in the centre of a 17-in. computer screen.

*Procedure.*—Participants were seated in a comfortable chair in a dimly lit chamber, with response buttons under the left and right index fingers. A computer screen was placed 100 cm in front of the participants' eyes, with the screen centre in the centre 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 with a left button press to a left-pointing target arrow, with a right button press to a right-pointing target arrow, and not to respond to inward-pointing target arrows.

Each trial began with the presentation of a prime stimulus (16 msec. duration), followed immediately by the mask (100 msec.), which in turn was immediately followed by a target (100 msec.). Primes and targets were either left- or right-pointing double arrows (Go stimuli) or inward pointing double arrows (NoGo stimuli). On Compatible trials, prime and target consisted of identical Go stimuli; on Incompatible trials, prime and target consisted of different Go stimuli. On Neutral trials, the target was a Go stimulus while the prime was a NoGo stimulus.<sup>2</sup> Compatible, Incompatible, and Neutral

<sup>2</sup>It could be argued that the NoGo prime should not be regarded as neutral. Since this prime might itself cause inhibition, performance costs on Compatible trials might be underestimated,

trials were equiprobable and randomised within each block. Trials on which both prime and target consisted of a NoGo stimulus were termed Consistent trials, and trials where the prime consisted of a Go stimulus and the target consisted of a NoGo stimulus were termed Inconsistent trials. Since the three primes appeared with equal probability independent of the subsequent target, there were twice as many Inconsistent trials as Consistent trials in each block, i.e., one-third of all NoGo targets were preceded by a NoGo prime, while two-thirds were preceded by a Go prime.

The experiment consisted of six blocks. In three blocks, NoGo targets were presented on 20% of all trials, and on 80% of all trials Go targets were presented (Go80 blocks). In the other three, these probabilities were reversed (Go20 blocks). The sequence of Go80 and Go20 blocks was completely randomised for each participant. At the beginning of each block, participants were informed about whether to expect a frequent response (Go80) block or an infrequent response (Go20) block. Go80 blocks consisted of 240 trials each, while Go20 blocks, to achieve a sufficient number of Go trials, consisted of 360 trials each. ITI was 1,000 msec. Within each block, there was a break of at least 20 seconds every 120 trials. After this time, participants could initiate the next series of trials when they felt ready.

*Data analysis.*—Repeated-measures analyses of variance were computed for correct response RTs, error rates (incorrect responses), and Misses on Go trials for the factors of Response Probability (80%, 20%) and Compatibility (compatible, incompatible, neutral). False Alarm rates on NoGo trials in Go80 and Go20 blocks were compared with a paired *t* test. Additional *t* tests for paired data compared Consistent and Inconsistent False Alarms rates for Go80 blocks and Go20 blocks separately.

### *Results and Discussion*

RTs were shorter in Go80 blocks than in Go20 blocks (416 msec. vs 503 msec.;  $F_{1,7} = 15.91, p < .005$ ), indicating that the experimental manipulation successfully influenced response readiness (see Fig. 1). However, RT was slowest on Compatible trials, intermediate on Neutral trials, and fastest on Incompatible trials in both Go80 and Go20 blocks (Go80: 442 msec., 413 msec., 394 msec.; Go20: 523 msec., 500 msec., 487 msec.; main effect of Compatibility:  $F_{2,14} = 34.04, p < .001, \epsilon = .728$ ; interaction of Response Probability  $\times$  Compatibility:  $F_{2,14} = 2.1, ns$ ). That is, not only were there negative compatibility effects in Go20 blocks, but these effects were not even significantly reduced under conditions of reduced response readiness. This was

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and performance benefits on Incompatible trials might be overestimated. However, the critical issue here is not the relative size of costs vs benefits but rather whether or not costs and benefits were different in Go80 and Go20 blocks. Therefore, we do not regard the issue of the neutrality of the NoGo primes to be problematic for the present purpose.

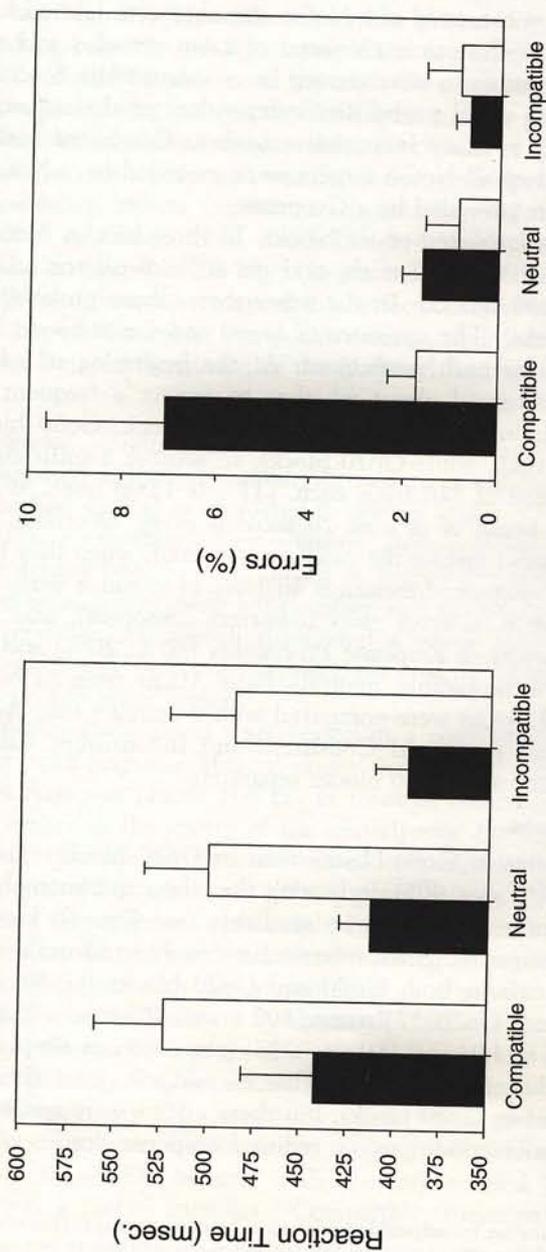


FIG. 1. Mean reaction times (left) and error rates (right) in Exp. 1 on Compatible, Neutral, and Incompatible Go-trials plotted separately for Go80 blocks (■) and Go20 blocks (□). Lines indicate standard error.

confirmed by a series of additional  $t$  tests. Four  $t$  tests comparing Compatible with Neutral trials and Incompatible with Neutral trials, separately for Go20 and Go80 blocks, showed significant costs as well as significant benefits on RTs for both response probability conditions (all  $t_{7s} > 2.45$ , all  $ps < .05$ ). Most importantly,  $t$  tests comparing Go80-costs with Go20-costs and Go80-benefits with Go20-benefits further confirmed that there was no significant difference between probability conditions for either costs or benefits (both  $t_{7s} < 1.5$ , both  $ps > .19$ ).

For error rates, a different pattern of results was obtained. Error rates were not statistically significantly higher in Go80 blocks than in Go20 blocks (3.1% vs 1.2%;  $F_{1,7} = 3.80$ ,  $.10$ ). Although the main effect of Compatibility fell short of statistical significance ( $F_{2,14} = 5.41$ ,  $p < .06$ ,  $\epsilon = .504$ ), there was an interaction of Compatibility  $\times$  Response Probability ( $F_{2,14} = 6.89$ ,  $p < .03$ ,  $\epsilon = .544$ ). Subsequent analyses indicated that compatibility effects were significant in the Go80 blocks ( $F_{2,14} = 6.14$ ,  $p < .04$ ,  $\epsilon = .509$ ), as error rates were highest on Compatible trials, intermediate on neutral trials, and lowest on Incompatible trials (7.1%, 1.6%, and 0.7%, respectively). No compatibility effects were obtained in the Go20 blocks ( $F_{2,14} < 1.84$ , ns). However, inspection of Fig. 1 suggests that again more errors were made on Compatible trials than on Incompatible trials. Given the facts that there were substantial compatibility effects on RTs in the Go20 blocks and that the absolute number of errors in these blocks was extremely low (less than one error per block on average), it seems unlikely that the missing compatibility effect truly indicates an influence of the experimental manipulation.

There was no effect of any of the experimental manipulations on the amount of Misses (all  $F_s < 2.6$ , all  $ps > .13$ ). False Alarm rate was considerably higher in the Go80 blocks than in the Go20 blocks (13.7% vs 0.7%;  $t_7 = 4.39$ ,  $p < .003$ ). In Go80 blocks, False Alarm rate was higher for consistent NoGo trials (containing a NoGo-prime) than for inconsistent NoGo trials (containing a Go-prime). Although the difference was quite substantial (20.3% vs 10.4%), it was not statistically significant ( $t_7 < 1.9$ , ns). Interestingly, on inconsistent trials participants showed a clear tendency to produce incongruent False Alarms, i.e., to respond with the hand opposite to the direction indicated by the prime ( $t_7 = 2.83$ ,  $p < .03$ ). Given the overall low number of False Alarms, these effects were not found in Go20 blocks. However, at least numerically the same tendency to produce more incongruent than congruent False Alarms was present even in these blocks. These results suggest that the active inhibition of the initial response tendency resulted in a partial activation of the alternative response, which on some trials was strong enough to trigger an incongruent overt reaction.

Taken together, the present findings show that, in the masked priming paradigm, prime/target compatibility effects are not systematically affected

by a reduced overall response readiness. Given the small number of errors in the low response-readiness condition, it is not clear whether error rates were influenced by response readiness. However, for RTs similar negative compatibility effects were found under both response-readiness conditions. Therefore, the present data do not support the assumption that high response readiness is necessary for a successfully masked prime to trigger a partial motor activation. However, these results only indicate that *general* response readiness is not crucial for the occurrence of partial response activation and subsequent inhibition triggered by masked primes. The possibility still exists that *specific* response readiness, e.g., whether to prepare for a left-hand response or for a right-hand response, is a critical factor. As outlined in the Introduction, it can easily be imagined that, for a masked prime to activate one of two responses, the motor system has to be in an unstable state of dynamic equilibrium, i.e., not strongly biased against one of the responses. In the following experiment, this issue was investigated.

#### EXP. 2: VARYING RELATIVE FREQUENCIES OF LEFT- AND RIGHT-HAND RESPONSES

In this experiment, specific response readiness was manipulated by varying the relative frequency of left-hand and right-hand responses between blocks. In the Baseline blocks, left-hand and right-hand responses were equiprobable. In the Response Bias blocks, 90% of all trials required a response with one hand, and 10% required a response with the other hand. Under conditions of unequal stimulus-response probability, frequent responses are known to be faster and more accurate than infrequent responses (e.g., LaBerge & Tweedy, 1964; Bertelson & Tisseyre, 1966; Blackman, 1972). Moreover, a preparation for the highly probable response is visible in the Lateralized Readiness Potential well before the stimulus is actually presented, at least if the time of stimulus onset is known in advance (Miller, 1998). Therefore, it was assumed that in the Response Bias blocks, hand-specific response readiness would be high for the frequently used response hand, and low for the infrequently used response hand.

There seem to be two ways in which specific response readiness might influence the negative compatibility effect. On the one hand, an unstable dynamic equilibrium might be necessary for each of the masked primes to trigger its corresponding motor activation. Were this the case, negative compatibility effects should be present in the Baseline blocks but absent in the Response Bias blocks. On the other hand, one might assume that high hand-specific response readiness enables the prime associated with this response to trigger a motor activation, while a low level of hand-specific response readiness does not. Were this the case, then only the prime associated with the frequent response should elicit motor activation and subsequent inhibi-

tion, while no such process should be triggered by the prime associated with the infrequent response. Therefore, performance costs on compatible trials and performance benefits on incompatible trials (relative to neutral trials) should be differentially affected for frequent and infrequent responses. For frequent responses, performance costs on compatible trials should be present. However, performance benefits on incompatible trials should be absent because on these trials the prime is associated with the infrequent response and, therefore, is not assumed to elicit motor activation and subsequent inhibition. Correspondingly, for infrequent responses performance benefits on incompatible trials should be present, and performance costs on compatible trials should be absent.

### *Method*

*Participants.*—Eight paid volunteers (4 men), aged 25–42 years ( $M: 29.1$ ) participated in the experiment. All were right-handed and had normal or corrected-to-normal vision, according to their self-report.

*Procedure.*—Stimuli and apparatus were identical to those in Exp. 1. The general experimental set-up also was similar to the previous experiment, except that no NoGo targets were included. Compatible, incompatible, and neutral trials were equiprobable and randomised within each block. The experiment consisted of nine blocks, each containing 180 trials with a constant intertrial interval of 1200 msec. In three blocks, 90% of all trials required a right-hand response, and 10% of all trials required a left-hand response (Frequent Right blocks). In another three blocks, these probabilities were reversed (Frequent Left blocks). In the remaining three blocks, left-hand responses and right-hand responses were equiprobable (Mixed blocks). The sequence of blocks was completely randomised for each participant. At the beginning of each block, participants were informed about whether to expect a Frequent Left block, a Frequent Right block, or a Mixed block.

*Data analysis.*—Data from the Frequent Left and Frequent Right blocks were collapsed, and analyses of variance were computed on RTs for correct responses and on error rates for the factors Response Frequency (90%, 50%, 10%) and Compatibility (compatible, incompatible, neutral). Also, the size of the costs and benefits of compatible and incompatible trials relative to neutral trials was computed. This was done by subtracting RTs (error rates) on neutral trials from RTs (error rates) on compatible trials (costs) and by subtracting RTs (error rates) on incompatible trials from RTs (error rates) on neutral trials (benefits).<sup>3</sup> Additional analyses of variance were computed on these values for the factors Response Frequency and Effect Type

<sup>3</sup>Note that with this procedure, performance differences between compatible trials and neutral trials were classified as Costs, and differences between incompatible trials and neutral trials were classified as Benefits, regardless of the actual direction of these differences.

(cost vs benefit). Where appropriate, Greenhouse-Geisser adjustments to the degrees of freedom were performed.

### *Results and Discussion*

RTs and error rates decreased with increasing response probability from 424 msec./30.1% errors for rare responses, to 370 msec./6.9% errors for equiprobable responses, and finally to 338 msec./0.9% errors for frequent responses (RT:  $F_{2,14} = 58.75$ ,  $p < .001$ ,  $\epsilon = .645$ ; error rates:  $F_{2,14} = 43.62$ ,  $p < .001$ ,  $\epsilon = .529$ ), indicating that the experimental manipulation affected hand-specific response readiness (see Fig. 2). However, as in the previous experiment, RTs were longest on Compatible trials, intermediate on Neutral trials, and shortest on Incompatible trials (frequent responses: 351 msec., 337 msec., 326 msec.; equiprobable responses: 388 msec., 368 msec., 353 msec.; infrequent responses: 443 msec., 419 msec., 411 msec.; main effect of Compatibility:  $F_{2,14} = 16.89$ ,  $p < .002$ ,  $\epsilon = .645$ ), and there was no significant interaction of Compatibility  $\times$  Frequency ( $F < 2.1$ , ns). Moreover, RT costs and benefits were evenly distributed across frequency conditions as there was neither a main effect of Response Frequency on costs and benefits, a main effect of Effect Type, or an interaction between these factors (all  $F_s < 2.9$ , ns).

Similarly, error rates were highest on Compatible trials, intermediate on Neutral trials, and smallest on Incompatible trials (19.8%, 9.7%, and 0.9%, respectively;  $F_{2,14} = 14.59$ ,  $p < .002$ ,  $\epsilon = .708$ ). Although there was a significant interaction of Compatibility  $\times$  Frequency ( $F_{2,14} = 11.97$ ,  $p < .002$ ,  $\epsilon = .430$ ), this was due to the fact that compatibility effects on error rates were most pronounced with rare responses, less pronounced with equiprobable responses, and least pronounced with frequent responses. Subsequent analyses of variance, conducted for each probability condition separately, showed significant compatibility effects for infrequent and equiprobable responses (both  $F_{2,14} > 11.5$ , both  $ps < .006$ ) but not for frequent responses ( $F < 2.6$ , ns). This result stands in marked contrast to the prediction that negative compatibility effects should be restricted to conditions of equiprobable responses or at least to conditions of high general or specific response readiness. As can be seen from Fig. 2, the pattern of negative compatibility effects on error rates did not differ systematically between response-readiness conditions. Rather, as in Exp. 1, the effect did not reach statistical significance only if the overall number of errors was extremely small (about 1.5 per block on average for frequent responses). Importantly, this was the case for the low response-readiness condition in Exp. 1 but for the high response-readiness condition in the present experiment. Taken together, the present results thus clearly indicate that negative compatibility effects on RTs and error rates were not influenced by general (Exp. 1) or specific (Exp. 2) response readiness.

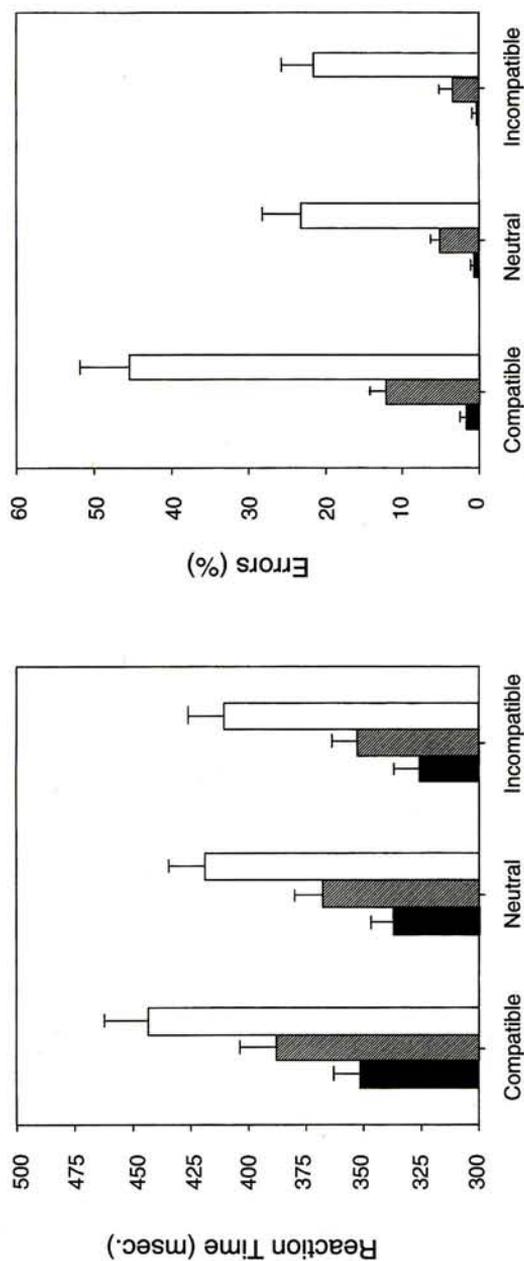


FIG. 2. Mean reaction times (left) and error rates (right) in Exp. 2 on Compatible, Neutral and Incompatible trials plotted separately for frequent responses (90%, black), equiprobable responses (50%, grey), and infrequent responses (10%, white). Lines indicate standard error.

## CONCLUDING REMARKS

Two experiments investigated whether negative compatibility effects elicited by masked primes are dependent on response readiness. The Absent Activation hypothesis stated that conditions of optimal response readiness are necessary for a perceptually weak stimulus like a successfully masked prime to trigger a motor activation at all. The Delayed Activation hypothesis stated that masked primes may trigger a motor activation even under conditions of reduced motor preparation but that the time course of the activation and subsequent inhibition processes will be delayed as additional time is needed to increase the general level of motor activation sufficiently before a hand-specific partial response activation can be initiated. The Reduced Activation hypothesis stated that under conditions of reduced motor preparation, masked primes will trigger a reduced partial activation of their corresponding motor response, so that no subsequent inhibition will be elicited (cf. Schlaghecken & Eimer, 2000).

Results suggest that neither hypothesis has empirical support. The pattern of reaction times and error rates obtained in both experiments showed that the manipulation of general and specific response readiness had been successful. However, neither reducing the general response readiness in a Go/NoGo task (Exp. 1) nor manipulating the specific response readiness by inducing a strong bias towards one out of two responses (Exp. 2) significantly influenced the negative compatibility effect for RTs. Analyses of error rates in Exp. 1 gave no clear evidence of whether error rates were influenced by the experimental manipulation of response readiness. However, analyses of the error rates in Exp. 2 indicated that the negative compatibility effect on error rates was by no means restricted to equiprobable responses. It therefore has to be concluded that negative compatibility effects elicited by masked primes are independent of general and specific response readiness.

Since there is strong evidence that these effects are based on a partial activation and subsequent inhibition of a motor response triggered by the prime (see above), one has to reach a surprising conclusion. While *motor performance* in response to clearly visible targets is influenced by differences in response readiness, *initial motor activation* in response to successfully masked primes is not. More specifically, the general ability of masked primes to elicit a partial motor activation as well as the time course of the activation and inhibition processes seems to be largely unaffected by response readiness. Presumably, early motor activation processes triggered by masked primes are similar to those triggered by clearly perceivable targets. Therefore, the present finding can be interpreted as indicating that early stages of motor activation are not susceptible to variations in response readiness.

This conclusion seems at odds with the assumption that the functional locus of response readiness occurs prior to or at the stage of early motor ac-

tivation processes, as suggested by the Pre-activation account of response readiness outlined in the Introduction (e.g., Coles, *et al.*, 1985; Gratton, *et al.*, 1988). If the same motor stages that were affected by the masked primes also were influenced by the response-readiness manipulation, one would have expected to find different priming effects for high versus low response-readiness conditions. This was clearly not the case. One tentative explanation for this could be that response readiness affects motor performance at some stage *after* the initial activation phase, for example, at or immediately prior to the response-execution stage. This hypothesis is not necessarily at odds with models of motor control assuming that effects of response readiness are the outcome of thalamic gating processes modulating thalamo-cortical streams of information processing (e.g., Brunia, 1997, 1999). However, the present results can be interpreted as indicating that the opening of thalamo-cortical channels does not lead to facilitation of early response activation but rather results in facilitation of response execution, for example, by lowering the execution threshold.

Although this explanation seems to be straightforward with respect to manipulations of general response readiness (Exp. 1), it is less clear whether it might also account for the results of Exp. 2 (manipulation of specific response readiness). Miller (1998) provided compelling evidence that, under conditions of unequal stimulus-response probabilities, shorter RTs for the frequent response are associated with a partial activation of this response prior to stimulus onset. One might assume that because in Exp. 2 the next trial started at a variable interval after the previous response, no such anticipatory preparation occurred. Were this the case, then the faster RTs for frequent responses might again be due to a lowering of the execution threshold, and the explanation outlined above would also apply to the findings of Exp. 2. On the other hand, the possibility cannot be ruled out that in this experiment anticipatory preparation for the more frequent response did occur. Were this the case, the threshold hypothesis would be insufficient to explain the data. Rather, one would have to conclude that stimulus-driven motor activation and expectancy-driven motor activation are different processes which affect motor performance at different stages (or via different pathways). Although this hypothesis is in line with behavioural and neurophysiological evidence indicating that motor preparation is by no means a unitary process (e.g., Brunia, 1999; Ilan & Miller, 1999), it has to remain speculative on the basis of the present experiments. Further research is clearly required to clarify these issues.

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