

COMMENTS

Active Masks and Active Inhibition: A Comment on Lleras and Enns (2004) and on Verleger, Jaśkowski, Aydemir, van der Lubbe, and Groen (2004)

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Verleger, Jaśkowski, Aydemir, van der Lubbe, and Groen (2004) and Lleras and Enns (2004) have argued that negative compatibility effects (NCEs) obtained with masked primes do not reflect self-inhibition processes in motor control. Instead, NCEs are assumed to reflect activation of the response opposite to the prime, triggered by the presence of prime/targetlike features in the mask. Thus, no NCEs should be elicited when masks do not contain such task-relevant features. In Experiments 1 and 3, the authors demonstrate that NCEs can be obtained when masks contain only irrelevant features. Experiment 2 demonstrates that positive compatibility effects (PCEs) will occur with such masks when masked primes are presented peripherally. These results are inconsistent with the mask-induced activation accounts but are in line with the self-inhibition hypothesis of the NCE. Although perceptual interactions and mask-induced motor activations may contribute to NCEs under certain conditions, they cannot provide a full explanation for these effects.

Keywords: masked priming, motor control, self-inhibition

In a masked priming paradigm, participants perform a speeded two-alternative-choice reaction time (RT) task to simple visual target stimuli such as left- or right-pointing arrows, which are preceded by backward-masked primes. Because masking reduces prime visibility, participants are usually unable to consciously perceive the primes, as evidenced by forced-choice prime identification performance at or near chance level (e.g., Eimer & Schlaghecken, 1998, 2002; Schlaghecken & Eimer, 1997). On compatible trials, primes and targets are associated with the same response (e.g., both are left-pointing arrows). On incompatible trials, they are associated with different responses. On neutral trials, the prime is not associated with any response. Behavioral benefits on compatible trials and costs on incompatible trials relative to neutral trials (positive compatibility effect; PCE) are observed when the target follows the masked prime with an interstimulus interval (ISI) of 0 to approximately 60 ms. When masked primes and targets are separated by longer intervals (about 100–150 ms), a negative compatibility effect (NCE) is observed, with behavioral costs on compatible and benefits on incom-

patible trials (Aron et al., 2003; Eimer, 1999; Eimer, Schubö, & Schlaghecken, 2002; Eimer & Schlaghecken, 1998, 2001, 2002, 2003; Klapp & Haas, 2005; Klapp & Hinkley, 2002; Praamstra & Seiss, 2005; Schlaghecken & Eimer, 1997, 2000, 2001, 2002, 2004; Schlaghecken, Münchau, Bloem, Rothwell, & Eimer, 2003; Seiss & Praamstra, 2004).

We have previously argued (Eimer, 1999; Eimer & Schlaghecken, 1998, 2003; Schlaghecken & Eimer, 1997, 2000, 2002, in press) that PCEs and NCEs reflect successive phases of automatic activation and subsequent self-inhibition processes in low-level motor control. Initially, masked primes trigger their assigned response, which—via lateral inhibitory links—causes inhibition of the competing response alternative. If the target appears immediately after the prime, then target-related response processes can start during this initial phase. Consequently, these processes will be affected by this imbalance in response activation levels, reflected in benefits on compatible and costs on incompatible trials (PCE). However, presentation of the masking stimulus abruptly terminates the initial activation phase. An effective mask removes the prime's neural representation.¹ Consequently, the initially primed response is no longer supported by corresponding sensory input. This sudden lack of supporting perceptual evidence triggers an active self-inhibition process, acting as an “emergency brake” mechanism to suppress a response tendency that

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¹ This is not meant to imply any specific view on the mechanisms underlying visual backward masking, which might be based on interruption (e.g., Turvey, 1973), on interactions between spatial frequency channels (e.g., Breitmeyer & Ganz, 1976; Delord, 1998), on object substitution (e.g., Enns & Di Lollo, 2000), or on a combination of these mechanisms. Here, it is relevant to assume only that processing of the mask causes the previously present unequivocal evidence for one particular response to be no longer available to the motor system.

has become obsolete. As a consequence, the competing response will be released from inhibition (Eimer & Schlaghecken, 1998; Schlaghecken & Eimer, in press).

If target-related response processes take place during this phase (because the target is presented some time after mask onset), self-inhibition of the primed response and disinhibition of its competitor result in costs on compatible and benefits on incompatible trials (NCE). This pattern of activation followed by inhibition is seen as a characteristic feature of low-level motor control, in which initial motor activations triggered by masked primes actively self-inhibit once they are no longer supported by perceptual evidence (see Schlaghecken & Eimer, 2002, for a functional model, and Bowman, Schlaghecken, & Eimer, 2006, for a computational implementation).

This interpretation of the NCE has been challenged by Verleger, Jaśkowski, Aydemir, van der Lubbe, and Groen (2004) and by Lleras and Enns (2004). These authors claimed that self-inhibition plays no role in the NCE. Instead, they argued that the reversal of priming effects—from PCEs with short prime/mask–target ISIs to NCEs with longer ISIs—reflects a sequence of two positive priming events of opposite direction. With respect to the initial, prime-induced activation of the response associated with the prime stimulus, there is no difference between our model and the views of Verleger et al and Lleras and Enns. However, the accounts differ with respect to the second phase. Our model proposes that the mask deprives the motor system of the sensory evidence needed to sustain the primed response and that this triggers self-inhibition. In contrast, Verleger et al. and Lleras and Enns argued that the mask itself causes activation of the opposite response, triggered by certain features contained in the masking stimulus.

For example, in many masked-prime experiments, primes and targets were left- and right-pointing arrows (“<<” and “>>”), and masking stimuli were constructed by superimposing these two stimuli. Each mask thus contained features associated with the primed response and, crucially, features associated with the opposite response, which might trigger a corresponding motor activation. According to Verleger et al. (2004) and Lleras and Enns (2004), the NCE results from this mask-induced activation. Their accounts differ with respect to the precise nature of the underlying mechanisms. Verleger et al.’s “active-mask” hypothesis emphasizes sensory interactions between prime and mask, whereas Lleras and Enns argued in favor of an “object-updating” process. However, the basic argument is analogous: The NCE occurs because the mask contains evidence for (and hence facilitates) the opposite response, not because it removes evidence for the primed response.

If this is correct, NCEs should only occur with masks that contain features similar to the prime and target stimuli. If the mask does not contain response-associated features, it should be incapable of triggering any motor response. With such a “neutral” mask, the only stimulus exerting any influence on target-related motor processes should be the prime itself, and consequently, only PCEs should be obtained. Verleger et al. (2004) and Lleras and Enns (2004) presented data in line with these predictions. While NCEs were found with masks composed of superimposed arrows or arrow-like stimuli, only PCEs were obtained when masks did not contain arrow-like features but were constructed from horizontal and vertical lines (Lleras and Enns) or from randomly arranged light and dark squares (Verleger et al.).

Here, we provide evidence demonstrating that the object-updating and active-mask hypotheses are insufficient to explain all instances in

which NCEs can be observed and that explanations of masked priming effects in terms of inhibitory motor control processes are therefore still needed. Before presenting this evidence, some words of clarification are in order. We endorse the view put forward by Lleras and Enns (2004) and Verleger et al. (2004) that perceptual and post-perceptual interactions between primes and masks may well have contributed to the NCEs observed in previous experiments. This is particularly the case for experiments (e.g., Eimer & Schlaghecken, 1998, Schlaghecken & Eimer, 2000) in which left- and right-pointing arrow primes were followed by superimposed arrow masks, so that mask presentation effectively added the opposite arrow to the initially presented prime. We have explicitly acknowledged that, under these conditions, perceptual interactions between primes and masks might have rendered those parts of the mask that were opposite to the prime more salient (e.g., Schlaghecken & Eimer, 2002, footnotes 1 and 5) and might have caused corresponding response activations. It was precisely to avoid the possibility that NCEs are determined by such inadvertent interactions between primes and masks that we and others have abandoned “arrow masks” in favor of a “scrambled-pattern” mask composed of randomly distributed lines of different length and orientation (e.g., Aron et al., 2003; Eimer & Schlaghecken, 2002; Praamstra & Seiss, 2005; Schlaghecken & Eimer, 2002, 2004, in press; Seiss & Praamstra, 2004).

It should be noted that the NCEs reported by Verleger et al. (2004) and Lleras and Enns (2004) were all observed in experiments in which arrow-mask procedures were used. Thus, there is no disagreement between us and Verleger et al. or Lleras and Enns that these effects may have been the result of specific interactions between perceptual objects, perhaps along the lines described by the object-updating account. However, the possibility that object updating or sensory interaction may contribute to the phenomenon of NCEs when there is feature overlap between primes and masks does not entail that such accounts provide a complete explanation of NCEs for all conditions. Crucially, both Lleras and Enns and Verleger et al. claimed that NCEs will only be found when primes and masks share perceptual features. When this is not the case, no activation of the opposite response will take place and, consequently, no NCE is elicited.

Here, we demonstrate that NCEs are present in the absence of such feature overlap, which is at odds with the proposals by Lleras and Enns (2004) and Verleger et al. (2004). Experiment 1 demonstrates NCEs with masks composed entirely of horizontal and vertical lines, similar to the “irrelevant mask” used by Lleras and Enns. Experiment 2 is a control experiment demonstrating that PCEs will be obtained with such masks when primes are presented in the periphery of the visual field. Experiment 3 demonstrates NCEs with masks composed entirely of randomly arranged light and dark squares, similar to the “checkerboard mask” used by Verleger et al.

Experiment 1: Diagonal- and Nondiagonal-Line Masks

According to our account of low-level motor control, self-inhibition occurs whenever an effective mask removes any prime-related representation, thus eliminating sensory evidence in support of the response activation triggered by the prime. Thus, the emergence of NCEs depends on mask effectiveness. When an ineffective mask is used, and sensory traces induced by the prime are therefore not completely removed, the initially primed response activation will persist, resulting in PCEs rather than NCEs. This situation may have arisen in Lleras and Enns’s (2004) exper-

iments. Effective pattern masking depends on feature similarities between primes and masking stimuli. Consequently, masking of diagonal-arrow primes is very difficult with nondiagonal masks and was in fact not very effective, with approximately 90% correct prime identification performance in most experiments. The absence of NCEs reported by Lleras and Enns with “irrelevant” nondiagonal-line masks may thus be primarily due to ineffective masking and not to the fact that there were no shared features between primes and masks.

Experiment 1 was designed to support this alternative explanation. Centrally presented arrow primes were masked, on half of the trials, with our standard scrambled-random-lines masks (“diagonal masks”), which combined horizontal, vertical, and diagonal lines of different length and orientation. On the other half, primes were masked with a nondiagonal-line mask, which contained only horizontal and vertical elements (equivalent to the irrelevant mask used by Lleras & Enns, 2004). To create efficient masks when these share no features with the to-be-masked stimulus, two different randomly generated nondiagonal-line masks were presented successively for 50 ms each (see Figure 1). This dynamic masking method also was adopted for the diagonal-line masks.

According to the object-updating account of masked priming, NCEs should be observed with the diagonal-lines mask, which contains visual features similar to the primes, whereas PCEs should be found with the “irrelevant” nondiagonal-lines mask. Such a pattern of results would confirm Lleras and Enns’s (2004) findings under conditions in which primes are effectively masked. In contrast, the self-inhibition account predicts NCEs with both types of masks.

Method

Participants. Twenty-four paid volunteers (7 male), aged 19–39 years (mean age: 24.1 years), were tested. According to self-report, all but one participant were right-handed, and all had normal or corrected-to-normal vision.

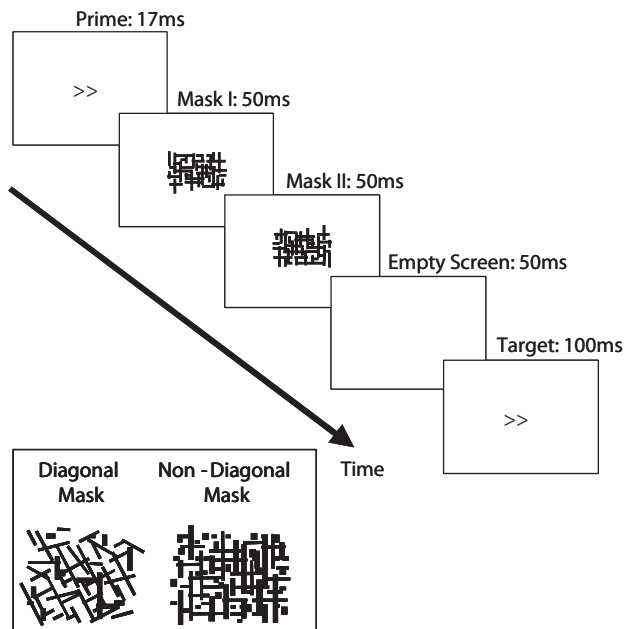


Figure 1. Trial structure and structure of masking stimuli in Experiment 1.

Stimuli and apparatus. Primes and targets were left- and right-pointing double arrows (“<<”, “>>”), subtending a visual angle of $0.9^\circ \times 0.3^\circ$. Masks were constructed within a 13×7 matrix, randomly filled with overlapping lines of different length (0.1° – 0.6°) and orientation, resulting in a rectangular array of $3.5^\circ \times 2.3^\circ$. New random masks were generated on each trial to avoid perceptual learning of the mask (Schubö, Schlaghecken, & Meinecke, 2001). In the diagonal-mask condition, approximately 80% of the lines were tilted, with an angle of 12° , 35° , 145° , or 168° (lines forming prime and target arrows were tilted at angles of approximately 20° and 160°). The remaining 20% of lines were horizontal or vertical. This mask was virtually identical to the scrambled-pattern mask used before (Aaron et al., 2003; Eimer & Schlaghecken, 2002; Schlaghecken & Eimer, 2002, 2004). In the non-diagonal mask condition, half of the lines were vertical, and half were horizontal, and additional small squares and rectangles ($0.1^\circ \times 0.1^\circ$, $0.1^\circ \times 0.3^\circ$, respectively) were randomly placed within each cell.

Procedure. Participants were seated in a dimly lit chamber with response keys under their left and right index fingers, facing a computer screen at a viewing distance of 100 cm. They were instructed to maintain central eye fixation. The experiment consisted of one reaction time (RT) part and one forced-choice (FC) part. Each part began with a 24-trials practice block, followed by 6 (RT part) or 3 (FC part) experimental blocks of 80 trials each. Participants were given a break of at least 2 minutes after each block and were encouraged to take longer breaks whenever necessary.

In the RT part, each trial consisted of a prime, presented for 17 ms (one screen refresh cycle, value rounded to the nearest ms), immediately followed by one of the two masks (diagonal or nondiagonal) presented for 100 ms. Mask presentation was broken into two 50-ms presentations of two different (randomly generated) masks of the same type (i.e., two diagonal or two nondiagonal) following each other immediately. Fifty ms after the offset of the (second part of) the mask, the target was presented for 100 ms. All stimuli were presented at the screen center. Intertrial interval (ITI) was 1,300 ms. On compatible trials, prime and target arrows pointed in the same direction. On incompatible trials, they pointed in opposite directions. All conditions (2 masks \times 2 compatibility) were equiprobable and randomized within each block, resulting in 20 trials per block per condition and 120 trials per condition overall. Participants were instructed to respond as quickly and accurately as possible with a left- or right-key press to left-pointing and right-pointing target arrows, respectively.

In the FC part, each trial consisted of a left- or right-pointing prime arrow, presented for 17 ms, 33 ms, 50 ms, or 67 ms, immediately followed by one of the two different masks, constructed and presented in the same way as in the RT part. No subsequent targets were presented, and ITI was 1,300 ms. Different trial types were randomized and equiprobable within each block. Participants were instructed to press the key corresponding to the prime arrow’s direction and to make a guess if they could not identify the prime clearly.

Data analysis. Repeated-measures analysis of variance (ANOVAs) were computed on the percentage of correct responses in the FC identification task for the factors mask (diagonal, nondiagonal) and duration (17 ms, 33 ms, 50 ms, 67 ms). ANOVAs were computed on correct RTs and error rates for the factors mask and compatibility (compatible, incompatible) in the RT task. Greenhouse–Geisser adjustments to the degrees of freedom were performed where appropriate, and corrected p values are reported. Effect size estimates are reported as partial eta squared. Individual results are presented in Table A1 of the Appendix.

Results

FC identification performance (see Table 1). Identification performance was lower for diagonal-line masks than for nondiagonal-line masks, $F(1, 23) = 27.45$, $p < .001$, $MSE = 39.59$, $\eta_p^2 = .544$, and decreased with decreasing prime duration, $F(3, 69) = 81.74$, $\epsilon = .631$, $p < .001$, $MSE = 205.08$, $\eta_p^2 = .780$. There was no interaction between these factors, $F(3, 69) < 1$.

Table 1
Forced-Choice Prime Identification Performance in Experiment 1 (Percentage of Correct Responses for Mask Type, Standard Deviations in Parentheses)

Mask	Prime Duration			
	17 ms	33 ms	50 ms	67 ms
Diagonal mask	52.8 (16.4)	69.8** (19.8)	81.7** (14.8)	89.0** (13.4)
Nondiagonal mask	60.1* (17.3)	74.6** (16.8)	86.4** (15.1)	91.3** (12.1)

Note. Asterisks indicate significant difference from chance performance.
* $p < .05$. ** $p < .001$.

However, subsequent one-sample t tests revealed that, whereas identification performance for 17-ms primes did not differ significantly from chance level (50%) with diagonal masks, $t(23) < 1$, it was significantly above chance with nondiagonal masks, $t(23) = 2.87, p = .009$. All longer prime durations resulted in above-chance identification performance, all $t(23) > 4.8$, all $ps < .001$.

RT task performance (see Table 2 and Figure 2, upper panel). Mean RTs were slightly but significantly faster with nondiagonal-line masks than with diagonal-line masks, $F(1, 23) = 22.84, p < .001, MSE = 24.55, \eta_p^2 = .498$, and were faster on incompatible trials than on compatible trials, $F(1, 23) = 54.55, p < .001, MSE = 109.66, \eta_p^2 = .703$. These NCEs were smaller for nondiagonal-line masks than for diagonal-line masks, $F(1, 23) = 15.98, p = .001, MSE = 36.98, \eta_p^2 = .410$. However, subsequent t tests, comparing compatible and incompatible trials for each mask separately, confirmed highly significant NCEs for both types of masks, both $t(23) > 3.7$, both $ps < .002$.

Error rates mirrored RT results, with fewer errors in the nondiagonal-mask relative to the diagonal-mask condition, $F(1, 23) = 19.82, p < .001, MSE = 2.52, \eta_p^2 = .463$; fewer errors on incompatible trials than on compatible trials, $F(1, 23) = 72.23, p < .001, MSE = 13.35, \eta_p^2 = .758$; and a significant interaction between these factors, $F(1, 23) = 17.59, p < .001, MSE = 3.11, \eta_p^2 = .433$, reflecting larger NCE with diagonal than with nondiagonal masks. Again, though, NCEs were found to be significant with both types of masks in subsequent t tests, both $t(23) > 5.5$, both $ps < .001$.

Discussion

Experiment 1 demonstrated that NCEs can be obtained not only with diagonal masks but also with nondiagonal masks. This is at odds with the object updating account of masked priming proposed by Lleras and Enns (2004), which for arrow primes predicts that NCEs should be found exclusively when masks contain arrowlike diagonal

lines, whereas PCEs should be observed with nondiagonal masks composed of only horizontal and vertical elements. We believe that Lleras and Enns did indeed obtain this result because their primes were not effectively masked, so that the sensory evidence supporting their corresponding motor activation was not successfully removed. Experiment 1 demonstrated that, with more effectively masked arrow primes, NCEs are elicited even with nondiagonal masks. This result is problematic for Lleras and Enns's object updating account but is fully consistent with recent results from Klapp (2005), who obtained NCEs with arrow primes and targets and irrelevant (nondiagonal) letter masks.

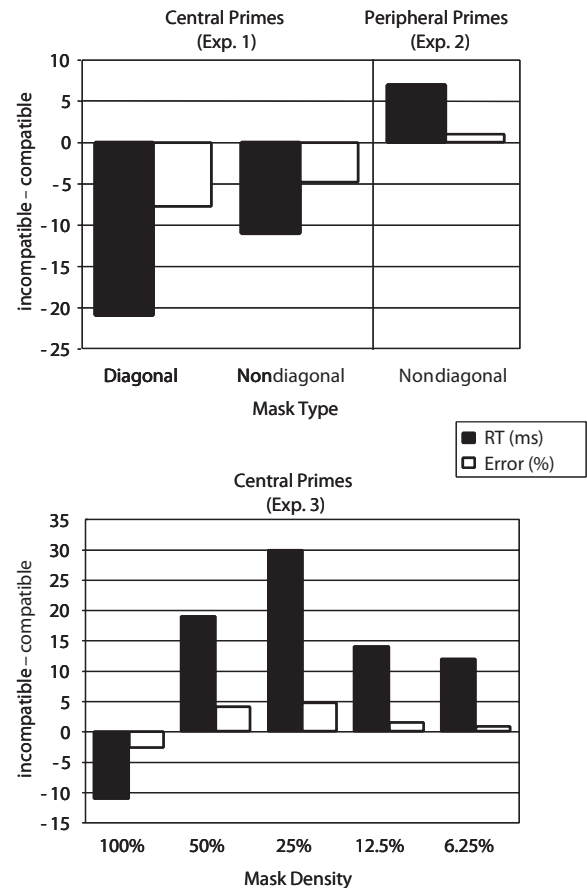


Figure 2. Summary of priming effects (incompatible-compatibly) in Experiments 1, 2 (upper panel), and 3 (lower panel). Black bars represent reaction time (RT) effects (in milliseconds); white bars represent error effects (in percentages).

Table 2
Mean Reaction Time (RT) and Error Rate for Each Priming Condition and Mask Type in Experiment 1 (Standard Deviations in Parentheses)

Mask	Measure	Priming Condition	
		Compatible	Incompatible
Diagonal mask	RT (ms)	358 (29)	337 (29)
	Error (%)	9.1 (4.3)	1.2 (1.0)
Nondiagonal mask	RT (ms)	348 (26)	338 (29)
	Error (%)	6.1 (4.6)	1.3 (0.9)

The fact that NCEs were significantly smaller with nondiagonal than with diagonal masks might indicate that different processes are associated with these two types of masks. However, the finding that nondiagonal masks also were significantly less effective in reducing prime visibility suggests a more parsimonious explanation. Unmasked (Klapp & Hinkley, 2002) and ineffectively masked primes (Eimer & Schlaghecken, 2002) are known to elicit PCEs rather than NCEs. When masks become less effective, the likelihood increases that sensory evidence for a primed response will persist on a subset of trials, so that no self-inhibition is triggered on these trials. Thus, a less effective mask should result in reduced NCEs (or even PCEs) relative to a more effective mask simply because prime-induced sensory evidence remains present on many trials. Evidence for such a relationship between mask effectiveness and direction of priming effects was found in an experiment in which mask effectiveness (as measured by prime identification performance) was manipulated by varying the line density of scrambled-pattern masks (Schlaghecken & Eimer, 2002). NCEs were restricted to effective masks, whereas PCEs were found with less effective masks.

Our hypothesis that the primes used by Lleras and Enns (2004) were ineffective and thus did not result in active self-inhibition is not at odds with the fact that Lleras and Enns obtained NCEs with “relevant” masks (arrow masks and masks with lines orientated at the same angle as the lines of the arrow primes), even though these were only slightly more effective at reducing prime visibility than the irrelevant masks. As stated above, we agree with Lleras and Enns and Verleger et al. (2004) that, under certain conditions, behavioral NCEs can be produced even when no self-inhibition processes are activated. This is the case in which arrow primes are followed by masks containing superimposed left- and right-pointing arrows (as was the case for most of Lleras and Enns’s and Verleger et al.’s experiments), so that mask presentation effectively consists in adding the opposite arrow to the initially presented prime. Here, NCEs might be explained along the lines of the object updating account proposed by Lleras and Enns, without any need to invoke self-inhibition processes. Essentially the same argument applies to the relevant mask used by Lleras and Enns in their Experiments 2 and 3: Unlike the diagonal-line masks used in the present Experiment 1 (which was composed of lines with varying length and orientation, none of which coincided with the line orientation of primes and targets), Lleras and Enns’s mask contained exclusively lines that were identical to the arrow primes in terms of both length and orientation. Hence, the overall mask configuration was one of multiple, spatially overlapping arrows pointing to the left and right (see Figure 4 in Lleras and Enns, 2004), and object updating can sufficiently explain NCEs obtained under these conditions, irrespective of mask effectiveness.

In summary, the results of Experiment 1 contradict the notion that NCEs always reflect object updating (as proposed by Lleras and Enns) but are in line with the self-inhibition hypothesis: NCEs are elicited irrespective of whether line masks do or do not share features with the prime stimuli. The possibility remains that the difference between the present findings (NCE with nondiagonal masks) and Lleras and Enns’s findings (PCE with nondiagonal masks) is mainly due to the different masking procedures. The present dynamic masking procedure, with its rapid switch between two versions of the same mask, may have introduced emergent “diagonal” features that could have triggered an activation of the opposite response. This was investigated in Experiment 2, in which “flickering” nondiagonal masks were used, but primes were presented in the periphery of the visual

field. Peripheral primes have been found to elicit PCEs rather than NCEs in our studies (e.g., Schlaghecken & Eimer, 2000) but triggered NCEs with diagonal masks in Lleras and Enns’s experiments. If the dynamic masking procedure introduces emergent diagonal features triggering an activation of the opposite response, then peripheral primes should elicit NCEs when a flicker mask is used. If dynamic masking does not induce activation of the opposite response, peripheral flicker-masked primes should elicit PCEs, similar to Lleras and Enns’s peripheral primes masked with nondiagonal masks.

Experiment 2: Nondiagonal Masks and Peripheral Primes

The aim of this experiment was to replicate Lleras and Enns’s (2004) results of PCEs with peripherally presented primes masked with nondiagonal masks while using the same “flicker” masks as in Experiment 1. The presence of PCEs would confirm that the dynamic masking procedure does not in itself trigger response activation opposite to the primed response and thus further support the interpretation of the results obtained in Experiment 1 in terms of self-inhibition processes that are triggered regardless of the presence or absence of “primelike” elements in the mask.

Method

Participants. Twelve paid volunteers (3 male), aged 20–33 years (mean age: 24.7 years), participated in the experiment. According to self-report, all but two participants were right-handed, and all had normal or corrected-to-normal vision.

Stimuli and apparatus. Primes and targets were left- and right-pointing double arrows (“<<”, “>>”), subtending a visual angle of $0.9^\circ \times 0.3^\circ$. Masks were constructed from a 6×5 matrix, randomly filled with overlapping horizontal and vertical lines of different length and with small squares and rectangles, resulting in a rectangular array of $1.7^\circ \times 1.4^\circ$. All stimuli were presented in black on a white background on a 17-inch computer screen.

Procedure. Procedure was similar to Experiment 1. The RT part began with one 16-trial practice block, followed by eight experimental blocks (80 trials each). The FC part began with one 24-trial practice block, followed by eight experimental blocks (64 trials each). In the RT part, each trial began with a fixation dot, presented at the center of the screen for 200 ms. After an interval of 320 ms, a 17-ms prime was presented either 3.5° above or below fixation. It was immediately followed by two masks, presented 3.5° above and below fixation (see Figure 3). As in the previous experiment, a flicker-masking procedure was used, in which mask presentation was broken up into two successive 50-ms presentations of two different masks. Next, the target was presented centrally for 100 ms.² ITI was 1100 ms. Trials were either compatible or incompatible. All conditions (2 prime locations \times 2 compatibility) were equiprobable and randomized within each block, resulting in 20 trials per block per condition and 160 trials per condition overall.

² This mask-target ISI of 0 ms differed from the 50-ms ISI of Experiment 1, but is in accordance with the procedure used in most previous peripheral-prime experiments (e.g., Schlaghecken & Eimer, 1997, 2000, 2002). The primary aim of Experiment 2 was to demonstrate that nondiagonal flicker masks produce effects equivalent to those previously obtained with diagonal masks or arrow masks. It was therefore deemed more important to use the standard masked peripheral-prime procedure than to keep ISIs constant across Experiments 1 and 2—in particular in light of recent findings providing compelling evidence that the PCEs triggered by peripheral primes decrease systematically with increasing ISI (Lingnau & Vorberg, 2005).

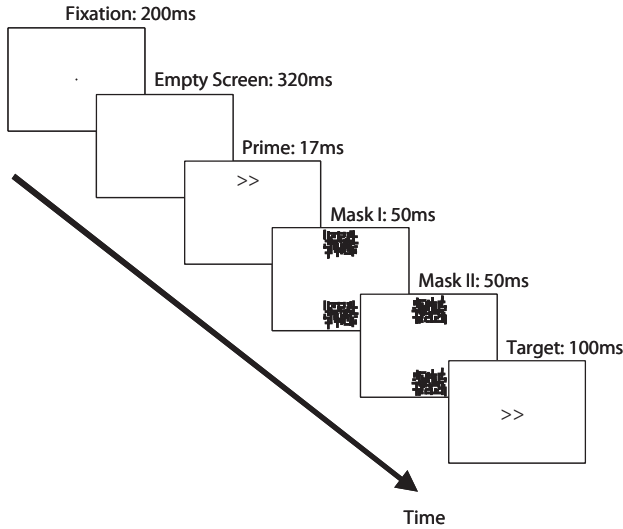


Figure 3. Trial structure in Experiment 2.

In the FC part, each trial consisted of a left- or right-pointing prime arrow, presented for 17 ms, 33 ms, 50 ms, or 67 ms in either location, immediately followed by the mask, constructed and presented in the same way as in the RT part. No subsequent targets were presented, and ITI was 1167 ms. All conditions (2 prime directions \times 2 locations \times 4 durations) were randomized and equiprobable within each block, resulting in 4 trials per block per condition and 32 trials per condition overall.

Data analysis. Data were collapsed across the two prime locations. Repeated-measures ANOVAs were computed on the percentage of correct responses in the FC identification task for the factor duration (17 ms, 33 ms, 50 ms, 67 ms). ANOVAs were computed on correct RTs and error rates for the factor compatibility (compatible, incompatible) in the RT task. Individual results are presented in Table A2 of the Appendix.

Results

Identification performance decreased with decreasing prime duration, $F(3, 33) = 22.66, \epsilon = .561, p < .001, MSE = 67.17, \eta_p^2 = .673$, and was significantly above chance level (50%) only for 67-ms and 50-ms primes, both $t_s > 3.5$, both $p_s < .005$, but not for 33-ms and 17-ms primes, both $t_s < 1.7$, both $p_s > .11$. RTs were faster and error rates lower on compatible than on incompatible trials, $F(1, 11) = 28.24, p < .001, MSE = 9.56, \eta_p^2 = .720$, and $F(1, 11) = 5.73, p = .036, MSE = 1.08, \eta_p^2 = .342$, respectively. Results are presented in Tables 3 and 4, and in the upper panel of Figure 2.

Table 3
Forced-Choice Prime Identification Performance in Experiment 2 (Percentage of Correct Responses for Each Prime Duration, Standard Deviations in Parentheses)

	Prime duration			
	17 ms	33 ms	50 ms	67 ms
Correct response (%)	49.6 (6.5)	54.3 (8.8)	62.5* (11.7)	68.6* (14.1)

Note. Asterisks indicate significant difference from chance performance. * $p < .05$.

Table 4
Mean Reaction Time (RT) and Error Rate for Each Priming Condition in Experiment 2 (Standard Deviations in Parentheses)

Measure	Priming condition	
	Compatible	Incompatible
RT (ms)	321 (31.1)	328 (31.7)
Error (%)	2.9 (2.1)	3.9 (2.8)

Discussion

Significant PCEs were obtained with peripheral 17-ms primes dynamically masked with nondiagonal-line masks. This replicates Lleras and Enns’s (2004) findings while using a flicker mask (similar to the one used in Experiment 1). In Experiment 1, we adopted the flicker-mask procedure to effectively mask centrally presented primes with nondiagonal-line masks. Such a flicker mask might conceivably have introduced emergent diagonal features, which could have been responsible for the NCEs observed in Experiment 1. The fact that PCEs were found in Experiment 2 effectively rules out this interpretation. Taken together, the results of Experiments 1 and 2 support the hypothesis that Lleras and Enns obtained PCEs with nondiagonal masks because they used insufficiently masked primes, not because they used masks without diagonal features.

Experiment 3: Random-Checkerboard Mask

The aim of Experiment 3 was to test the claim central to Verleger et al.s (2004) “active-mask” hypothesis that NCEs cannot be obtained with random-checkerboard masks. According to our self-inhibition account, the nature of the mask should not affect the direction of masked priming effects (provided that masking is effective in preventing prime visibility). Thus, checkerboard masks such as those used by Verleger et al. should produce NCEs, just like the scrambled-lines masks used in most of our previous studies and in Experiment 1. To test this, we used random-checkerboard masks of five densities, ranging from 100% (maximum masking) to approximately 6% (leaving the prime clearly visible). This procedure was similar to the procedure used by Eimer and Schlaghecken (2002), in which the density of a scrambled-line mask was varied between 0% (no mask) and 100%. If the checkerboard masks were equivalent to standard scrambled-line masks, PCEs obtained with low-density masks should turn into NCEs with high-density masks, analogous to our previous results.

Method

Participants. Thirty volunteers (5 male), aged 18–39 years (mean age: 22.4 years), participated in the experiment. According to self-report, all but three participants were right-handed, and all had normal or corrected-to-normal vision. Six participants were excluded from further analysis because their RTs or error rates were more than 2.5 standard deviations above the group mean or because their prime identification performance indicated that they could clearly see fully masked 17-ms primes (correct identification rate of 75% or more).

Stimuli and apparatus. Primes and targets were identical to Experiment 1. Masking stimuli were constructed on the basis of a 12 \times 12 matrix, randomly filled with black, gray, and white squares (0.1° \times 0.1°), resulting

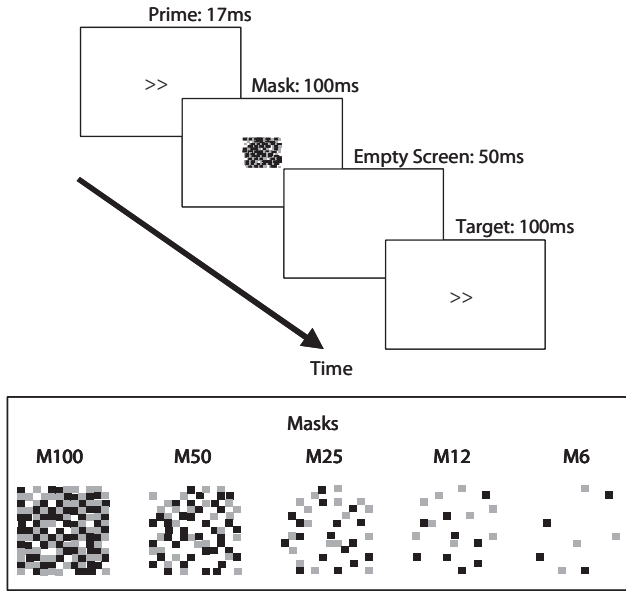


Figure 4. Trial structure and structure of masking stimuli in Experiment 3.

in a rectangular array of $1.1^\circ \times 0.9^\circ$. Gray squares were created by filling the square with alternating black and white pixels. In the maximum density condition, approximately 90% of the cells contained black or gray squares (in roughly equal proportion), and the remaining cells held white squares. Filling of the cells of the matrix was either complete (M100 condition) or partial, with 50% of the cells filled (M50), 25% of the cells filled (M25), 12.5% of the cells filled (M12), or 6.25% of the cells filled (M6). In the partial conditions, the to-be-filled cells were chosen in a pseudorandom fashion, ensuring more or less equal distribution of squares over the matrix. A new random mask was created on each trial.

Procedure. Procedure was similar to Experiment 1. The RT part began with 1 practice block (20 trials), followed by 12 experimental blocks (80 trials each). After the 6th experimental block, participants were asked to take a break. The FC part began with two 20-trial practice blocks, followed by 2 experimental blocks of 80 trials each. Trial structure was similar to Experiment 1, with the following exceptions: Five different masks (M6, M12, M25, M50, M100) were used, and masks were presented for one continuous 100-ms interval (see Figure 4). All conditions (5 masks \times 2 compatibility) were equiprobable and randomized within each block, resulting in 8 trials per block per condition and 96 trials per condition overall.

The FC part was similar to Experiment 1, except that primes were presented only for either 17 ms or 33 ms (to keep the number of trials

within manageable limits despite the larger number of masks) and were followed by one of the five different masks (100-ms duration).

Data analysis. This was similar to Experiment 1, except that the factor mask had five levels (M100, M50, M25, M12, M6), and the factor duration in the FC part had only two levels (17 ms, 33 ms). Individual results are presented in Table A3 of the Appendix.

Results

FC identification performance (see Table 5). Prime identification performance deteriorated with increased mask density, $F(4, 92) = 70.66, \epsilon = .796, p < .001, MSE = 173.24, \eta_p^2 = .754$, but was not significantly influenced by prime duration (main effect and interaction: both $F_s < 1.1$, both $p_s > .35$). Subsequent one-sample t tests confirmed that prime identification did not differ significantly from chance level (50%) with full masks (M100) for either 17-ms or 33-ms primes, both $t_s < 2$, both $p_s > .05$. With all other mask densities, identification was significantly above chance level, all $t_s > 8$, all $p_s < .001$.

RT task performance (see Table 6 and Figure 2, lower panel). Mean RTs showed a U-shaped distribution, with shortest RTs in the M25 condition and RT increase both with more and with less dense masks, $F(4, 92) = 20.09, \epsilon = .712, p < .001, MSE = 76.32, \eta_p^2 = .466$. RTs were generally faster on compatible than on incompatible trials, $F(1, 23) = 12.25, p = .002, MSE = 748.00, \eta_p^2 = .348$. Crucially, a significant Mask \times Compatibility interaction indicated that these PCEs changed with changing mask density, $F(4, 92) = 21.23, p < .001, MSE = 200.61, \eta_p^2 = .480, \epsilon = .637$. Subsequent paired t tests confirmed significant PCEs under M6, M12, M25, and M50 conditions, all $t_s > 2.5$, all $p_s < .02$, and a significant NCE with M100 masks, $t(23) = 4.86, p < .001$.

Error rates were slightly higher with intermediate mask densities than under M100 and M6 conditions, $F(4, 92) = 33.75, \epsilon = .956, p = .001, MSE = 6.71, \eta_p^2 = .186$, and were lower on compatible than on incompatible trials, $F(1, 23) = 7.36, p = .012, MSE = 24.39, \eta_p^2 = .242$. A significant interaction between these factors, $F(4, 92) = 12.14, \epsilon = .885, p < .001, MSE = 9.54, \eta_p^2 = .345$, was due to the fact that error rate effects showed the same pattern as RT effects, with NCE for completely masked primes (M100), $t(23) = 5.49, p < .001$, and PCEs for incompletely masked primes. PCEs were significant only for M50 and M25 masks, both $t_s > 3.5$, both $p_s < .002$, but failed to reach significance for M12 and M6 masks, both $t_s < 1.4$, both $p_s > .18$.

Table 5
Forced-Choice Prime Identification Performance in Experiment 3 (Percentage of Correct Responses for Each Mask Density and Prime Duration, Standard Deviations in Parentheses)

Prime Duration	Mask density				
	100%	50%	25%	12.5%	6.25%
17 ms	56.0 (14.8)	83.1** (13.2)	88.6** (11.9)	85.4** (15.4)	90.9** (11.0)
33 ms	57.6 (21.1)	79.2** (16.8)	90.1** (13.3)	89.6** (16.2)	92.5** (11.5)

Note. Asterisks indicate significant difference from chance performance (50% correct).
** $p < .001$.

Table 6
Mean Reaction Time (RT) and Error Rate for Each Priming Condition in Experiment 3 (Standard Deviations in Parentheses)

Measure	Trial Type	Mask density				
		100%	50%	25%	12.5%	6.25%
RT (ms)	Compatible	361 (25)	338 (26)	330 (25)	339 (24)	347 (29)
	Incompatible	350 (27)	356 (28)	360 (32)	353 (28)	359 (29)
Error (%)	Compatible	4.1 (3.1)	2.6 (2.8)	2.1 (2.1)	4.2 (2.9)	3.9 (3.1)
	Incompatible	1.5 (1.7)	6.7 (4.6)	6.8 (4.3)	5.7 (4.2)	4.8 (3.7)

* $p < .05$. ** $p < .001$.

Discussion

In Experiment 3, PCEs were found for low-density checkerboard masks, whereas NCEs were obtained with the highest density mask (M100), analogous to our earlier findings with scrambled-line masks (Eimer & Schlaghecken, 2002). This observation contradicts the “active-mask” hypothesis put forward by Verleger et al. (2004), which claims that NCEs are triggered by arrow primes only when arrowlike masks are used but not with checkerboard masks. Although the size of the NCE was relatively small, it was similar to those observed with scrambled-line masks. As expected, PCEs were obtained with coarser masks, which did not mask the primes effectively, confirming that masked priming effects obtained with random-checkerboard masks exhibit similar regularities as those obtained with random-line masks (Eimer & Schlaghecken, 2002).

This raises the obvious question of why Verleger et al. (2004) failed to find NCEs with checkerboard masks. Procedural differences between the present Experiment 3 and the experiments reported by Verleger et al. may be responsible for this discrepancy. First, only random-checkerboard masks were used in Experiment 3, whereas trials with checkerboard masks and trials with arrow masks were randomly intermixed in most of the experiments reported by Verleger et al. Second, Verleger et al. used red rings as fixation aids, which may have impaired prime perception via forward masking. This could have reduced the perceptual strength of the primes, resulting in response activations below the threshold of self-inhibition (Schlaghecken & Eimer, 2002). Finally, the present Experiment 3 contained an empty interval of 50 ms between mask offset and target onset (to improve target identification). In contrast, masks and targets followed each other immediately in the Verleger et al. study, which may have made target identification more difficult, thus preventing the fast and efficient perceptuo-motor processing necessary to obtain NCEs. For example, Klapp and Hinkley (2002) and Klapp and Haas (2005) used a modified masked prime paradigm in which targets were presented for only 16 ms and thus were difficult to identify. In these studies, participants had to complete an entire training session before they showed reliable NCEs. No such training was included in the experiments reported by Verleger et al. Further studies will be needed to establish whether these or other factors are responsible for the discrepancies between Verleger et al.’s findings and the present results.

Conclusion

Under certain conditions, primes presented close to threshold trigger negative compatibility effect (NCEs; i.e., performance benefits for trials where masked primes and targets are mapped to opposite responses, and costs when they are mapped to the same response). The processes responsible for this surprising effect are currently under debate. We have proposed that NCEs reflect self-inhibition and disinhibition mechanisms operating at low levels of motor control (Bowman et al., 2006; Schlaghecken & Eimer, 2002; in press). In contrast, Lleras and Enns (2004) and Verleger et al. (2004) have argued that these effects are exclusively due to mask-induced activation processes of the motor response opposite to the one associated with the prime. To support their view, these authors presented evidence demonstrating that NCEs are triggered only when primes and masks share perceptual features, while positive compatibility effects (PCEs) are elicited when there is no feature overlap between primes and masks.

Here, we demonstrate that NCEs can be obtained under conditions in which the mask-induced priming account proposed by Lleras and Enns (2004) and Verleger et al. (2004) would have predicted PCEs, suggesting that mask-induced activation cannot be the only process contributing to the NCE. Another set of results that seems problematic for a purely activation-based explanation of masked priming effects comes from a recent study investigating motor control processes in old age. Schlaghecken and Maylor (2005) found that aging reduces NCEs at longer prime/mask-target intervals (150 ms, 300 ms, and 450 ms), but leaves PCEs at short intervals (0 ms) unaffected. Although this result can be easily explained in terms of reduced inhibition in old age (e.g., Hasher & Zacks, 1988), it is difficult to reconcile with the notion that PCEs and NCEs reflect essentially the same response activation mechanism, triggered by either prime or mask.

More recently, Lleras and Enns (2005) have argued that NCEs obtained with irrelevant masks might reflect attentional or perceptual phenomena triggered when prime and target occur at the same location (e.g., negative priming or repetition blindness) rather than low-level motor inhibition. However, NCEs have also been demonstrated for primes and targets presented at different locations (Eimer, 1999; Praamstra & Seiss, 2005; Schlaghecken & Eimer, 2000; Seiss & Praamstra, 2004). Because such effects cannot be explained solely by perceptual interactions or object updating accounts alone, they should be regarded as evidence for self-inhibition mechanisms in low-level motor control.

It thus seems reasonable to conclude that the mask-induced priming account is insufficient to explain all instances in which NCEs can be observed. However, we acknowledge that sensory-perceptual interactions between primes and masks or object-updating processes may well contribute to inverse priming effects when primes and masks contain identical (or at least highly similar) perceptual features. Such perceptual interactions may substantially increase the size of NCEs or even give rise to NCEs in the absence of self-inhibition processes (Klapp, 2005; Lleras & Enns, 2005). Thus, the cautionary tale of mask-dependent priming told by Lleras and Enns (2004) and Verleger et al. (2004) is necessary and important. In fact, it is precisely because of these possibilities that we have abandoned the arrow-mask procedure in favor of masks that are composed of randomly distributed lines that differ from primes in their length and orientation. Although one could argue that such diagonal-lines masks have still some similarity to prime and target arrows, the present results provide unequivocal evidence that NCEs can be observed even when the perceptual elements used to construct masking stimuli are—according to Lleras and Enns (2004) and Verleger et al.—completely dissimilar from any features of the primes (see also Klapp, 2005).

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Appendix

Priming Effects (Incompatible–Compatible) on Reaction Times (RTs; in Milliseconds) and Error Rates (in Percentages) From All Three Experiments, Separately for Each Participant.

Table A1
Experiment 1

Participant	Diagonal mask		Nondiagonal mask	
	RT effect	Error effect	RT effect	Error effect
1	-14	-5.9	-20	-4.4
2	-14	-9.7	-23	-3.9
3	-3	-8.8	0	-5.8
4	-27	-3.9	3	-2.7
5	-29	-15.4	-15	-12.4
6	-17	-7.0	-6	-0.5
7	-11	-4.2	2	-1.9
8	-8	-5.4	18	-0.8
9	-16	-6.5	3	-1.0
10	-14	-8.5	-25	-10.2
11	-34	-14.7	-34	-2.1
12	-20	-3.9	-21	-0.5
13	-22	-3.6	-5	-4.0
14	-12	-5.5	-11	-4.9
15	-12	-9.1	-8	-3.9
16	-22	-8.4	-4	-7.3
17	-29	-2.6	-23	-2.5
18	-28	-9.6	-30	-12.2
19	-40	-5.5	-28	-2.7
20	-12	-12.3	-3	-3.4
21	-25	-5.9	5	-4.2
22	-23	-10.7	10	-3.8
23	-33	-4.8	-25	-3.3
24	-36	-16.4	-23	-17.5

Table A2
Experiment 2

Participant	RT effect	Error effect
1	2	0.7
2	2	1.3
3	9	2.8
4	14	0.3
5	5	1.3
6	12	-1.0
7	8	2.2
8	1	3.9
9	12	0.3
10	3	-0.6
11	9	-0.6
12	6	1.6

(Appendix continues)

Table A3

Experiment 3

Participant	RT effects					Error effects				
	M100	M50	M25	M12	M6	M100	M50	M25	M12	M6
1	-6	16	47	62	69	0.0	3.1	6.3	3.2	4.2
2	-1	26	32	10	28	-2.1	8.4	5.2	-5.3	-1.1
3	-5	2	-2	-3	-9	0.0	1.0	-3.1	-3.1	-8.3
4	-38	-4	7	14	1	-3.1	0.0	0.0	4.2	7.3
5	-13	-15	3	-13	-12	-2.1	-3.2	-2.1	-6.2	-3.1
6	-9	26	35	10	20	-2.1	2.1	2.1	5.2	3.1
7	-11	4	20	39	54	-3.2	2.1	9.4	9.4	15.7
8	-7	13	45	41	24	-9.4	4.2	5.3	-1.0	5.2
9	-4	-8	6	-27	-15	-4.2	0.0	1.1	-6.3	2.1
10	-19	11	9	7	-16	0.0	3.2	5.2	-3.2	1.0
11	-20	54	50	9	-5	-1.0	11.5	2.1	-1.1	0.0
12	0	54	73	11	22	-3.2	8.3	9.4	5.2	0.0
13	-11	51	60	35	12	-2.1	9.4	4.2	14.6	3.1
14	-27	-5	-1	-8	1	-2.1	-1.0	2.1	-3.1	-7.3
15	-16	24	27	0	7	-2.0	6.3	3.1	10.4	-3.1
16	-2	-6	-2	-4	2	-4.1	-3.1	-4.2	-3.1	-3.2
17	16	56	24	0	4	-1.0	15.6	5.2	2.1	-1.0
18	-22	38	63	38	21	-9.4	9.4	15.6	5.2	10.5
19	4	41	65	49	28	-2.1	9.4	11.4	7.3	1.0
20	-14	3	-7	-20	-9	-2.1	-2.1	2.1	-3.1	-2.1
21	-28	-16	11	-9	-7	-3.2	-1.1	5.2	2.1	-2.1
22	-10	45	51	34	25	-2.1	12.5	9.3	6.2	2.1
23	-19	25	87	59	33	-1.0	2.1	10.4	2.1	1.0
24	-13	17	4	-8	-6	-2.1	0.0	7.3	-4.2	-2.0

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