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Perceptual and motor contributions to the negative compatibility effect

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ABSTRACT

The current study focused on contributions to the negative compatibility effect (NCE) from object-updating at the perceptual level and self-inhibition (i.e., automatic motor inhibition) at the response (motor) level. We hypothesized that contributions to the NCE from these two levels were moderated by the strength of stimulus and reaction (S–R) link: object-updating should have greater impact on the NCE with weak S–R links, but both object-updating and self-inhibition should impact on the NCE when the S–R links became strong. To test this hypothesis, in two experiments we used a novel type of stimuli and manipulated mask relevance (relevant versus irrelevant mask) and prime/target compatibility. Participants performed two tasks over three successive days. Results showed that under equivalent masking effectiveness between the two conditions of mask, a significant NCE was observed only in the relevant mask condition when the S–R links were weak, but both close to equal NCE sizes were observed in the two mask conditions when the S–R links were acquired through practice. The results indicated that perceptual and motor contributions to the NCE were moderated by the strength of S–R links, if the strength of the links was too weak to trigger the following inhibition, the NCE primarily originated from object-updating at the perceptual level; if the strength of the links was reinforced by practice, which exceeded the inhibitory threshold, the NCE originated from both object-updating and self-inhibition, but the latter was primarily responsible.

1. Introduction

The negative compatibility effect (NCE), first reported by Eimer and Schlaghecken (1998), is an unexpected phenomenon, in which a masked stimulus influences behavior in a way contrary to what one might expect. Eimer and Schlaghecken presented a left or right pointing arrow prime (presented 16 ms), followed by a pattern mask that was eventually replaced by another arrow target (both mask and target were presented 100 ms). The task requires a participant to determine the orientation of the target. The typical NCE finding is that viewers' responses to targets show quantifiable *gains* (e.g., fast RTs) when the targets are preceded by incompatible primes (i.e., cueing the opposite responses to the targets), but their responses are *delayed* if the targets are preceded by compatible primes (i.e., cueing the same responses to the targets).

To account for their results, Eimer and Schlaghecken proposed that the initial motor activation elicited by a subliminal prime is automatically followed by inhibition (Eimer, 1999; Eimer & Schlaghecken, 1998, 2002; Klapp, 2005; Klapp & Hinkley, 2002; Schlaghecken & Eimer, 2002, 2004, 2006). In this view, inhibition occurs only if a mask terminates perceptual evidence of the prime (Eimer & Schlaghecken, 2002) and if the prime's activation strength is sufficiently great that it triggers an inhibitory mechanism (Schlaghecken & Eimer, 2002). According to this self-inhibition account, the prime automatically causes an activation of the motor mechanisms associated with it, but the appearance of the mask removes the prime-induced perceptual evidence which, in turn, leads to automatic inhibition of the initial motor activation (Bowman, Schlaghecken, & Eimer, 2006). Then, if a compatible target emerges, the required response is still inhibited, resulting in performance costs and the negative compatibility effect (NCE).

A different view of the NCE mechanisms was suggested by Lleras and Enns (2004) (also see Verleger, Jaśkowski, Aydemir, van der Lubbe, & Groen, 2004). They hypothesized that the NCE results from object-updating triggered by a perceptual interaction between prime and relevant mask. The relevant mask is defined as a stimulus that shares features with the prime (e.g., two overlaid opposite pointing double arrows). According to this object-updating account, the rapid serial visual presentation of prime and mask is interpreted by the visual system as a changing object. An initial representation of the object is established when the prime emerges, but once the mask appears, the object is updated with the new attributes of the representation (Lleras & Moore, 2003). If the mask is composed of two overlaid double arrows, the updated elements (prime incongruent elements) call for the alternative response to that induced by the prime. This leads to the NCE.

The present study attempts to investigate contributions to the NCE from object-updating and from self-inhibition, with these contributions

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measured by the effect size calculated as mean reaction time (RT) in compatible minus incompatible trials. Klapp (2005) differentiated NCE processing based upon 1) perceptual updating, which only occurred with relevant masks at the perceptual level (i.e., NCE occurred at the perceptual level, NCE-P), and 2) response inhibition, which occurs with irrelevant (sharing no feature with the prime) as well as relevant masks at the response level (i.e., NCE occurred at the response level, NCE-NP). Klapp also suggested that both types of NCE might co-exist.

Subsequent researches on this topic have been reported by Schlaghecken and Eimer (2006) as well as Sumner (2008). Originally, Schlaghecken and Eimer (2006) used double arrows as primes and targets; they manipulated the mask relevance, with random diagonal lines defining the relevant mask versus random vertical and horizontal lines defining the irrelevant mask. They also orthogonally varied the compatibility of prime and target, with compatible trials defined by same responses between these two stimuli and incompatible trials defined by opposite responses between prime and target. The goal was to assess whether the NCE would occur even in the unequivocally irrelevant mask condition. The results showed that both the relevant (containing both NCE-P and NCE-NP processes) and irrelevant (containing only NCE-NP process) mask conditions yielded significant NCEs. Furthermore, a comparison of the NCE's size as a function of masking type (relevant versus irrelevant) indicated that the effect size was greater (21 ms) with the relevant mask than that with the irrelevant one (10 ms). These results implied that the NCE might devolve into two sub-forms: the NCE-P (the effect size in the relevant mask condition minus that in the irrelevant mask condition: 21 ms − 10 ms = 11 ms) and the NCE-NP (the effect size in the irrelevant mask condition: 10 ms). However, the irrelevant mask was also significantly less effective in reducing prime visibility according to the forced choice[1] results, which would result in reduced NCE sizes compared to a more effective mask (i.e., relevant mask) (Eimer & Schlaghecken, 2002; Klapp & Hinkley, 2002). Consequently, it may be invalid to compare the NCE's size if the masks under comparison differ in their masking effectiveness, and one might argue that the smaller size of the NCE-NP in the irrelevant mask condition might be due to the increased prime visibility.

Sumner (2008) further investigated contributions to the NCE from object-updating and from self-inhibition with equivalent prime visibility, i.e., masking effectiveness. He used two vertical and two horizontal lines as primes and targets, and manipulated factors similar to those in Schlaghecken and Eimer (2006). The results showed close to equal NCE sizes with both types of mask (relevant versus irrelevant). This pattern of results was interpreted to mean that self-inhibition (NCE-NP) dominated the NCE processing. However, it is still arguable that the relevant masks used in this study were not as relevant as in the previous studies, which were not sufficiently relevant to support strong object-updating in Sumner (2008).

1.1. Potentially influential factors in the previous studies

Two potentially influential factors mentioned above, that have not been explored in prior research, motivated the present design. Respectively, these involve 1) the differences in the effectiveness of relevant and irrelevant masks in reducing visibility of the primes (Schlaghecken & Eimer, 2006) and 2) the reduced effectiveness of updating with a less relevant mask (Sumner, 2008). These will be discussed in turn.

1.1.1. Effectiveness of relevant and irrelevant masks

A typical NCE paradigm uses arrow stimuli as both primes and targets. Thus the NCE-NP was usually investigated using irrelevant masks that consisted of vertical and horizontal lines in order to avoid triggering a feature updating process. However, it is difficult for such irrelevant masks to cover the after-image of the primes; in this case, these masks would not immediately cease activation of the primes. If the mask fails to occlude the after-image of the prime, this could violate a theoretical precondition of the NCE-NP, namely that perceptual evidence of the prime must be immediately ceased by the mask.

1.1.2. Reduced effectiveness of updating with a less relevant mask

A second concern is that less relevant masks might lead to attenuated strength of object-updating. The most effective relevant mask should be one that would produce complementary stimuli of the primes through updating.

Therefore, contributions to the NCE from the NCE-P and NCE-NP need to be investigated in a context in which the masks not only cover the after-image of the primes, but also avoid feature updating with masks in the irrelevant mask condition. Meanwhile, a highly relevant mask should be used in the relevant mask condition to avoid a less effective updating with a less relevant mask.

1.2. The present study

The current study used numerical stimuli comprising short lines of equal length (shown in Fig. 1). Use of these stimuli has three main advantages. First, the mask covers the after-image of all the primes. Thus, in theory it should cease the activation of primes immediately in both masking conditions. Second, object-updating with the mask produces complementary stimuli of the primes in the relevant mask condition, which matches the theoretical precondition of the NCE-P. This is because the complementary stimuli of the primes can improve performance to the targets' responses in incompatible trials. However, in the irrelevant mask condition, updating with the mask only produces ruleless lines. In theory it mismatches the precondition of the NCE-P, because these updated features (i.e., ruleless lines) could not improve performance to the target responses both in compatible and incompatible trials. Third, comparisons of the NCE's sizes between relevant (containing both NCE-P and NCE-NP processes) and irrelevant masks (containing only NCE-NP process) can shed light upon the respective contribution from the NCE-P and NCE-NP to the NCE. Furthermore, these comparisons will have greater validity if both the mask conditions have the same physical characteristics.

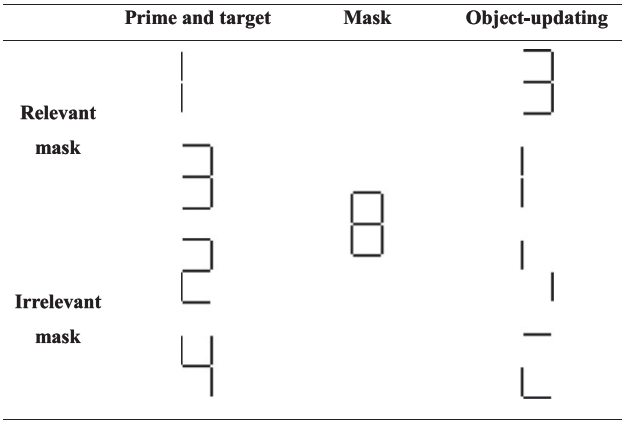

Fig. 1. The stimuli used in the current study. Note that mask relevance is varied by changing the prime and target stimuli, the relevant mask condition is defined as "1" and "3" as primes and targets, and the irrelevant mask condition is defined as "2" and "4" as primes and targets.

[1] The visibility of a prime can be influenced by a mask. Prime visibility is low when a mask is effective. Since theoretically this is a factor in self-inhibition hypothesis, it is important to assess prime visibility. In this research this was accomplished using a forced choice task which was conducted using primes and masks as traditional NCE procedure, except no target was presented. Participants were asked to respond to the directions of the primes after the masks' presentation. If the accuracy of the forced choice task does not significantly differ from chance level (50%), this indicates that the masks effectively cease the initial activation of the primes.