Invulnerable negative compatibility effect
for direction of colored double-headed arrows

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Researchers have shown the negative compatibility effect (NCE) consistently using arrows. However, they provided inconsistent interpretations about the reason why the NCE happens. The purpose of the present study is to test the factors suggested to be critical for the NCE including automatic inhibition, updated information and top-down control. Presented with arrays of masked prime and targets composed of colored double-headed arrows, participants demonstrated invulnerable NCE on the basis of direction of arrows in the judgment of direction with corresponding hands (Experiment 1), with reverse-mapping hands (Experiment 2) and even in the color-judgment task (Experiment 3). These results imply that the main sources of NCE might be perceptual dominance and inherent properties of stimuli and responses; this contrasts with previously proposed explanations.

Keywords : negative compatibility effect (NCE), double-headed arrows, direction

Compared to the response after the initial presentation of a stimulus, the response to stimuli presented repeatedly may be faster and more accurate. This so-called priming effect has been confirmed in various paradigms using different stimuli [1, 2]. This positive compatibility effect or positive priming has been observed when the initial stimulus is similar to the second stimulus or is associated with the same response or has some cognitive association with the second one, relative to the neutral case in which the first one has no association with the second one or any response [3]. However, under certain circumstances, the effects can be reversed so that prior exposure to a stimulus may result in a detrimental effect on the subsequent response. This negative compatibility effect (NCE) has been observed in many studies since the original work of Eimer and Schlaghecken [4].

In their first observation of NCE, Eimer and Schlaghecken [4] used double-headed arrows as targets and composits of two target arrows as their masks. The response to the target arrows became faster and more accurate when the prime and target arrows pointed in different directions as compared to when the prime and target arrows pointed in the same direction, when the prime remained below the threshold of conscious perception. In later studies, factors such as prime visibility, temporal interval between prime and mask [5, 6], and similarity between a prime and a mask [7, 8] were found to be important for triggering the NCE. Though some ad hoc interpretations have been suggested to explain these results, the exact requirement for NCE and its underlying mechanism remain unknown.

Several hypotheses have been proposed to account for NCE. The self-inhibition (SI) hypothesis [4, 6, 9, 10] assumes that if the sensory input does not continue, the initial motor activation induced by a prime is automatically followed by the inhibition phase. According to this hypothesis, the NCE reflects an automatic process and the role of a mask is only to block the sensory input [11]. This hypothesis can easily account for the straight priming effect that occurs with a short interval between prime and target.

However, in addition to the contradictory nature of the basic assumption of strong sensory input and its simultaneous effective removal at the same time, this hypothesis cannot fully explain NCE with suprathreshold primes [12], where the participants consciously catched the primes.

Llers and Enns [7] suggested the object-updating (OU) hypothesis, which emphasizes that the mask consists of target-like figures or at least contains features of the target in all studies showing the NCE. It was suggested that the mask that was added to the prime acted as another prime and thus triggered the NCE. According to this hypothesis, in a succession of stimuli the short interval between prime and mask and the updating process could lead to a perceptual state in which the new features of the mask govern the priming effect. As a result, the observed RT difference that seemed to be the result of negative compatibility effect based on the prime is actually the result of positive compatibility effect based on the new features of the mask.

Jaśkowski and colleagues proposed the mask-triggered inhibition (MTI) hypothesis [13-16]. The role of the mask in the NCE was identified by manipulating the type and density of the mask. The observed priming effect was changed from positive to negative, as the mask had more relevant features for the task. From this view, the inhibition of ongoing activation would be prompted by the task-relevant dimension in the mask thereby would facilitate the alternative response based on the task. Moreover, when the elements of the mask are similar to the target, the inhibition of ongoing action is supposed to be strong [17]. He suggested it is caused because such elements call for the system that the ongoing activation should be modified.

There are several major differences between these three hypotheses. The SI and MTI hypotheses assume that inhibition is involved in the NCE; the OU hypothesis does not. Concerning the role of the mask, however, the SI and MTI hypotheses are different. The SI hypothesis assumes that the mask simply blocks the prime, whereas in MTI hypothesis, the task-relevant component in mask was regarded to trigger the NCE. On

the other hand, the OU and the MTI hypotheses equally assume that the mask would interact with the target for the NCE to occur the SI hypothesis does not. However, as for which element in mask would affect the prime and target processing, they make different explanations.

To test these hypotheses and identify the factors that determine the direction of the priming effect, we used a typical prime-mask-target paradigm. In this paradigm, unlike previous experiments, the prime and target had two features (direction and color) manipulated independently and the mask was fixed as the composite of prime and opposite orienting double-headed arrows with different color. As a result, mask and target could share both, either of or none of two features, while the relation between prime and mask held constant. In addition, the focus of task in this research was the direction or the color, independent of the shared features between mask and target. The RTs and error patterns for the various types of target along with the task difference predicted by each of these hypotheses are different.

According to the SI hypothesis, the exact same degree of NCE based on the task-relevant feature would occur as long as the temporal arrangement of prime, target and the mask hold constant, even if the targets may include different feature. For example, in case that the color was the task-relevant, the NCE based on color would be observed, irrespective of other feature (such as direction) in the target. This would be the case since in the SI hypothesis, the NCE is assumed to be the result of automatic inhibition following the motor activation in response.

In contrast, the OU hypothesis assumes that the response to the target sharing all of the added features in mask should be faster than the response to the target with only a part of the new features or none of them. For, in the OU hypothesis, the occurrence of the NCE is attributed to the positive compatibility effect on the basis of the new elements in mask. On the basis of the OU hypothesis, the response to the target with the same direction and color as the mask should be faster and more

accurate than the target sharing only the same direction or only the same color or none of the features.

On the other hand, according to the MTI hypothesis, the NCE is supposed due to the inhibition of ongoing activation by the task-relevant feature in mask. Even if the prime-mask-target displays were identical, the inhibited feature by the mask would differ according to the instructed task. In addition, the response patterns would be varied following the similarity between mask and target.

In sum, we tried to test the proposed hypotheses for the NCE with traditional direction judgment tasks and additional color judgment task. But unlike the previous experiments, we used colored double-headed arrows as stimuli. Adding color dimension to the arrows, we could examine other possibilities for the NCE.

Experiment 1: Direction judgment with corresponding hands

It is generally accepted that the NCE based on direction occurs in prime-mask-target displays of double-headed arrows, provided that the prime is briefly flashed and the interval between prime and target is long enough. In Experiment 1, the prime, mask and target were colored as follows. The color of the double-headed arrows in the prime and target were either red or green. The mask was always made up of the prime (red or green double-headed arrows) and the oppositely oriented double-headed arrows in the other color. Thus, the prime-mask compatibility was fixed and the prime-target and mask-target compatibilities were manipulated.

Methods

Participants

After giving informed consent, fifteen undergraduates at Yonsei University participated in the study to fulfill course requirements. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiment.

Apparatus and stimuli

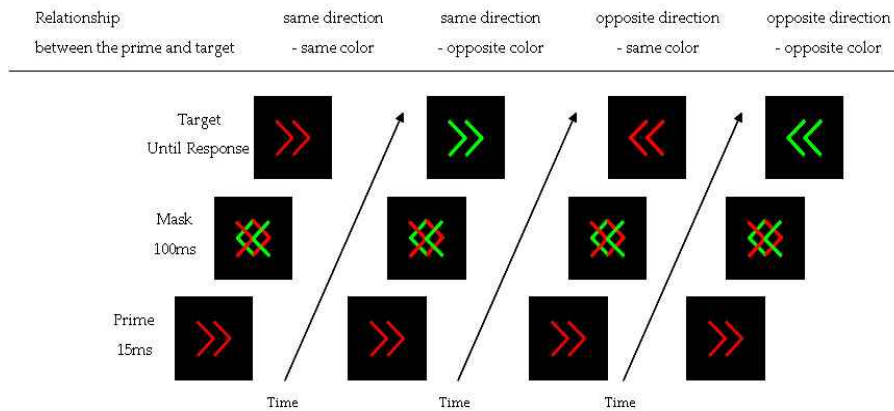All stimuli were presented centrally on a 17-in CRT monitor at a viewing distance

Figure 1. Examples of display sequence in Experiments 1-3. The prime and target were one of the following: red left-pointing, red right-pointing, green left-pointing and green right-pointing double-headed arrows. Thus the prime and target were independently congruent or incongruent in direction and color. Each display shows the example of the relationship between the prime and target in direction and color (same direction_same color, same direction_opposite color, opposite direction_same color and opposite direction _opposite color) respectively. The mask always consisted of the prime and arrows of opposite direction with the other color

of 100 cm (screen resolution 1024 × 768 pixels, 256 levels of gray). The double-headed arrows for the prime and target were presented in a 1.3° × 1.2° region of visual angle, and the masks were of the same visual angle. Prime and target were one of the four types (red right-pointing, red left‐pointing, green right‐pointing or green left‐pointing) and the mask was the composite of the prime and opposite-orienting arrows with the other color. The layout and sequence of each trial are shown in Figure 1.

Procedure

Participants were instructed to fixate on the cross that was presented in the center of the monitor at the beginning of each trial for 500 ms after the 500 ms blank period. The prime was displayed for 15 ms and backward masked for 100 ms. Then, the target was presented in the same position and withdrawn after the response. There was no blank interval between prime and mask or between mask and target. Participants were required to respond to the direction of the target as quickly and accurately as possible by pressing the shift keys on the keyboard with their index fingers. The left shift key was allocated to the left-pointing arrows and depressed by left index finger whereas the right shift was allocated to the right pointing arrows and depressed by right index finger.

The experiment consisted of 7 blocks of 72 trials for direction judgments and 2 blocks of 72 trials for the prime identification task. Between blocks, participants could rest and start again by pressing the space bar. In all of the nine blocks, the response keys were maintained. There were six conditions for the target judgment task. In two, the masks were red or green overlaid double-headed arrows. Although they were included to balance the experimental conditions, responses were not analyzed. The other 4 conditions were 2 (direction) × 2 (color) combinations of the relation between prime

and target: same direction, same color (sd_sc)same direction, opposite color (sd_oc) opposite direction, same color (od_sc) and opposite direction, opposite color (od_oc). In the last 2 blocks of 72 trials, participants were instructed to discriminate the direction of the prime with the same hand as in preceding sessions; if they did not catch it, participants were encouraged to guess.

Results and Discussion

Target –direction discrimination

Mean correct response times (RTs) and accuracies are shown in Figure 2 for direction (same, opposite) × color (same, opposite) trials. Analysis of variance (ANOVA) for the correct RTs revealed that RTs to targets oriented in the same direction as the prime were significantly longer than oppositely oriented targets [negative compatibility effect (NCE), $F(1, 14) = 44.54, p < .001$]. But neither the main effect of color nor the interaction effect of direction and color did reach statistical significance.

Additional analyses confirmed that the NCE observed in RTs was not due to the speed-accuracy trade off. Participants responded more accurately to the targets of oppositely oriented than to the same-orienting target [$F(1, 14) = 21.37, p < .001$], even though responses in the opposite condition were faster. When the color of the target was the same as that of the prime, the responses for the direction became less accurate, but the size of this effect was only marginal [$F(1, 14) = 4.53, p = .052$].

Prime identification

The mean accuracy of prime identification for 144 trials was 53.33%. Participants

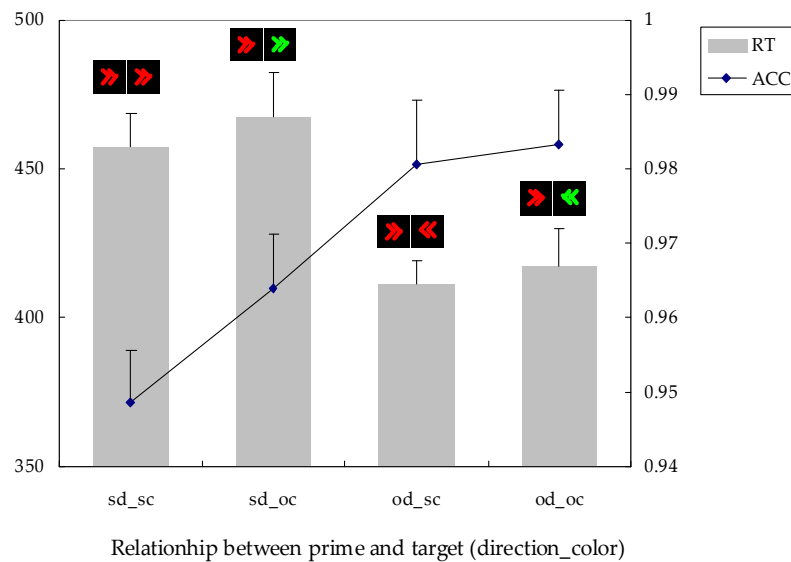Relationhip between prime and target (direction_color)

Figure 2. Mean correct response times (bars) and accuracies (lines) in Experiment 1. Abbreviations on the X-axis stand for the relationship between the prime and target in direction and color. sd_sc: prime and target were same direction and same color, sd_oc: same direction and opposite (red/green) color, od_sc: opposite (left-orienting/right-orienting) direction and same color and od_oc: opposite direction and opposite color. Considering that the intervening mask was constant with superimposing prime and oppositely oriented arrows with the other color, the compatibility between mask and target was quite different. While the targets of so_sc and oo_oc conditions shared the same features of the mask, those of so_oc and oo_sc held only a part of the features in the mask. When the prime and target double-headed arrows were of the same direction, the judgment of the direction to the target was significantly slower (negative compatibility effect). Error bars represent one standard error of the mean (SE).

reported that they were unaware of the direction of primes or did not notice the primes at all, but their performances were marginally better than could be attributed to chance [$t(14)$ = 3.03, p = .01]. As Klapp and Hinkley [18] suggested, the insertion of the mask in addition to brief presentation of the prime was made the prime

"invisible." However, it is not easy to confirm that no information about the masked prime enters awareness with this identification accuracy. Considering that the sensitivity of the separate prime identification task is controversial [19] and subliminal processing of the prime doubtful [20], accuracy above that attributed to chance alone did not weaken the NCE in our RT data. If the prime were visible against the original intention, it would have induced positive priming rather than the NCE (e.g., in Klapp & Hinkley's Result a).

Experiment 1 shows the same NCE based on direction as observed in previous studies [4, 18, 21, 22]. Increased RTs when the prime and the target were of the same direction could be explained by either the SI hypothesis or the MTI hypothesis. However, the prediction based on the OU hypothesis was not supported. It was expected that the more the target shared the updated features in the mask, the faster the judgment would occur. However, this was not the case. The response to targets with the same direction and same color as the added elements to the prime in mask (od_oc in Figure 2) was not faster than the response to targets with only the same direction as the added feature (od_sc in Figure 2). Moreover, the RTs to targets not sharing the added elements in mask (sd_sc in Figure 2) were not the slowest.

Experiment 2: Direction judgment with reverse-mapping hands

Almost all studies for NCE use double-headed arrows as stimuli, and the responses measure judgment of direction as in Experiment 1. However, the arrows are highly interconnected and over-learned with respect to direction, so the response to the direction of the arrows is nearly automatic and involuntary. The natural question is whether the NCE can be sustained when the displays do not involve any hard-wired responses.

If the NCE were maintained even with reverse-mapping hands, its cause would be attributed to properties other than the hand-direction relationship. If the NCE disappeared in the opposite stimulus-hand response, its cause would be the stimuli per se.

Methods

Participants

After giving informed consent, twelve undergraduates at the Yonsei University participated in the experiment to fulfill course requirements. None of them participated in Experiment 1. All of them had normal or corrected-to-normal vision and were naïve to the purpose of the experiment.

Stimuli and procedure

The stimuli and procedures were the same as those used in Experiment 1. The only exception was the responding hand, which was the opposite of the arrow-pointing direction. Thus, participants were asked to press the key with the left hand when the head of the arrows was oriented to the right, and with the right hand when the arrows pointed to the left.

Results and Discussion

Target - direction discrimination

Mean correct RTs and accuracies are shown in Figure 3 for direction (same, opposite) × color (same, opposite) trials. ANOVA for the correct RTs revealed that RTs in the same direction trials were still significantly longer than those in opposite direction trials even for responses with reverse-mapping hands [NCE, $F(1, 11) = 55.27$, $p < .001$]. The effect of the color and the interaction effect of color and direction were not statistically significant.

The analysis of accuracy showed that the NCE in RTs was not due to the
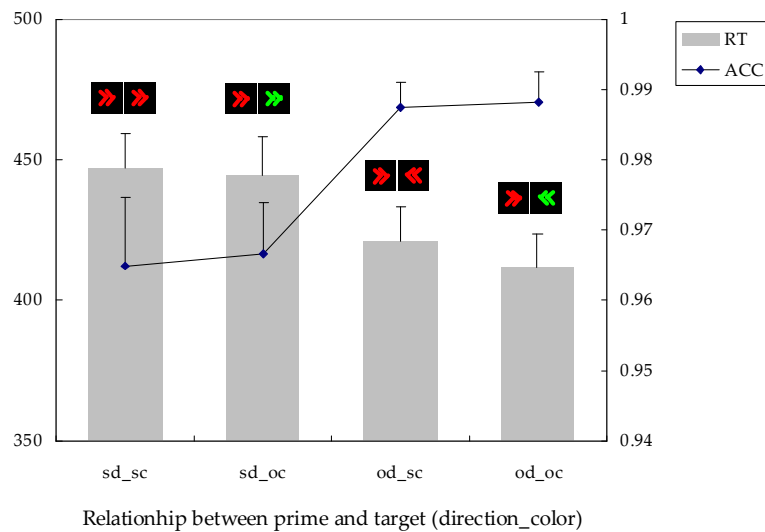

Figure 3. Mean correct response times (bars) and accuracies (lines) in Experiment 2. When prime and target arrows were of the same direction and participants were asked to respond with reverse-mapping hands, the judgment of the direction took significantly longer (NCE). Error bars represent one standard error of the mean (SE).

speed-accuracy trade-off; participants responded more accurately under opposite direction conditions where RTs were reduced than in conditions with the same direction [F(1, 11) = 10.85, p < .01]. The other effects did not reach statistical significance.

Prime identification

The mean accuracy of prime identification for 144 trials was 51.50%. Participants in Experiment 2 also reported that they were unaware of the direction of primes or did not notice the primes at all. However, accuracies for the prime identification did not differ from that attributed to chance alone [t(11) = 1.29, $n.s.$]. From this result, primes were regarded to be processed unconsciously and subliminally.

The results of Experiment 2 offer supports for all of the suggestions based on three main hypotheses. So the reason for the NCE could not be clarified only with this finding. The aim of Experiment 2 was to examine the alternative cause of the NCE other than three hypotheses. The current finding of the invulnerable NCE based on direction even with the reverse-mapping hand response suggests that the cause of the NCE with the double-headed arrows was probably not due to the tight association between hand and direction. However, mere reversal of hand and direction mapping cannot rule out the influence of coupling between them. We will consider this problem in the general discussion.

Experiment 3: Color judgment

In Experiments 1 and 2, the NCE was observed for tasks judging direction of the arrows either with corresponding or the reverse-mapping hands. However, it was not revealed whether the NCE was a stimuli-driven phenomenon irrespective of the

observer's intentions. Therefore, participants' responses to the same stimuli with a different task should tell us the potential influence of top-down control on the NCE.

Concentrating on the main effect of direction, comparisons of RTs and accuracies among conditions were overlooked. A closer look suggests that RTs in the same direction-opposite color condition were consistently longer than in the opposite direction-same color condition [$t(14) = 5.20$, $p < .01$ in Experiment 1, $t(11) = 3.63$, $p < .01$ in Experiment 2]. These two conditions were comparable because neither of their targets shared the exact same component in the mask. A plausible reason for this pattern could be the instructed task according to the both of SI and MTI hypotheses. In the SI hypothesis, the type of task instructed to the participants is assumed to induce the NCE. On the other hand, the MTI hypothesis emphasizes the task-relevant feature of mask in the occurrence of the NCE. Consequently, whatever we relied on to explain the NCE, if the task is switched to color judgment from direction discrimination, the pattern of response times should be changed. However, if the switch of task would not modulate the response patterns, the NCE could be attributed to the updated properties in mask as in OU hypothesis.

Methods

Participants

After giving informed consent, sixteen undergraduates at the Yonsei University participated in the experiment to fulfill course requirements. None participated in Experiment 1 or 2. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiment.

Stimuli and procedure

The stimuli were the same as those used in Experiments 1 and 2. However, the task was different in that participants were asked to respond to the color of the target arrows, while ignoring their direction, as accurately and quickly as possible. Half of the participants were instructed to judge red color with the right hand and green with left, and the other half were asked to make the converse judgment.

Results and Discussion

Target - color judgment

Mean correct RTs and accuracies are shown in Figure 4 for direction (same, opposite) × color (same, opposite) trials. ANOVA for the correct RTs revealed that although the focus of the response was changed from direction to color, the NCE for direction was still observed [$F(1, 15) = 10.55, p < .01$]. Whereas judgment of the color in target arrows that were different from the prime took longer than judgment of the same color when the prime and target were of the same direction, this pattern was reversed when the directions of the two stimuli were opposite. However, these differences did not reach statistical significance. Whereas the error rates were mirrored by the RT in the two direction judgment tasks, the accuracies did not show any statistically significant difference for any main effect or an interaction effect in the color judgment task. This result demonstrates that opposite direction between prime and target did not render the judgment of color more accurate as in Experiments1 and 2. In addition, the RT difference in Experiment 3 was not due to the speed-accuracy trade-off.
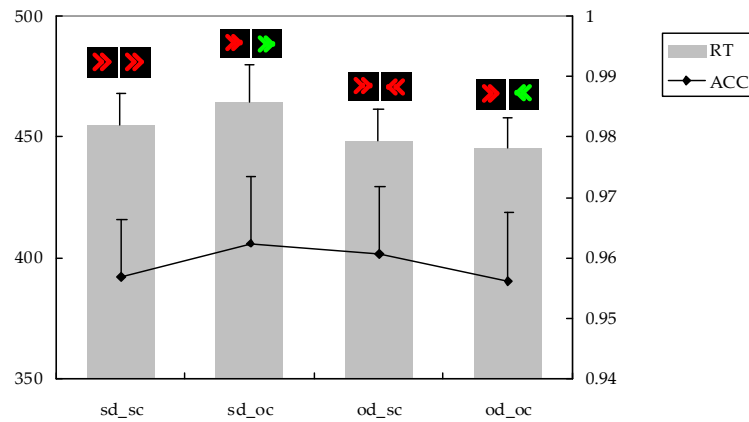
Relationship between prime and target (direction_color)

Figure 4. Mean correct response times (bars) and accuracies (lines) in Experiment 3. When the participants' tasks included the judgment of color in the target, the response to the target of the same direction as the prime became slower regardless of color (NCE on the basis of the direction). Response keys were counterbalanced between participants. Error bars represent one standard error of the mean (SE).

Prime identification

Unlike in the direction discrimination task, accuracy in the color judgment of the prime was calculated excluding dummy trials. In 48dummy trials, the prime, mask and target were of the same color. Therefore, the prime was not masked efficiently and the task was made easier. For the remaining 96 trials with color changing through prime, mask and target, the mean accuracy for the judgment of the prime was not different from that attributed to chance [$t(15) = .093$, *n.s.*].

Compared with the response patterns in Experiment 1 and 2, the responses to the targets with opposite direction with the primes (od_sc and od_oc) became slower and

less accurate in color judgment task. It showes that the impact of direction on response could be weakened by the type of task. However, the results of Experiment 3 show that the task instructed to the participants did not modulate the RT patterns, especially the NCE for direction. When the prime and the target were arrows in the same direction, even the response irrespective to the direction became slower than with arrows in opposite directions. Moreover, when the two components (direction and color) of the arrow competed in the masks, the task relevancy did not have any influence on the response. This implies that the main cause of the NCE based on direction in the display of arrows is neither automatic inhibition following motor activation of response as predicted by the SI hypothesis nor top-down control by task relevancy as predicted by the MTI hypothesis.

General Discussion

The present study shows that the invulnerable NCE occurs for direction in the prime-mask-target paradigm of colored double-headed arrows. The increased RTs to the target following the prime of the same direction were found in the task of direction discrimination with corresponding stimulus/hand response (Experiment 1), with the reverse-mapping response (Experiment 2) and even in the color judgment task (Experiment 3). All of these results cannot be accounted for by any of the hypotheses proposed thus far.

The SI hypothesis assumes that when the focus of the task is transferred from direction to color, the basis for the NCE changes as well. However, the results of Experiments 1 and 3 show that this is not the case. Furthermore, the OU hypothesis cannot explain why the color-based NCE would not occur, despite the added color element. Moreover, although the target shared more updated information, the NCE was

not stronger. The MTI hypothesis is not supported by the findings of Experiments 1 and 3. It was demonstrated that as long as the displays of prime, mask and target were kept constant, the NCE based on direction was maintained regardless of the task. This result implies that automatic inhibition, updated information and observers' intentions have little, if any, influence on the occurrence of the NCE. There may exist other factors which may give rise to the NCE, which will be considered in following paragraphs.

First, the perceptual interaction among dominant features in prime, mask and target could be a critical factor for NCE. Phenomena such as repetition blindness (e.g. [23]) or prime-mask and/or mask-target perceptual interaction as in the study by Sumner [3] could impair the perception of prime-compatible targets [24]. Perceptually, direction was a more salient property than color for double-headed arrows and consequently, the invulnerable NCE could be induced by direction. Although the NCE was not interpreted as a perceptual phenomenon in a previous study [25], that conclusion is distinct from the present results because the former study involved a mix of the prime-mask-target paradigm and free choices. Moreover, the extent to which processing primes can really affect or interact with this effect is still debatable [26-29]. Further studies comparing the effect on the NCE of modulation of a relatively dominant property by a less salient property might elucidate this possibility.

A second alternative explanation for the invulnerable NCE on the basis of direction is stimulus-response compatibility (e.g. [30, 31]). To test the potential influence on the NCE, the response hands were manipulated to inverse mapping in Experiment 2. The direction-specific NCE was still observed. In fact, participants demonstrated higher accuracies in reverse mapping. This demonstrates that inverse mapping with left-orienting (right-orienting) to the right hand (left hand) is not sufficient to eliminate the intrinsic directional feature. Even in Experiment 3 with the task of color judgment, the arrows were still highly related to the direction, as the response was made with

either the left or right hand. A plausible explanation for the overall results involves the orienting properties of the arrows and the responses. Experiments with identical display and tasks with a direction-irrelevant response such as voice may resolve this.

In summary, the invulnerable NCE for direction in the present study cannot be explained by any of the previously suggested hypotheses. Neither automatic inhibition following activation (SI), updated information in the mask (OU) nor top-down control of observer (MTI) was revealed as the critical factor for invulnerability of the NCE based on direction. Therefore, other plausible factors such as perceptual dominance and the inherent properties of the stimuli and responses should be further examined.

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(요 약)

색을 가진 이중 부등호에서 방향에 대한 견고한 부적 일치 효과

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이중 부등호를 이용한 여러 실험을 통해 부적 일치 효과(negative compatibility effect: NCE)가 일관적으로 관찰되었다. 그러나 왜 이 현상이 발생하는가에 대해서는 몇 가지 서로 다른 가설이 제기되어 왔다. 본 연구에서는 부적 일치 효과의 발생 원인으로 가정되어 온 자동 억제, 정보의 업데이트 및 하향적 통제 등과 같은 요인들의 타당성을 확인하고자 하였다. 색이 다른 이중 부등호로 구성된, 차폐된 점화자극과 목표자극의 배열에 대해서 목표자극인 부등호의 방향에 대해 판단하는 경우에, 참가자들은 부등호의 방향과 손의 반응이 일관적인 과제 (실험 1), 부등호의 방향과 손의 반응이 반대인 과제 (실험 2)에서는 물론, 색 반응 과제 (실험 3) 에서도 방향에 근거한 부적 일치 효과를 나타냈다. 이 결과는 부적 일치 효과의 주된 원인이 지각적 우세성이나 자극과 반응 사이의 본질적 속성에서 기인할 수 있음을 시사한다.

주제어 : 부적일치효과, 이중 부등호, 방향 판단