Hemispheric Asymmetry in Nonconscious Processing

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Abstract

Here we investigated whether hemispheric asymmetry effects can be observed in nonconscious processing with a basic-level animal categorization (cat/dog) task. We found a significant nonconscious congruency priming effect when the prime was presented in the right visual field/left hemisphere but not when it was presented in the left visual field/right hemisphere when the prime duration was only 10 ms; the left-lateralized congruency priming effect was consistent with the left hemisphere superiority in processing abstract category information reported in the literature (e.g., Marsolek, 1999). This result thus showed that nonconscious processing can go beyond the sensory level to influence hemispheric asymmetry in the processing of category information. In contrast, this hemispheric difference was not observed when the prime was presented for 50 ms (nonconscious) or 150 ms (conscious). This effect may be because 10 ms subliminal information was insufficient to allow inter-hemispheric transfer/processing, allowing the hemispheric difference to emerge. It also suggests that hemispheric asymmetry may be better observed at subliminal level.

Keywords: subliminal priming; hemispheric asymmetry; attention; nonconscious processing;

Introduction

It has been well established in the literature that subliminal stimuli are able to elicit subsequent cognitive and behavioral influences (see Kouider & Dehaene, 2007 for a review). It remains unclear, however, how a subliminally presented stimulus is processed. Here we aim to examine whether a subliminally presented stimulus can induce hemispheric asymmetry effects.

In the literature of hemispheric asymmetry in perception, hemispheric asymmetry effects typically did not emerge until a late perceptual stage (Fendrich & Gazzaniga, 1990; Hsiao., Cipollini., & Cottrell., accepted; Sergent, 1982). More specifically, hemispheric asymmetry effects were typically observed in tasks involving high-level perception such as face recognition (e.g., Keenan, Whitman, & Pepe, 1989), but not in tasks more relevant to early perceptual processes such as grating detection (e.g., Fendrich & Gazzaniga, 1990). Based on these findings, it has been argued that hemispheric asymmetry effects "must result from processing taking place beyond the sensory level" (Sergent, 1982). Thus, examining hemispheric asymmetry effects in subliminal priming can help us understand whether nonconscious processing can go beyond early perceptual processes to induce hemispheric asymmetry effects.

Nevertheless, in the literature on subliminal priming, whether hemispheric asymmetry effects can be observed in the processing of subliminal stimuli was rarely studied. Marzouki, Grainger, and Theeuwes (2007) examined subliminal priming effects in a letter/pseudo-letter judgment task. In their experiment, the target stimulus always appeared at the center, while the preceding 45-ms prime (the same letter as the target) could be in the left visual field (LVF) or the right visual field (RVF). The results showed that in the trials with a letter target, a robust priming effect was found, however, only when the prime was presented in the RVF/left hemisphere (LH), but not when it was presented in the LVF/right hemisphere (RH). While Marzouki et al. (2009) interpreted the results as an attentional bias in favor of the RVF, their results may suggest a hemispheric asymmetry effect in subliminal letter processing as well. However, it is also possible that the RVF priming effect Marzouki et al. (2007) observed was due to perception-response compatibility, as participants always used their right hand to respond to the letter targets. Thus, it remains unclear whether hemispheric asymmetry effects can be observed in subliminal priming.

Using a supraliminal priming paradigm, Marsoleck (1999) found hemispheric asymmetry effects in processing category-related information. In Marsoleck (1999)'s study, participants were asked to name pictures of objects presented for 17 ms in either the LVF or the RVF. Before the target presentation, the same object or another object from the same basic category as the target object was presented centrally for 3 seconds as the prime. While a same-object priming effect was found for both LVF and RVF targets, the same-category different-object priming effect was only observed in the RVF/LH. This result suggested that the LH may be biased towards abstract-category representations whereas the RH is biased towards exemplar-specific representations. This hemispheric asymmetry in the representation of category knowledge was further supported by several follow-up studies using various stimuli (Laeng, Zarrinpar, & Kosslyn, 2003; Studer & Hübner, 2008).

Thus, in the present study, we aimed to examine whether this hemispheric asymmetry in the representation of category knowledge can be induced with subliminal stimuli in a category judgment task (Marsolek, 1999), with perception-response compatibility controlled (cf. Marzouki

et al., 2007). The results of this examination can shed light on whether subliminal information can go beyond the sensory level to influence late perceptual processes.

In the representation of object category information, there are multiple levels of abstraction. A cat can be identified as "cat" (the basic level), or "animal" (the superordinate level), or "Sam" (a specific cat, the subordinate level). The current study focuses on the processing of basic-level category information (i.e., a cat/dog classification task). In a previous study (Finkbeiner & Palermo, 2009), the authors investigated nonconscious congruency priming effects in an animal/tool classification task (experiment 1a; or an animal/vegetable classification task in experiment 2a), which was at the superordinate level. In their study, the prime was always at the top location and the target was always at the button location. And the top prime can be spatially cued or not. The results showed that a nonconscious congruency priming effect was found only in the condition when the prime was cued. This effect suggests that nonconscious processing of superordinate-level category information relies on the engagement of spatial attention.

Thus, the other aim of the current study was to examine whether nonconscious processing of basic-level category information also relied on spatial attention. Previous studies showed that, compared with superordinate-level category information, basic-level information was more accessible (e.g., Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), basic-level terms were preferred in naming objects (e.g., Jolicoeur, Gluck, & Kosslyn, 1984; Rosch et al., 1976) and recognizing objects at the basic level required less reaction time (e.g., Tanaka, 2001). Thus, it is possible that nonconscious processing of basic-level category information is more automatic than that of superordinate-level category information and does not require attention.

Therefore, in the current study, we aimed to 1) examine whether there is a hemispheric asymmetry in the subliminal priming effect by presenting the prime in either the LVF or the RVF, and 2) investigate whether nonconscious processing of basic-level category information relies on the engagement of spatial attention. In addition, we manipulated the duration of the prime (150-, 50-, and 10-ms) in order to compare hemispheric asymmetry and attentional modulation effects across conditions with different levels of consciousness.

Experiment 1

In experiment 1, the prime (150-ms duration) was visible in order to: 1) examine whether the congruency priming effect can be found at the supraliminal level, and 2) investigate whether this congruency priming effect can be modulated by hemispheric asymmetry and spatial attention.

Method

Participants 20 students (13 females, age mean = 20.7, range = 18-24) at the University of Hong Kong participated in exchange for course credits or payment. All were Asian, with normal or corrected-to-normal vision.

Stimuli Dog and cat images, all frontal-view or close to frontal-view, were selected from the Oxford-IIT Pet Dataset (Parkhi, Vedaldi, Zisserman, & Jawahar, 2012), with cat images from the species of British Shorthair and dog images from that of Shiba Inu. Only the head parts of the animal images were used and were converted to grayscale, and were further cropped to fit within a black oval. They all had equal size, luminance, and contrast.

Two types of black and white noise images were used as masks. The random noise mask was generated by assigning a random value between 155 and 255 to each pixel, while the animal mask was created by, firstly, combining a cat and a dog image, and then scrambling the combined image. The animal mask was used as a backward mask for the prime as well as the target.

Each stimulus, including both animal images and masks, spanned 4° visual angle vertically and 2.5° horizontally with a 60-cm viewing distance.

Design and Procedure The experiment used a 2 (spatial attention: prime-cued vs. uncued) × 2 (congruence between the prime and target: congruent vs. incongruent) × 2 (visual field: LVF vs. RVF for the location of the prime) within-participant design. Participants were instructed to judge the category of the target pictures, i.e., a dog/cat judgment. They made the binary choice by pressing two buttons ("F" and "J") on a keyboard with their two index fingers simultaneously, or another two buttons ("D" and "K") with their middle fingers simultaneously. The response buttons were counterbalanced across participants.

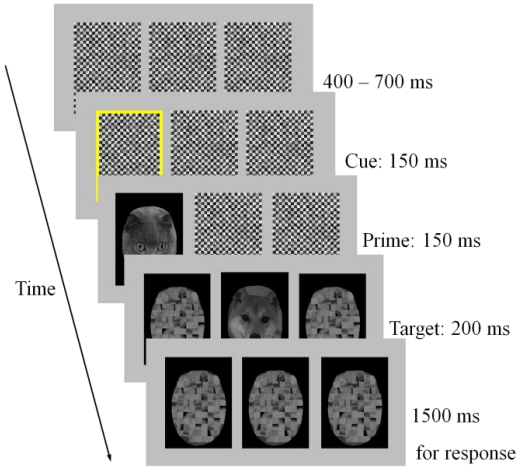

Figure 1: Sequence of stimuli in a single trial

The basic trial structure was similar to Marzouki, Grainger and Theeuwes (2007)'s study (Figure 1). After a forward mask with a duration randomly selected among 400, 500, 600, and 700 ms, a yellow box cue was presented

either at the left or the right side for 150 ms, followed by the 150-ms prime image at either the same (Prime-cued) or the opposite (Prime-uncued) side of the cue. Then, the target image appeared for 200 ms at the center together with two animal backward masks at both the left and right sides. Following the target, another animal mask appeared at the center for 1500 ms (See Figure 1). Participants were instructed to make their judgment as quickly and as accurately as possible after they saw the target.

Before the main experiment, a practice section with 20 trials was performed. The procedure of the practice was the same as the main experiment. The images used in the practice never appeared in the main experiment. After the main experiment, in order to confirm that the prime images were visible, participants were instructed to do a prime-discrimination task, i.e., to judge the category of the prime images. The procedure was identical to the main experiment except that participants were to make judgments on the prime instead of the target stimulus, and that the backward masks at the end of each trial stayed until participants made their response.

40 images (20 cat and 20 dog images) were used as the target as well as the prime stimuli in all four conditions (congruent with prime cued, congruent with prime uncued, incongruent with prime cued, incongruent with prime uncued), with the constraint that the prime and the target could not be the same image. In each condition, all 40 images appeared once as the target, resulting in 160 trials in total. Trials were presented in a random order, with the limits that the same target did not appear in succession, that no more than 3 trials in a row elicited the same response, and that no more than 3 trials in a row were in the same condition. In the prime-discrimination task, there were also 160 trials.

Results

In analyzing the response times (RTs), null responses and incorrect responses (6.47%) were excluded. And any RT outside 2.5 standard deviations from the mean, for each participant, was treated as outliers (2.78%). In analyzing the accuracy data, only null responses (0.75%) were excluded.

The result of the prime-discrimination task confirmed that the 150-ms prime was visible. The mean accuracy reached 77.7%, significant higher than the 50% chance level, $t(19) = 9.57$, $p < .001$.

A 2 (spatial attention) × 2 (congruency) × 2 (visual field) repeated measures ANOVA on the RTs revealed a significant main effect of congruency, $F(1, 19) = 4.90$, $p < .039$, with faster RTs for congruent trials (Mean = 638 ms) than incongruent trials (Mean = 648 ms). No significant main effects of spatial attention or visual field (both $p > .10$) were found. There was no interaction between spatial attention and congruency ($p > .70$) or between visual field and congruency ($p > .29$), suggesting that spatial attention and visual field did not modulate the priming effect under this supraliminal condition.

The same 2 × 2 × 2 repeated measures ANOVA was conducted on the accuracy data; no reliable effects or interactions were observed (all $p > .10$).

Discussion

The 150-ms prime was long enough for conscious processing of category information, as participants had well above-chance performance in the prime-discrimination task. At the conscious level, a robust congruency priming effect was observed, both when the prime was cued or uncued. This result was consistent with the results of Lachter, Forster and Ruthruff (2004)'s study (experiment 1). In a lexical decision task, Lachter et al. (2004) observed a significant repetition priming effect in conditions where a supraliminal prime (110 or 165 ms) was at a task-relevant or task-irrelevant position. At supraliminal level with a long prime duration, participants were typically able to shift their attention to the prime even when the prime was at an irrelevant location (Lachter, Forster, & Ruthruff, 2004) or uncued. Thus, no attentional modulation effect was observed.

Experiment 2

In experiment 2, the prime duration was changed to 50 ms in order to be rendered invisible, as was in the previous studies (Finkbeiner & Palermo, 2009; Harry, Davis, & Kim, 2012). In contrast to the superordinate level recognition task (animal vs. tool; or animal vs. vegetable) used in Finkbeiner and Palermo (2009)'s study (the animal condition); participants in the current study were to categorize images at the basic level (cat vs. dog). Finkbeiner and Palermo (2009) found that nonconscious processing of superordinate-level category information relies on the engagement of spatial attention. Here we aimed to examine whether a similar effect can be found in the processing of basic-level category information.

Method

Participants 16 students (9 females, age mean = 21.8, range = 18-27) at the University of Hong Kong participated in exchange for course credits or payment. All were Asian, with normal or corrected-to-normal vision. None of them participated in experiment 1.

Stimuli, Design and Procedure All settings in experiment 2 were exactly the same as those in the experiment 1, except that the prime duration was changed from 150 ms to 50 ms.

Results

In analyzing the RTs, null responses and incorrect responses (6.8%) were excluded. And any RT outside 2.5 standard deviations from the mean, for each participant, was treated as outliers (3.7%). In analyzing the accuracy data, only null responses (1.5%) were excluded.

The result of the prime-discrimination task confirmed that the 50-ms prime was invisible, with the mean accuracy of

51.6% being not significantly different from the 50% chance level, t (15) = 1.64, p > .10.

A 2 (spatial attention) × 2 (congruency) × 2 (visual field) repeated measures ANOVA on the RTs showed a significant main effect of congruency, F (1, 15) = 4.88, p < .043, with faster RTs for congruent trials (668 ms) than incongruent trials (680 ms). In contrast to the results of Finkbeiner and Palermo (2009), however, we did not find evidence of attentional modulation on the congruency priming effect, F (1, 15) = 0.65, p = .43. In addition, follow-up analysis revealed a significant priming effect when the prime was uncued, F (1, 15) = 6.91, p < .019; but the priming effect when the prime was cued failed to reach significance, p > .50. There was no main effect of visual field (p > .40) or interaction between visual field and congruency (p > .60).

The same 2 × 2 × 2 repeated measures ANOVA on the accuracy data revealed a main effect of congruency, F (1, 15) = 6.74, p < .02, with lower accuracy in congruent trials (93.5%) than incongruent trials (95.7%). No modulation effects of attention (p > .70) or visual field (p > .50) were found.

Table 1: Mean RTs (SE) in experiment 1 and 2

Condition	RTs (ms)	
	Prime-cued	Prime-un-cued
150-ms prime		
Congruent	635(14)	641(15)
Incongruent	647(14)	648(13)
Priming	12	7
50-ms prime		
Congruent	670(17)	666(18)
Incongruent	676(19)	685(18)
Priming	6	19

Discussion

The results in experiment 2 showed no evidence suggesting attentional modulation on the nonconscious priming effect in the basic-level categorization task; in addition, a significant nonconscious priming effect was observed when the prime was not cued. This effect suggests that nonconscious processing of basic-level category information does not rely on spatial attention, in contrast to the finding that nonconscious processing of superordinate-level category information depends on spatial attention (Finkbeiner & Palermo, 2009).

Results in some earlier studies examining nonconscious priming effects with visual word stimuli (Fuentes, Carmona, Agis, & Catena, 1994; Kiefer & Brendel, 2006) were consistent with this finding. In Fuentes et al. (1994)'s study, for instance, a lexical decision task was used. In experiment 2, the two nonconscious prime words, one presented in the foveal and the other in the parafoveal vision, were presented at the same time, followed by masks. The center target could be semantically related to the foveal prime or the parafoveal prime. The results showed that similar, reliable priming effects were found for both the foveal and parafoveal prime. It was argued that semantic representations stored in the long-term memory were ready to be activated even when no attention was drawn to the nonconscious prime word (Kiefer & Brendel, 2006). Thus, similar to semantic information, basic-level category information may also be readily accessible even when no attention was drawn to the nonconscious prime picture.

Experiment 3

In experiment 3, the prime duration was further changed to 10 ms. As no modulation from attention or VF was observed in experiment 1 and 2, experiment 3 aimed to explore it further by testing the condition where the awareness of the prime was extremely low.

Method

Participants 18 students (14 females, age mean = 22.9, range = 18-29) at the University of Hong Kong participated in exchange for payment. All were Asian, with normal or corrected-to-normal vision. None of them participated in experiment 1 or 2.

Stimuli, Design and Procedures All settings were exactly the same as those in experiment 1, except that the prime duration was changed to 10 ms and that there was a 40-ms inter-mask between the prime and the target.

Results

In analyzing the RTs, null responses and incorrect responses (4.8%) were excluded. And any RT outside 2.5 standard deviations from the mean, for each participant, was treated as outliers (3.3%). In analyzing the accuracy data, only null responses (1.0%) were excluded.

The results of the prime-discrimination task confirmed that the 10-ms prime was invisible, with the mean accuracy of 50.5% being not significantly different from the 50% chance level, t (17) = 0.69, p > .50.

A 2 (spatial attention) × 2 (congruency) × 2 (visual field) repeated measures ANOVA on the RTs did not find any reliable effect or interaction (all p > .10).

The same 2 × 2 × 2 repeated measures ANOVA on the accuracy data, however, showed a significant interaction between VF and congruency, F (1, 17) = 5.64, p < .03, but no main effect of congruency, p > .15, or interaction between attention and congruency, p > .70. Follow-up analysis revealed a significant congruency priming effect when the prime was presented in the RVF, F (1, 17) = 9.19, p < .01, with a higher accuracy in the congruent trials (97.3%) than that in the incongruent trials (95.2%); in contrast, no congruency priming effect was observed in the LVF, p > .60. This priming effect in the RVF did not interact with spatial attention, F (1, 17) = 1.41, p > .25. Also, there was no significant interaction between congruency and spatial attention overall, F (1, 17) = 0.15, p > .70.

Discussion

With extremely low awareness of the prime (with only 10-ms duration), a significant congruency priming effect was obtained on accuracy in the RVF/LH, but not when the prime was presented in the LVF/RH. Marzouki et al. (2007) found similar results using a 45-ms prime with letter/pseudo letter stimuli. One potential concern in Marzonki et al. (2007)'s study was that, participants always used their right hand to respond to letter targets. Thus it was possible that the RVF superiority effect was due to the compatibility between prime location and response hand. In the present study, the location-response compatibility was counterbalanced across participants, and a strong RVF (LH) advantage was still observed.

The finding of the RVF/LH superiority in congruency priming in the basic-level categorization task here is consistent with Marsolek's (1999) results, which suggested that the LH was biased towards abstract-category representations whereas the RH was biased towards exemplar-specific representations (e.g., Laeng et al., 2003; Marsolek, 1995, 1999; Studer & Hübner, 2008). Here our participants were required to make a basic-level category judgment on the target, with a prime presented in either the LVF or the RVF. The target and the prime were always different exemplars from the same category or from different categories. Since the prime was always different from the target, the abstract category representation in the LH activated by the prime was able to facilitate the categorization of the target. Thus, the priming effect was only observed with a RVF prime but not a LVF prime.

A critical difference between the present study and the earlier studies was that visual information projected to the LH and the RH was rendered nonconscious by masks and brief duration. Our findings suggested that the processing of nonconscious information could go beyond the sensory level to induce hemispheric asymmetry effects

General Discussion

In the current study, we aimed to examine whether there is hemispheric asymmetry in the processing of nonconscious information. We observed a nonconscious congruency priming effect on accuracy when the prime was presented in the RVF/LH, but not when the prime was presented in the LVF/RH, with a 10-ms prime, in a basic-level object categorization task.

Previous studies have shown that hemispheric asymmetry effects typically do not emerge at an early visual processing stage, such as findings in grating detection tasks (e.g., Fendrich & Gazzaniga, 1990). In contrast, hemispheric specialization can typically be observed in high-level perception tasks such as face recognition (e.g., Keenan et al., 1989). Our results of hemispheric asymmetry in subliminal priming suggest that the processing of subliminal information can go beyond the sensory level to influence high-level perceptual processes. It is consistent with previous findings that nonconscious information could influence semantic processing (e.g., Yeh, He, & Cavanagh, 2012).

The LH advantage in the present study was in accordance with the abstract-specific representation account of hemisphere asymmetry in the representation of category knowledge proposed by Marsolek (1999). However, surprisingly, this effect was not found under the 50-ms (nonconscious) and 150-ms (conscious) prime conditions. The effect that longer prime presentation duration diminished hemispheric asymmetry effects in subliminal priming may be due to interhemispheric communications. It is possible that for a prime appeared in the LVF/RH, 50 ms or longer was long enough for the information to reach the LH through the corpus callosum, and to consequently activate the abstract representation of the corresponding category, resulting in a similar level of priming as compared with a prime presented in the RVF/LH. 10 ms duration, however, might be insufficient for a LVF/RH subliminal prime to reach the LH. Without the activation of abstract representations stored in the LH (Marsolek, 1999), a prime in the LVF/RH failed to facilitate the processing of the target in the basic-level categorization task; consequently, a significant priming effect was observed only with a RVF prime. This effect also suggests that hemispheric asymmetry may be better observed at subliminal level.

Note that in the present study, the prime was followed by a mask. Previous studies have revealed that a backward mask is able to block brain processing of stimuli (Bacon-Macé, Macé, Fabre-Thorpe, & Thorpe, 2005). In Bacon-Macé et al.'s (2005) study, an image (with 6.25 ms duration) was followed by a 100-ms mask. The SOA between the image and the mask was manipulated, raning from 6 ms to 106 ms. Participants were asked to judge whether there was an animal in the image. The behavirol accuracy decreased as the SOA became shorter, reaching the chance level when the SOA was 6 ms. In addition, brain activities trigerred by the image decreased rapidly with shorter SOAs, indicating that brain processing was impaired significantly by the backward mask. These findings further suggest that in our study the 10-ms LVF/RVF subliminal prime with a backward mask was too fragile to reach the other side of the brain, allowing hemispheric difference to emerge.

Another major finding in the current study was that no attentional modulation on the nonconscious congruency priming effect in the basic-level categorization task was observed across the 3 experiments with different prime durations; in particular, we observed a significant priming effect when attention was not drawn to the 50-ms, invisible prime (experiment 2). This result was in contrast to the superordinate-level categorization task used in Finkbeiner and Palermo (2009)'s study, in which the nonconscious priming effect depended on attention. Our results provided evidence for the influence from levels of abstraction in a categorization task in nonconscious processing. This is consistent with previous findings that basic-level category information was accessed first in the perception of visual objects and named first by children (Rosch et al., 1976).

Why is basic level information special? It is possible that in the human evolution, people had to recognize "tiger" as a tiger (i.e., the basic level), rather than as an animal (i.e., the superordinate level), in order to detect and escape from potential dangers in the environment. The basic-level categorization was crucial for survival, and thus through evolution we developed the ability to process basic-level category information both nonconsciously and without attention.

Acknowledgments

We are grateful to the Research Grant Council of Hong Kong (project code HKU 745210H to J.H. Hsiao) and the HKU Seed Funding Program for Basic Research (project code 201011159124 to J.H. Hsiao).

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