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RESEARCH ARTICLE

Attentional shift by gaze is triggered without awareness

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Abstract Reflexive attentional shift in response to another individual's gaze direction has been reported, but it remains unknown whether this process can occur subliminally. We investigated this issue using facial stimuli consisting of drawings (Experiment 1) and photographs (Experiment 2). The gaze direction was expressed by the eye gaze direction (Experiment 1), and the eye gaze and head direction (Experiment 2). The gaze cue was presented either supraliminally or subliminally in the center of the visual field, before target presentation in the periphery. The task for participants was to localize the target as soon as possible. The reaction time needed to localize the target was consistently shorter for valid than invalid gaze cues for both types of gaze cues in both subliminal and supraliminal conditions. These findings indicate that attentional shift can be triggered even without awareness in response to another individual's eye gaze or head direction.

Keywords Attentional shift · Awareness · Gaze · Subliminal presentation

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Introduction

The glance of another individual's gaze can trigger multiple psychological processes in the observer (Kendon 1967). For example, the perception of gaze can induce an observer's gaze following behavior to look in the direction in which the observed person is looking. At the same time, it could also cause the observer to infer the intention of the person, and elicit emotion in the observer.

Psychological studies on gaze following have demonstrated that another individual's gaze direction reflexively triggers attentional shift (for a review, see Langton et al. 2000). These studies applied Posner's (1980) cueing paradigm. For example, Friesen and Kingstone (1998) presented a gaze cue in the center of visual field, which was expressed by the eye gaze direction of a schematic face. The participants' reaction time (RT) to detect, localize, or identify a target was shorter when the target was preceded by a valid gaze cue than by an invalid or neutral one. Langton and Bruce (1999) reported identical results using head direction in photographic stimuli. In these studies, an attentional shift occurred when the cue was unpredictive of the target location. Some studies (Driver et al. 1999; Friesen et al. 2004) additionally demonstrated that an attentional shift occurred when the cue was counterpredictive of the target location. These data suggest that the process could occur without expectancy and that it is beyond intentional suppression, which is a characteristic of automatic processes (Ruz and Lupianez 2002). Based on the findings, some researchers have proposed that the gaze-triggered attentional shift is automatic (e.g., Langton and Bruce 1999).

Psychological studies investigating the automatic attentional shift by non-social cues indicate that an attentional shift can occur as a result of cues presented below the threshold of conscious awareness (McCormick 1997;

Ivanoff and Klein 2003). For example, McCormick (1997) presented a peripheral cue before a target, either supraliminally or subliminally. In the subliminal presentation condition, the valid cue shortened the RT to localize the target relative to the invalid one. Similar results have been shown in the neuropsychological literature (Danziger et al. 1998; Kentridge et al. 1999a, b). For example, Kentridge et al. (1999a) investigated a blindsight patient, and reported that valid peripheral cues preceding targets induced shorter RT to detect the targets than invalid cues, even when cues were presented in the blind visual field of the patient, and he was, therefore, unaware of them. Taken together, these findings indicate that attentional shift can occur without the awareness of cues. Attentional shift without awareness, however, has never been studied in a paradigm using social cues presented in the central visual field. Based on its automatic characteristics, we hypothesized that the gaze-triggered attentional shift could occur without awareness.

In this study, we tested the above hypothesis using the cueing paradigm with the centrally presented gaze cue. The gaze cue was presented either supraliminally or subliminally. The subliminal presentations of stimuli were implemented using backward masking (Esteves and Öhman 1993). To express the gaze directions, we used line drawings in Experiment 1 and photographs of real faces in Experiment 2, because these methods have complementary advantages. The gaze direction was expressed by the eye gaze in Experiment 1 and by the eye gaze and head direction in Experiment 2.

Experiment 1

In Experiment 1, schematic facial stimuli were used to express the eye gaze directions, as in previous studies (e.g., Friesen and Kingstone 1998). These schematic stimuli have the advantage that they minimize the extraneous complexities associated with real faces (e.g., face asymmetry). We predicted that the response to the target would be faster when the target was preceded by a valid gaze cue under both supraliminal and subliminal conditions.

Methods

Participants

Twenty healthy volunteers (9 females and 11 males; mean ± SD age, 24.8 ± 6.6 years) participated in Experiment 1. All participants were right-handed, and had normal or corrected-to-normal visual acuity. Informed consent was obtained from all participants in written form after the experimental procedures had been fully explained.

Design

The experiment was constructed as a within-participants two-factorial design, with cue validity (valid or invalid) and presentation condition (subliminal or supraliminal) as the factors.

Apparatus

The events were controlled by SuperLab Pro 2.0 (Cedrus) and implemented on a Windows computer (MA55J, NEC). The stimuli were presented on a 19-inch CRT monitor (GDM-F400, Sony) with a refresh rate of 100 Hz and a resolution of 1,024 pixels × 768 pixels. We used these settings to implement correct stimulus presentations. SuperLab Pro software uses off-screen buffering and updates the image synchronously as the monitor refreshes; the CRT monitor precisely controls the refreshing of the monitor (Wiens et al. 2004). The participants' responses were recorded using a response box (RB-400, Cedrus).

Stimuli

The gaze cues were schematic faces in which the eye gaze was directed either to the left or right (Fig. 1). Masks were mosaic patterns that covered all of the facial features of the cue stimuli. The cues and masks subtended 6.5° vertically × 6.5° horizontally. The target was an open circle subtending 1.0° vertically × 1.0° horizontally. These stimuli consisted of a black line drawing on a white background.

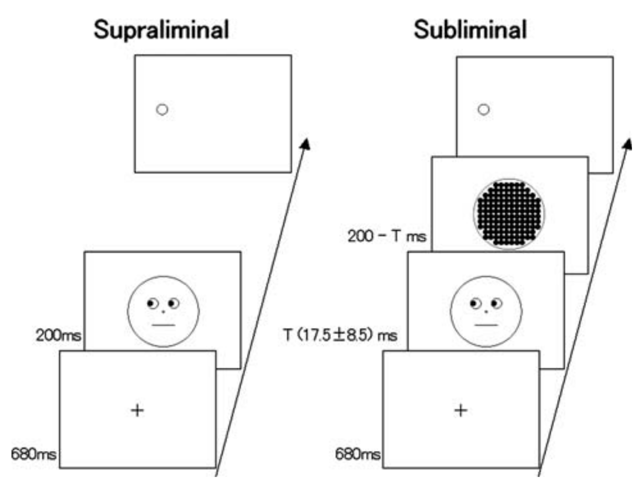

Fig. 1 Illustrations of stimulus presentations in Experiment 1: supraliminal presentation (*left*) and subliminal presentation (*right*). In the subliminal presentation, the presentation time of the gaze cue (*T*) was adjusted for each participant's threshold and the presentation period of the mask was also adjusted so that the total period of the gaze cue and the mask was 200 ms

Procedure

The experiments were conducted individually in a chamber room. The participant was comfortably seated with her/his head supported by a chin-and-forehead rest, 0.57 m from the monitor. A threshold assessment session was first conducted to determine the appropriate presentation period of the subliminal gaze cue for each participant. The trial session was then conducted.

Threshold assessment session

The thresholds for the subliminal presentations were assessed using the same method as in a previous study (Kubota et al. 2000). It has been reported that if the stimulus onset asynchrony (SOA) between the target and mask is sufficiently brief, participants are not aware of the target stimuli (Esteves and Öhman 1993). To assess the upper limit of SOA for subliminal presentation in each participant, blocks of 20 subliminal cue presentation trials, i.e., ten each for the left and right gaze directions, were prepared. In each trial, after the presentation of a fixation point, i.e., a small black "+" lasting 680 ms, the gaze cue was presented in the center of the monitor, after which the mask was presented in the same location. The presentation time of the mask was adjusted so that the total presentation period of the gaze cue and the mask was 200 ms. The order of gaze direction was randomized. The participant was asked to orally answer the question, "Did you see the gaze? If so, report the direction of the gaze." The participants responded either "Yes" or "No," and in the case of the former, they then reported the gaze direction that they had seen. Starting with 10 ms, the SOA was prolonged by 10 ms increments. After the participants finished each block, the performance was investigated. If the participant correctly recognized at least one of the 20 stimuli, the corresponding SOA was regarded as the lower limit of conscious awareness for the cue for that participant, and an SOA, 10 ms shorter than that limit was used in the trial session. The mean (±SD) SOA was 17.5 ± 8.5 ms.

Trial session

The participants completed a total of 144 trials, presented in two blocks of 72. Each block contained an equal number of valid and invalid trials for each presentation condition. The order of cue validity was randomized within each block. The order of presentation condition was counterbalanced across participants. At the beginning of each block, participants received ten practice trials. A short break was interposed after 36 trials in each block, and a longer break was interposed after each block.

For each trial, a fixation point, i.e., a small black "+," was presented for 680 ms at the center of the screen. The gaze cue was then presented at the same location. In the supraliminal condition, the presentation period of the gaze cue was fixed at 200 ms for all participants and there was no masking. In the subliminal condition, the presentation time of the gaze cue was adjusted for each participant's threshold and was followed by the presentation of the mask in the same place; the presentation time of the mask was adjusted so that the total presentation period of the gaze cue and the mask was 200 ms. After the gaze cue (in supraliminal condition) or mask (in subliminal condition) disappeared, a target was presented in either the left or right visual field (5.0° apart from the center) until a response was made.

As in previous studies (Friesen and Kingstone 1998; McCormick 1997; Okada et al. 2003), participants were instructed to localize whether targets appeared either on the left or right side of the monitor as quickly as possible. Participants were told that the stimuli preceding the targets were not predictive. The response for the left or right target was made by pressing the key on the switch box using the left or right index fingers, respectively. The time from the target onset to the response was recorded as the RT.

After the completion of all trials, debriefing was conducted and the participants were asked whether they had consciously perceived the gaze cues in the subliminal presentations. The interview confirmed that none of the participants had consciously perceived the gaze cues in the subliminal presentations.

Data analysis

The data were analyzed using SPSS 10.0J (SPSS Japan). Incorrect responses were excluded from the analysis of RT. The median RT under each condition was calculated for each participant. To satisfy assumptions of normality for the subsequent analyses, the data were subjected to a log transformation. The log-transformed RT was analyzed using a 2 (cue validity) × 2 (presentation condition) repeated-measures ANOVA. For significant interactions, follow-up split analyses were conducted.

To confirm that the RT data were not explained by a speed-accuracy trade-off phenomenon, the numbers of errors were also analyzed using repeated-measures ANOVA of the same design with the RT analysis.

The results of all tests were considered statistically significant at $P < 0.05$. Based on our preliminary analyses, the gender and age of the participants, which showed no significant effects on the results, were disregarded in the following analyses.

Results

RT analysis

The results of RT are shown in Fig. 2. The ANOVA for the log-transformed RT revealed a significant main effect of cue validity and a significant interaction of cue validity × presentation condition [$Fs(1,19) = 41.90$ and 45.33, respectively, all P values <0.001]. The main effect of presentation condition was marginally significant [$F(1,19) = 3.48$, $P < 0.1$].

Follow-up analyses indicated that the simple effect of validity, indicating shorter RTs for valid than for invalid cues, was significant for both supraliminal and subliminal conditions [$Fs(1,19) = 62.99$ and 7.96, P values <0.001 and .05, respectively]. Follow-up analyses also indicated that the simple effect of presentation condition was significant for the invalid condition, indicating longer RTs for supraliminal invalid cues than for subliminal invalid cues [$F(1,19) = 22.60$, $P < 0.001$].

Error analysis

The mean (±SD) error rates (%) were 0.69 (±2.53), 4.72 (±4.24), 1.67 (±3.30), and 1.81 (±1.86) for supraliminal valid, supraliminal invalid, subliminal valid, and subliminal invalid cues, respectively. For the number of errors, the ANOVA revealed significant main effects of both cue validity and presentation condition, and a significant interaction of cue validity × presentation condition [$Fs(1,19) =$ 17.45, 7.69, and 14.66, P values <0.005, 0.05, and 0.005, respectively]. The main effect of cue validity indicated that errors occurred more frequently for invalid cues than for valid cues. Follow-up split analyses showed significant simple effects of validity for the supraliminal condition, indicating more frequent errors for invalid than for valid cues [$F(1,19) = 24.25$, $P < 0.001$]. These results suggest that an RT-accuracy trade-off does not explain the RT findings.

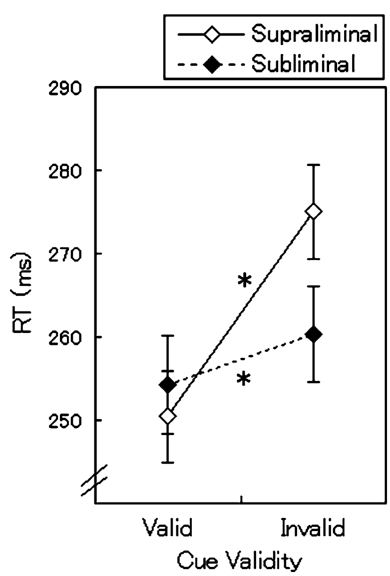

Fig. 2 Mean (with SEM) RTs in Experiment 1. *Asterisks* indicate the significant simple main effects of cue validity, indicating shorter RTs for valid cues than for invalid cues

Discussion

In the supraliminal condition, valid eye gaze directional cues induced shorter RTs than did invalid cues. This is consistent with the results of previous studies (e.g., Friesen and Kingstone 1998).

In the subliminal condition, the RTs for valid gaze cues were also shorter than the RTs for invalid cues. This is also in line with the results of previous studies that demonstrated that the attentional shift was triggered without awareness (e.g., McCormick 1997), and supports our hypothesis that gaze cues can trigger attentional shift without awareness.

There was an interaction between cue validity and presentation condition, indicating more evident effects in the supraliminal than in the subliminal condition. A similar result has been reported in a previous study using peripheral non-social cues (Ivanoff and Klein 2003). This result may be plausible considering that the gaze cues were presented for a longer duration in the supraliminal condition than in the subliminal condition. Another possibility is that (partly) different neural mechanisms may underlie the subliminal and supraliminal processing.

Experiment 2

In Experiment 2, photographs of real faces were used to express the gaze directions, as in previous studies (e.g., Langton and Bruce 1999). The photo stimuli have the advantage that they are real, relative to drawings. Because the directions of both eye gaze and head direction, when presented using photographs, have been shown to have the capacity to trigger an attentional shift (e.g., Driver et al. 1999; Langton and Bruce 1999), we tested both of these types of gaze cue. We predicted that the responses to the targets would be faster for valid gaze cues for both eye gaze and head direction in both the supraliminal and subliminal conditions.

Methods

Participants

Twenty-six healthy volunteers (22 females and 4 males; mean ± SD age, 20.4 ± 1.2 years) participated in Experiment 2. All participants were right-handed and had normal or corrected-to-normal visual acuity. Informed consent was obtained from all the participants in written form after the experimental procedures had been explained fully.

Design and apparatus

The experiment was constructed as a within-participants three-factorial design, with cue validity (valid or invalid), presentation condition (subliminal or supraliminal), and cue type (eye gaze or head direction) as the factors.

Stimuli

The cues were gaze directions represented with grayscale photographs of a female looking either to the left or right, as indicated either by the direction in which the eyes were gazing or by the direction of the head itself (Fig. 3). Masks were mosaic patterns made from the photograph of the same individual's full face; the photograph was divided into 25 vertical × 20 horizontal squares and reordered randomly. The cues and masks subtended 6.5° vertically × 6.5° horizontally. The target was identical to that used in Experiment 1.

Procedure

The procedure was identical to that used in Experiment 1, except for the inclusion of the cue type condition. Each cue type was tested in each block of 72 trials. The order of cue type was counterbalanced across participants. The participants completed a total of 288 trials.

As a result of the threshold assessments for the subliminal presentations, the mean (±SD) SOAs were determined as 10.6 ± 7.3 and 10.8 ± 5.4 ms for eye gaze and head direction, respectively.

Data analysis

The method of data analysis was identical to that used in Experiment 1, except for the design of ANOVA. The 2 (cue validity) × 2 (presentation condition) × 2 (cue type) repeated-measures ANOVA was conducted.

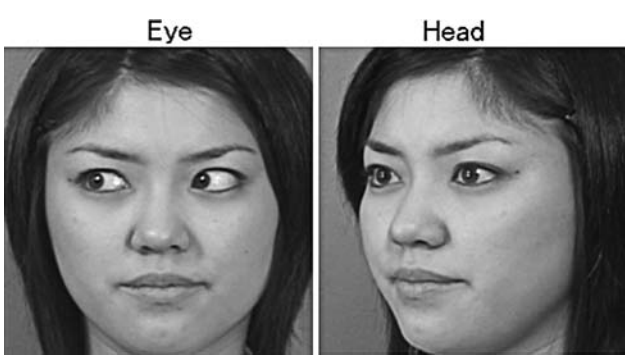

Fig. 3 The eye (*left*) and head (*right*) cues used in Experiment 2

Results

RT analysis

The RT results are shown in Fig. 4. The ANOVA for the log-transformed RT revealed a significant main effect of cue validity and significant interactions of cue validity × presentation condition, cue validity × cue type, and cue validity × presentation condition × cue type [Fs(1,25) = 55.45, 24.12, 16.85, 32.88, respectively, all P value <0.001].

As follow-up analyses for the significant three-way interaction, 2 (validity) × 2 (presentation condition) split ANOVA was conducted for each cue type. For the eye gaze condition, there was a significant main effect of validity and a significant interaction of validity × presentation condition [Fs(1,25) = 95.12 and 61.83, respectively, all P values <0.001]. Follow-up split analyses indicated that the simple effect of cue validity, indicating shorter RTs for valid than for invalid cues, was significant for both supraliminal and subliminal presentations [Fs(1,25) = 98.64 and 12.63, P values <0.001 and .05, respectively]. Follow-up split analyses also indicated that the simple effect of presentation condition was significant for both valid and invalid cues, with shorter RTs for supraliminal valid cues than for subliminal valid cues and longer RTs for supraliminal invalid cues than for subliminal invalid cues [Fs(1,25) = 7.19 and 37.12, P values <0.05 and 0.001, respectively]. For the head direction condition, only the main effect of validity was significant, indicating shorter RTs for valid than for invalid cues [$F(1,25) = 8.83$, $P < 0.01$].

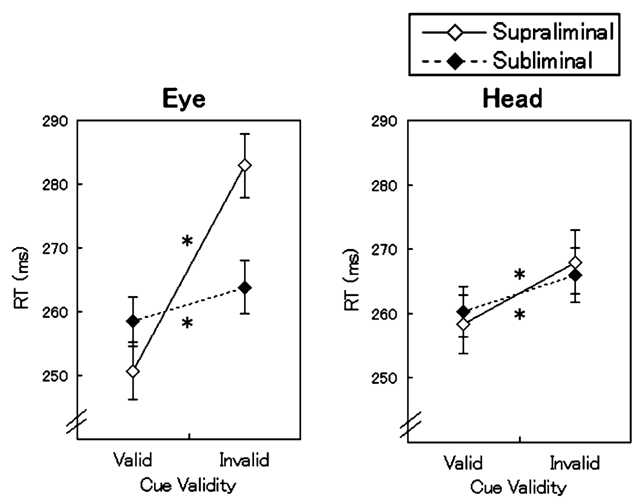

Fig. 4 Mean (with SEM) RTs for eye (*left*) and head (*right*) cue types in Experiment 2. *Asterisks* indicate the significant simple main effect of cue validity, indicating shorter RTs for valid cues than for invalid cues

Error analysis

The mean (±SD) error rates (%) were 0.64 (±1.43), 8.01 (±7.21), 2.78 (±3.85), and 4.70 (±4.63) for valid eye gaze, invalid eye gaze, valid head direction, and invalid head direction under supraliminal conditions, respectively, and 1.71 (±3.52), 2.24 (±2.83), 2.35 (±3.49), and 2.46 (±4.18) for those (in the same order) under subliminal conditions, respectively. For the number of errors, the ANOVA revealed significant main effects of cue validity and presentation condition and significant interactions of cue validity × presentation condition, cue validity × cue type, and cue validity × presentation condition × cue type [$Fs(1,25) = 22.46$, 17.09, 26.43, 17.45, and 5.62, P values <0.001, 0.001, 0.001, 0.001, and 0.05, respectively]. All of the significant main effects and simple main effects regarding cue validity indicated that errors occurred more frequently for invalid than for valid cues. These results suggest that an RT-accuracy trade-off does not explain the RT findings for the effects of cue validity.

Discussion

In the supraliminal condition, valid gaze cues induced shorter RTs than did invalid cues, like in Experiment 1. Both eye gaze and head direction elicited the same effect. These results are consistent with those of previous studies using photo stimuli of eye gaze (e.g., Driver et al. 1999) and head direction (e.g., Langton and Bruce 1999). The visual stimuli used as head directional cues, unlike eye gaze cues, have large asymmetry in terms of luminance, to which the effect of attentional shift might be attributable. However, if this were the case, cuing effects would be larger for head directional cues than for eye gaze cues. Along with similar cuing effects for different types of head directional cues found in previous studies (e.g., Langton and Bruce 1999), it seems difficult to account for the cuing effect based on the asymmetry in luminance.

In the subliminal condition, the RTs for valid gaze cues of both eye gaze and head direction were also shorter than the RTs for invalid cues. These results support our hypothesis that gaze cues can trigger attentional shift without awareness.

As in Experiment 1, an interaction between cue validity and presentation condition was found for eye gaze. For head direction, on the other hand, this interaction did not occur. The discrepancy between the stimulus types suggests the involvement of different process for supraliminal and subliminal eye gaze, but not for head direction. The reason is not clear since there have been few studies on the difference in effects of eye gaze and head direction on attentional shift (e.g., Hietanen 1999). However, our results seem reasonable upon consideration of the evolutionary processes for these physiognomic signals. Ethological studies indicate that the use of face direction in social interactions is evident even in rats, suggesting its long history (Chance 1962). In contrast, anatomical and ethological studies indicate that the use of eye gaze in social interactions is specifically evident in humans compared to other animals, suggesting its recent emergence (Kobayashi and Kohshima 2001). Thus, it is plausible that different neural mechanisms for the processing of head direction and eye gaze may have developed through evolution. Processing for head direction is considered to be primitive in comparison to the more elaborate processing of eye gaze.

General discussion

The results of both experiments consistently indicate that in the subliminal condition, valid gaze cues shortened the RTs relative to invalid cues. These results are consistent with those of previous studies using a gaze-cuing paradigm (e.g., Friesen and Kingstone 1998), which confirmed that gaze cues induced the participants' attentional shift automatically. However, it was heretofore unknown whether this process could occur without the awareness of the gaze. Our results are also in accord with those of previous studies indicating that attentional shift occurs without awareness (e.g., McCormick 1997). These previous studies, however, did not address the issue of the effects of centrally presented non-social or social cues. The present study demonstrates that centrally presented gaze cues can trigger attentional shift without awareness, which extend the boundary of the literature about attentional shift regarding types of cue and awareness.

In a previous neuropsychological study (Vuilleumier 2002), it was proposed that the gaze might not be processed at the preattentive stage. This was based on the data of the right parietal damaged patients who had left visual extinction for bilaterally presented stimuli. When a schematic neutral face with either averted or straight eye gaze direction was presented in the left visual field with a shape in the right visual field, the gaze direction in the face had no influence on the extinction. Regarding this issue, a previous study with the patients with visual extinction using the non-facial pictures such as spiders (Vuilleumier and Schwartz 2001) suggests that the emotional significance of the stimuli enhanced the patients' perceptual awareness. It has been shown that the averted/straight head direction in neutral facial expressions had no effect on the subjective emotion elicitation, whereas the head direction in angry facial expressions modulated the emotional elicitation (Sato et al. 2004). Therefore, there is a possibility that both averted and straight gaze were processed without awareness, having an equivalent ability to direct the attention to the faces, which resulted in the seemingly negative finding of Vuilleumier (2002). Consistent with this idea, our results clearly demonstrated that the averted gaze is processed without awareness. Future investigation on the processing of straight gaze without awareness would elucidate further the nature of preconscious gaze processing.

Our results offer interesting suggestions regarding the cognitive mechanisms for gaze processing. The results consistently indicated that the subjective perception of gaze and attentional shift by gaze could be dissociable. The results also suggested that the supraliminal and subliminal attentional shift triggered by eye gaze might occur through different processing.

We speculate that a plausible neural substrate for the subliminal attentional shift by gaze may involve the subcortical structures including the amygdala. A recent neuropsychological study (Okada et al. in press) revealed that the amygdala is involved in gaze-triggered attentional shift, although subliminal conditions were not tested. Because the amygdala receives visual input from the subcortical pathway via the pulvinar and superior colliculus (Adolphs 2002), it may implement rapid gaze processing even before the generation of conscious awareness. Because the amygdala projects to visual cortices directly and indirectly (Amaral et al. 1992), it can modulate visual processing. Consistent with the notion of subcortical input to the amygdala, some neuroimaging studies (e.g., Morris et al. 1999) reported the activation of the amygdala and its functional connectivity with the pulvinar and superior colliculus in response to subliminally presented facial stimuli. A recent study that measured the effects of gaze cues on saccades also suggested the involvement of the superior colliculus in gaze processing (Nummenmaa and Hietanen 2006).

In contrast, it has been reported that conscious awareness of visual stimuli is implemented in the cortical visual areas (Treisman and Kanwisher 1998). Some neuroimaging studies (e.g., Tong et al. 1998) have reported that the activity of the fusiform gyrus is related to the subjective awareness of facial stimuli. The conscious awareness of gaze may be implemented in the fusiform gyrus, independent of attentional shift. Alternatively, the superior temporal sulcus may be involved in the visual analysis and subjective perception for gaze directional stimuli, since some studies reported the activation of the posterior part of this region in response to averted eye gaze (e.g., Hoffman and Haxby 2000).

Some studies using the supraliminal presentation of eye gaze stimuli have found that other cortical regions are also involved in gaze processing. For example, an fMRI study reported the activation of the superior parietal sulcus and intra parietal sulcus while viewing averted, rather than direct, eye gaze (Hoffman and Haxby 2000). A neuropsychological study (Vecera and Rizzo 2006) reported that damage to the frontal lobe impairs attentional shift by eye gaze. Together with our data, these suggest that multiple neocortical regions might be involved in the conscious processing of eye gaze, in addition to the subcortical structures.

Taken together, we speculate that the unconscious and conscious gaze-triggered attentional shift and conscious perception of gaze may be implemented by the activity of multiple subcortical and cortical neural mechanisms. Future neuroimaging and neuropsychological studies are necessary to evaluate this idea.

There are some limitations to our study. First, we tested only valid and invalid conditions in order to investigate this new issue with as simple a design as possible. It remains unclear whether the effect was a facilitating effect of valid cues, an interfering effect of invalid cues, or both. Studies using a paradigm including neutral cues seem important for further investigation of this phenomenon.

Second, although we assessed the threshold of visual awareness for each participant using subjective measures, it appears possible to assess the threshold for awareness using objective measures (Merikle and Reingold 1998). We used subjective measures because these measures are valid and may be preferable for assessing the presence/absence of awareness (Merikle et al. 2001). In contrast, objective measures usually provide more conservative estimates than subjective measures and could even reduce the likelihood of processing without awareness (Merikle et al. 2001). Future studies using threshold assessments with objective measures would strengthen our findings.

In summary, we found that valid eye gaze and head direction cues, when presented subliminally, shortened the RTs taken to localize the targets relative to invalid cues. These results indicate that attentional shift as a result of another individual's gaze can occur without awareness.

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