RUNNING HEAD: ATTENTION AND AWARENESS OF LOCATION AND IDENTITY

Does Attention Accompany the Conscious Awareness of Both Location and Identity of an Object?

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Abstract

The question of whether consciousness and attention are the same or different phenomena has always been controversial. In trying to find an answer to this question, two different measures for consciousness and attention were used to provide the potential for dissociating between them. Conscious awareness of either the location or the identity of the object was measured as the percentage of correct reports of that aspect. The location of the focus of attention, on the other hand, was determined using the shooting-line illusion (SLI). In the SLI, a static line is perceived as growing from the location of a preceding cue (i.e., the location of the focus of attention). To investigate whether conscious awareness of the location of an object could be dissociated from conscious awareness of its identity, the attentional blink (AB) was used. It is known that during the AB, identification of the second of two consecutively and briefly presented targets (T1 and T2) is impaired if the temporal lag between the two targets is less than about 500 ms. In three experiments, an SLI was induced during the AB to determine whether attention was at the location of T2 when the observer was consciously aware of its location, its identity, or both. Observers were instructed to report the identity and location of the targets, and the direction of the SLI. Three important findings emerged. First, the SLI was seen as growing from T2 only when T2 was identified correctly. Second, observers could report T2 location even when unaware of its identity. Third, the SLI occurred from T2 only when T2 identity – not its location – could be reported correctly. These results indicate that focal attention does not necessarily accompany conscious awareness of some aspects of the object, while it does accompany conscious awareness of its identity.

It can readily be argued that attention and consciousness are tightly interlinked and serve parallel functions in our day-to-day experience. Attention, for instance, is selective, excluding objects or locations that fall outside its focus. Those unattended objects or locations are seen less clearly, processed less well, and reacted to more slowly than they would be if attended. Consciousness can be argued to serve a similar selective function – we are never aware of all of the information available to us in the world, and we are provided with a filtered view of that world by the information that does reach our consciousness.

There is substantial evidence to support the proposal that consciousness and attention are inseparably linked (e.g., Dehaene et al., 2006; Taylor & Fragopanagos, 2007). Consider, for example, the phenomenon of *change blindness* in which observers watch repeated alternations of two versions of a single photograph, in which one element in the photo is different in the two versions. The task is simply to identify what is changing; that change can be quite substantial, such as the disappearance and reappearance of the engine in a photograph of an airplane. It has been shown that in this task, the change is only detected when attention is directed specifically to the element that is changing. In other words, without attention, the element does not reach conscious awareness and hence the change is not detected (O'Reagan et al., 2000; Rensink, 2000; Rensink, O'Reagan, & Clark, 1997; Simons & Levin, 1997; Simons & Rensink, 2005). Mack and Rock (1998) reported the phenomenon of *inattentional blindness* in which objects which are not attended, even when substantial and surprising, do not reach conscious awareness. Given evidence such as this, many have concluded that attention and consciousness are one and the same.

Other scientists and philosophers, however, have questioned whether it is justified to say that attention and consciousness are inseparably linked. Is it really necessary to pay attention to something in order for it to reach consciousness? Can items which have not reached consciousness attract attentional processes? Research has shown that observers can become conscious of an isolated object or the gist of a scene despite the near absence of top-down attention; conversely, observers can attend to perceptually invisible objects which do not reach consciousness (Koch & Tsuchiya, 2007). Along the same lines, stimuli that are attended are not always consciously perceived (Super et al., 2001).

Given the continued debate as to whether attention and consciousness are linked at theoretical and conceptual levels, it is especially difficult to dissociate them at an empirical level (Koch & Tsuchiya, 2007). This is particularly true when one considers the phenomenological diversity of both attention and consciousness as well as the dynamic nature of the attention-consciousness relationship. In this sense, dissociating attention and consciousness is one of the items in the list of fundamental problems in the field. To answer this question, some recent studies have used procedures that manipulate consciousness and attention independently, and the current research follows this trend.

In the present paper, we will build on the distinction between conscious awareness of the location of an object and conscious awareness of the identity of that same object as proposed by Atkinson and Braddick (1989). Further, we will use an index of attention that will enable us to distinguish whether attention accompanies both aspects of conscious awareness (suggesting that attention and conscious awareness are fully linked) or whether conscious awareness of the location of an object and conscious awareness of its identity are differentially accompanied by attention (suggesting that attention and conscious awareness can be dissociated). In determining whether attention accompanies conscious awareness of both location and identity, we employed two separate measures, one for attention and one for consciousness. Specifically, we utilized the attentional blink (AB) paradigm to manipulate the observers' conscious awareness of the identity of an object, and the shooting-line illusion (SLI) to index the location of attention.

In a rapid serial visual presentation (RSVP) when there are two targets (T1 and T2) embedded in a stream of distractors and the task is to report those two targets, a deficit in the perception of the second target is usually observed if the inter-target lag is not longer than about half a second (e.g., Chun & Potter, 1995; Raymond, Shapiro, & Arnell, 1992). Most studies on this phenomenon, known as the attentional blink, have shown that what was *impaired* during the AB was the identification (e.g., Potter, Chun, Banks, & Muckenhoupt, 1998) of the second target. The attentional blink is an ideal tool for

manipulating an observer's conscious awareness of the identity of a stimulus (Sergent, Baillet, & Dehaene, 1995) as the change from being aware of the identity of the stimulus to being unaware of its identity appears to be an all-or-none process (Sergent & Dehaene, 2004). Hence, in the current experiments we used the attentional blink in order to manipulate and measure whether or not the observers were consciously aware of the identity of the target stimuli.

In the current research we used a second phenomenon known as the shooting-line illusion to index the location of attention. In the SLI (Hikosaka, Miyauchi, & Shimojo, 1993a, b), a line that is displayed all at once is perceived as if drawn progressively from one end to the other. A temporally-leading cue – the *inducing stimulus* – is used to orient the observer's attention to one end of the line, and the line then appears to grow from that end. Hence, the SLI is critically dependent on attention being focused at the location of the inducing stimulus, and we can therefore use the occurrence and direction of the SLI to index the location of the focus of attention.

In combining the SLI and the AB to test the interaction between attention and conscious awareness of identity and location, we built on the paradigm developed by Kawahara (2002). In his study, Kawahara presented distractor digits in three separate RSVP streams located at the apices of an imaginary triangle. Two of these streams also contained a letter-target. A line was also displayed simultaneously with T2, and it could appear in one of three locations: 1) between the stream that contained T1 and the stream that contained T2, 2) between the stream that contained T1 and the stream that contained neither target, or 3) between the stream that contained T2 and the stream that contained neither target. The results revealed a pronounced AB deficit in that T2 was identified more accurately at a long inter-target lag than a short inter-target lag. More importantly, observers perceived the line as shooting from the T1-stream regardless of whether the other stream contained T2 or a distractor. This led to the conclusion that T1 acted as a spatial cue, which focused the observers' attention on the location of the T1-stream, thus mediating the SLI.

In this study, we use the same basic method as Kawahara (2002) did, to examine the observers' conscious awareness of the location of the target, conscious awareness of the identity of the target, and whether attention accompanied both forms of conscious awareness. The critical difference between the current experiments and those of Kawahara (2002) is that the inducing stimulus was T2 instead of T1 so that we could use the attentional blink to control whether observers had conscious awareness of the identity of T2. Specifically, at short inter-target lags, observers would not be consciously aware of the identity of T2 whereas at long inter-target lags they would be.

EXPERIMENT 1A

The current research aims to separate the conscious awareness of the identity of a stimulus from the conscious awareness of its location, and to determine whether attention equally accompanies both aspects of conscious awareness. Given that we use the attentional blink in order to achieve this goal, we must first confirm that the SLI can occur in response to a correctly-identified T2 as the inducing stimulus as it did when T1 was the inducing stimulus in Kawahara's (2002) experiment. Hence in Experiment 1A, we ask the participants to report the identity of T1 and T2, and to report the direction towards which they perceive the line as growing. Correct identification of T2 indicates conscious awareness of its identity while the occurrence of the SLI indicates that attention was focused on T2's location.

Method

Observers

Twelve University of British Columbia undergraduates participated for course credit.

Apparatus and Stimuli

Observers viewed a computer display from a distance of 57 cm. The targets (upper-case letters, except for I, O, Q, and Z) and distractors (digits 1-9) subtended 1° of visual angle. All stimuli were white on a black background and were displayed at the corners of an imaginary equilateral triangle inscribed within an imaginary circle of 1.5° radius. A line segment was presented along one of the sides of the imaginary triangle.

Procedure

Each trial began with the presentation of a fixation cross. After a delay of 500-1000 ms, three synchronized RSVP streams were displayed, such that in every frame there was one item at each corner of an imaginary triangle (Figure 1).

The stimuli in each frame were different from one another and from the stimuli in the two preceding frames. Each frame was displayed for 30 ms, followed by an inter-stimulus interval (ISI) of 70 ms during which the fixation screen was displayed. There were 6-10 distractor-frames preceding T1. In three-quarters of the trials, T2 was displayed directly after T1 (in the ordinal position known as Lag 1). This was done to maximize the number of trials on which T2 was likely to be missed. In the remaining trials, T2 was displayed 700 ms after T1 (in the ordinal position known as Lag 7), with intervening distractors continuing to be presented during the longer inter-target lag. T1 and T2 were never presented at the same location on any given trial. The RSVP streams continued for an additional 3-6 frames after T2. On the third frame after T2, the line was presented for 30 ms along one side of the imaginary triangle in one of three possible locations: between the two target-streams (the Inter-Target condition), between the T1- and the distractor-stream (the T1-D condition), or between the T2 stream and the distractor stream (the T2-D condition). At the end of each trial, observers reported the identity of T1 and T2, and were required to judge the direction in which the line appeared to grow. Each observer completed 10 practice trails and 288 experimental trials.

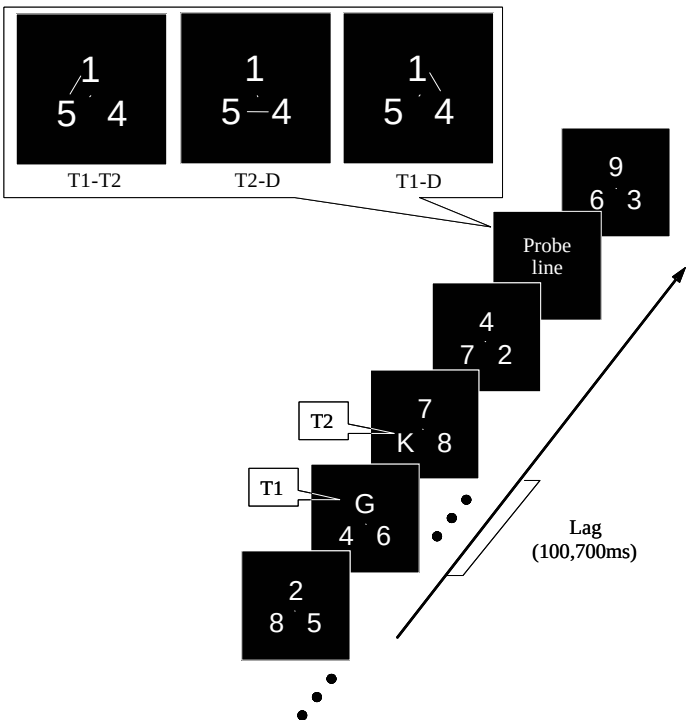

Figure 1. Schematic diagram of the sequence of events in the experiments.

Results and Discussion

Mean accuracy for T1 was 90.3%. Mean accuracy for T2 was 55.6% at Lag 1 and 87.9% at Lag 7. A paired-samples t-test revealed a significant AB deficit, $t(11) = 9.38$, $p<0.001$.

The results for the SLI are summarized in Figures 2a and 2b. The critical issue is whether the line was seen as shooting from the location of the T2 stream on trials in which T2 was correctly identified. As expected, the line was seen as shooting from T2 only on trials in which T2 was identified correctly (Figure 2a), $z = 4.50$, $p < .001$ (T2-D condition), and $z = 3.19$, $p < .001$ (Inter-Target condition). On trials in which T2 was missed (Figure 2b), the line was seen as shooting either *to* or *from* T2, at chance, $z = 0.54$, (n. s., T2-D condition) and $z = 1.17$, (n. s., Inter-Target condition).

The T1-D condition was analyzed to verify that the SLI is obtained from an attended target, whether the target is T1 or T2. As expected, in this condition the line was seen as growing from T1 regardless of whether T2 was identified correctly (Figure 2a; $z = 2.83$, $p < .005$) or incorrectly (Figure 2b; $z = 4.89$, $p < .001$).

This pattern of results strongly suggests that the line was seen as originating from the location of T2 *only* when T2 was identified correctly. In the present experiment, however, we did not analyze the data from Lag-7 trials because of their scarcity. To make sure that the results from Lag-7 trials are in

accordance with the results of Lag-1 trials, in the next experiment the number of Lag-7 trials is increased from one-quarter to three-quarters of trials.

EXPERIMENT 1B

In Experiment 1A, the results from the Lag-7 trials were not analyzed because they comprised only 25% of the trials. Therefore, a separate experiment was conducted in which 75% of the trials were Lag-7 trials. This was done with two objectives in mind. The first objective was to check on the consistency of the SLI at Lag 7 and Lag 1, namely, whether the SLI is obtained only when T2 is identified correctly at Lag 7, as was the case for Lag 1 in Experiment 1A. The second objective was to investigate the temporal course of the SLI across inter-target lags. We expected that by Lag 7 the SLI would no longer originate from the location of T1 because, by that point in time, the attentional focus would be fully relocated from T1 to T2.

Method

Twelve experimentally naïve observers participated in this experiment. The methods were identical to those of Experiment 1A except that on 75% of the trials T2 was presented at Lag 7.

Results and Discussion

Mean accuracy for T1 was 88.4%. Mean accuracy for T2 was 49.6% at Lag 1 and 87.8% at Lag 7. A paired-samples *t*-test revealed a significant AB deficit, $t(11) = 11.7$, $p < 0.001$.

The pattern of the SLI results (Figures 2c and 2d) was similar to that in Experiment 1A, except that the direction of the SLI in the T1-D condition was at chance levels. Namely, there was no tendency to see the line as growing from T1. This is because, by Lag 7, processing of T1 has been completed, and the attentional focus has been repositioned to the location of T2.

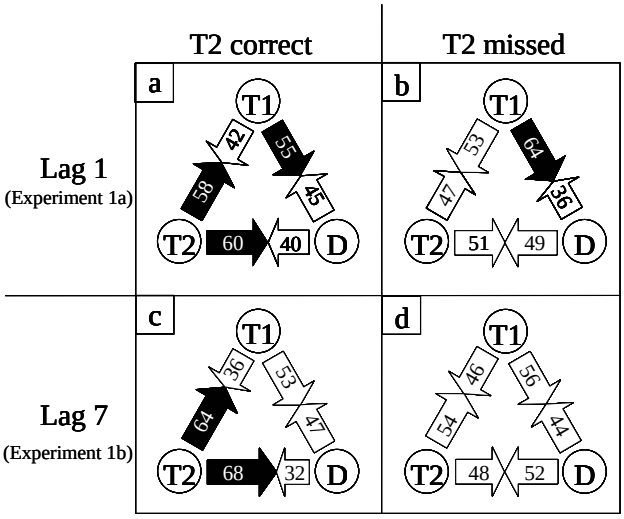

Figure 2. Shooting-Line Illusion results of Experiments 1A and 1B. Each arrow and its number represent the percentage of trials in which the SLI was perceived as originating from the item in the tail of the arrow growing towards the item to which the head is pointing. Arrow pairs in which one arrow is black indicate proportions that are significantly different from chance.

In Experiments 1A and 1B, we observed that the SLI is perceived to originate from the location of T2 when (and only when) the identity of T2 is reported correctly. Hence, in Experiment 1A we confirmed that the SLI can occur in response to a T2 as the inducing stimulus, indicating that when the observer is consciously aware of the identity of T2, attention is focused at T2's location. The goal of the current research is to separate the conscious awareness of the identity of a stimulus from the conscious awareness of its location in order to determine whether attention equally accompanies both aspects of conscious awareness. As such, it is also necessary to assess whether the attentional blink, which renders the observer unaware of the identity of the target at short inter-target lags, can leave the conscious awareness of the location of that target intact. We tested this in Experiment 2, in which observers were required to report not only the identity of T2, but also its location.

If the attentional blink functions in the intended manner, then on some portion of those trials in which the identity of the second target does not reach conscious awareness, the observer should still be consciously

aware of the location of that target. This would be indexed by an incorrect report of T2-identity accompanied by a correct report of T2-location.

EXPERIMENT 2

In Experiments 1A and 1B, we showed that the SLI occurs from T2 only when T2 is identified correctly. The next step is to investigate whether conscious awareness of the location of T2 can occur without conscious awareness of its identity during the AB. If this is the case, we will be able to dissociate the two levels of conscious awareness. To this end, the same stimuli and almost the same procedure as in the previous experiment were used, except that observers were required to report the identity and location of the first and second targets (T1 and T2), and to ignore the line.

Method

Experiment 2 was the same as Experiment 1A, except that 12 observers reported the identity and location of T1 and T2, and were asked to ignore the line. In this experiment, as in Experiment 1A, T2 was displayed directly after T1 (Lag 1) in three-quarters of the trials. In the remaining trials, T2 was displayed at Lag 7.

Results and Discussion

Only trials in which T1 was identified correctly were analyzed. Mean accuracy for T1 was 88.1%. A significant AB deficit was obtained: T2 accuracy was 63.6% at Lag 1 and 87.4% at Lag 7; $t(11) = 7.02$, $p<0.001$.

Of the 36.4% of trials in which T2 was missed at Lag 1, observers reported its location correctly 62.9% of the times. Hence, even when the observers failed to identify T2, they could report its location a significant proportion of the time, $z = 7.10$, $p < 0.001$. It needs to be stressed that T2 could be localized without being identified on a relatively modest proportion of the trials (12.9%) beyond the 50% chance level. To wit, this was a relatively infrequent event. Nevertheless, it exceeded the chance level by a margin that was highly significant, attesting to its reliability. This previously unreported finding strongly suggests that, during the AB, the blinked target is processed to an extent sufficient to extract spatial information but not identity information.

This conclusion may be questioned, however, because when T2 identity was missed but its location was reported correctly, observers might have known that a letter was presented at that location but could not identify it, perhaps because it belonged to a highly confusable pair (e.g. E-F). We addressed this possibility, by constructing a confusion matrix involving all 22 stimulus letters and 22 response letters. Given the above hypothesis, most of the 965 errors (summed over all trials and observers) should involve highly confusable letter pairs, such as E and F. On the contrary, we found that most errors (109) occurred upon presentation of J (confused mostly with D, G, H, R, S, Y) and S (92 errors, confused with H, K, L, T, Y). The letter F was confused with E seven times, and E with F only four times. Clearly, confusions occurred not between similar letter pairs but between letters and digit distractors (J with 1, S with 5 or 8). Notably, errors primarily involved pressing a key in or near the home typing positions on the keyboard. We conclude that correct localization was not an artefact arising from confusable letter pairs.

In general, the conclusion from Experiment 2 is that during the AB, conscious awareness of the location of T2 is sometimes preserved even when conscious awareness of its identity is not. That is, our manipulation for dissociating the two levels of conscious awareness was successful. From Experiment 1A we remember that the SLI is seen as growing from T2 only when the identity of T2 is reported correctly. In other words, the focus of attention accompanies conscious awareness of the identity of an object. By combining Experiments 1A and 2, we investigate whether the focus of attention also accompanies conscious awareness of the location of an object.

EXPERIMENT 3

Experiments 1A and 1B confirmed that the SLI can be used to index whether or not the focus of attention has been shifted to T2. Experiment 2 further established that the attentional blink enables us to separate the conscious awareness of the identity of T2 from the conscious awareness of T2's location. Experiment 3 is the key experiment in this study, and observers were required to report the identity and location of both targets, as well as the direction of the SLI. This allows us to probe whether attention

accompanies the conscious awareness of the identity of T2 (i.e., when T2 is correctly reported) and separately whether it accompanies conscious awareness of the location of T2 (i.e., when T2 was incorrectly identified but correctly localized). If the SLI is seen to emanate from the location of T2 in both cases, attention can be said to accompany conscious awareness of both location and identity; if the SLI is seen to emanate from the location of T2 when it can be correctly identified, but not when it can only be correctly localized, then attention can be presumed to accompany the conscious awareness of the identity of an item, but not the conscious awareness of the location of that item.

Method

Experiment 3 followed the same procedures as Experiments 1A, 1B, and 2, except that the 13 observers reported SLI direction, the identities of the two targets, and their locations, in that order. To maximize the number of trials on which T2 was likely to be missed (the only condition in which conscious awareness of location can be dissociated from conscious awareness of identity), T2 was always presented at Lag 1.

Results and Discussion

Mean accuracy for T1 and T2 was 86.7% and 60.7%, respectively. The results for the SLI are summarized in Figures 3. When T2 was identified correctly, the pattern of the SLI results was similar to that in Experiments 1A and 1B (see Figures 2a and 3a).

The line was seen as shooting from T2 only on trials in which T2 was identified correctly (Figure 3a), $z = 4.89$, $p < .001$ (T2-D condition), and $z = 2.56$, $p < .01$ (Inter-Target condition). Critically, when T2 identity was missed, but its location was reported correctly, the SLI did not originate from T2 (Figure 3b). Specifically, in the Inter-Target condition the line appeared to shoot from T1 ($z = 3.57$, $p < .001$), and in the T2-D condition, the line appeared to shoot either from T2 or from the distractor, at random ($z = 1.57$, $p > .05$). This supports the conclusion that attention accompanies the conscious awareness of identity, but not the conscious awareness of location.

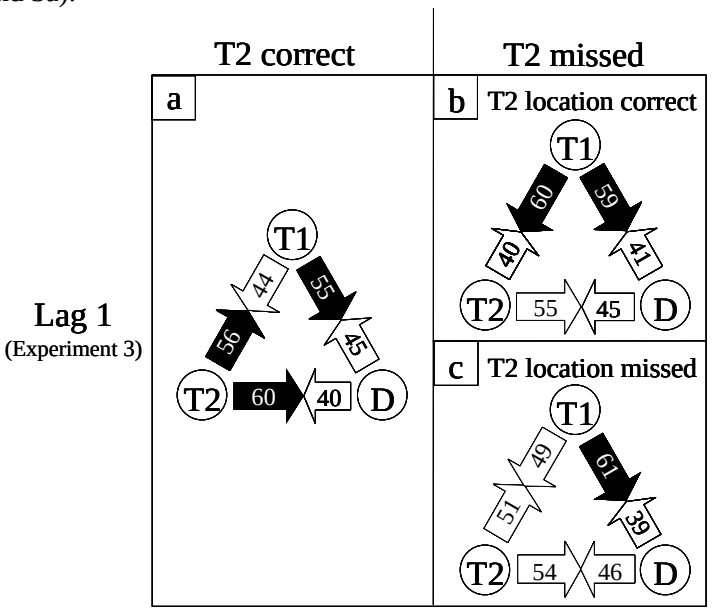

Figure 3. Shooting-Line Illusion results of Experiment 3. Each arrow and its number represent the percentage of trials in which the SLI was perceived as originating from the item in the tail of the arrow growing towards the item to which the head is pointing. Arrow pairs in which one arrow is black indicate proportions that are significantly different from chance.

As expected, in the T1-D condition, the line was seen as shooting from the location of T1 irrespective of T2 report (in Figure 3a, when T2 identity was correct, $z = 2.52$, $p < .01$; in Figure 3b, when T2 identity was missed and when T2 location was correct, $z = 2.16$, $p < .01$; and in Figure 3c, when T2 identity and location were missed, $z = 3.18$, $p < .005$). This pattern of results is consistent with that of Experiment 1A, suggesting that, at shorter inter-target lags, the attentional focus has not fully disengaged from the location of T1 and, therefore, the SLI is perceived as originating from that location.

General Discussion

Two important findings emerged from the present study. First, observers were able to report the location of a target even when they were unaware of its identity. This finding may speak to the issue of whether mental representations are graded (Farah, 2000; Kanwisher, 2001) or all-or-none (Sergent & Dehaene, 2004) in nature. Specifically, given that mental representations of target objects are presumed

to contain both spatial and identity information, and given that the current research shows that spatial information can be independently registered prior to identity information, this suggests that mental representations are graded in nature. As such, an account of our findings can be couched in the finding that coarse spatial information about a target becomes available before its identity (Atkinson & Braddick, 1989; Huang & Pashler, 2007; Sagi & Julesz, 1985). This means that observers would know that a letter had been presented in a given stream (i.e., at a given location) before knowing the identity of that letter. This alone, however, does not explain why observers could report the location of T2 but not its identity. To account for this finding, we need an additional factor: backward masking. In the RSVP stream, T2 was always followed 100 ms later by a mask (the trailing distractor) which interrupted its processing (Breitmeyer, 1984). On trials in which the location of T2, but not its identity, was reported correctly, the mask may have arrived after location information had been extracted but before identity information could be fully processed. Thus, coarse location information escaped masking, but identity information was impaired.

The second important finding was that the SLI was obtained only when T2 was identified correctly. Knowledge of the location of T2 without knowledge of its identity was not sufficient for mediating the illusion. An account consistent with the foregoing discussion can be given in terms of spatial gradients of activation. It has been argued that the SLI results from faster visual processing at the locus of attention (Schmidt & Klein, 1997; von Grunau, Saikali, & Faubert, 1995). It has further been proposed that the mechanism underlying this illusion is a spatial gradient of facilitation that forms around the cue, with the amount of facilitation being greatest at the center of the gradient (Hikosaka, Miyauchi, & Shimojo, 1996). Hence, signals from locations closer to the cue reach the motion sensors in the brain faster than signals from locations farther from the cue. This causes the line to be seen as growing from the end closer to the cue.

The gradient of facilitation has been shown to develop gradually: It begins by being relatively shallow, and becomes progressively steeper as a function of processing time since the presentation of the cue (Miyauchi, 1997). Our account of why the SLI was not seen when T2 was missed is based on two assumptions. First, we assume that the arrival of the mask cuts short both the identification of T2 and the development of the spatial gradient. Second, we assume that the rate at which the gradient develops and T2 is processed fluctuates from trial to trial. On these assumptions, we suggest that, on trials in which T2 was missed, processing was relatively slow, and the mask interfered with both T2-identification and the developing gradient of facilitation. As a consequence, the gradient did not develop to the required steepness, and the illusory motion from the location of T2 failed to be seen. In contrast, on trials in which T2 was identified correctly, we assume that processing was faster thus allowing the gradient of facilitation to develop to a steepness capable of mediating the SLI before the arrival of the mask.

The principal objective of this study was to investigate whether conscious awareness of an aspect of the object – in this case, its location – could be attained before attention was oriented to that location. To this end, two operational definitions and thus, two different measures were used for consciousness and attention. We measured conscious awareness of the aspect of the object by the percentage of correct responses to that specific aspect (e.g., location or identity), and we found the location of the focus of attention by determining where the SLI originated from. Combining these two different measures for consciousness and attention provides the potential for dissociating between consciousness and attention, and for investigating whether focal attention accompanies conscious awareness of the location or of the identity of an object, or both. As discussed above, the results showed that the conscious report of the location of an object can take place before either attention to that location or the conscious report of the identity of that object can occur.

On the face of it, this conclusion seems to be consistent with the model suggested by Lamme (2003). In his model, Lamme proposes that observers are conscious of a great deal of visual input, but only at a “phenomenal” level (Block, 1996). Of those visual inputs, some that are related to the task at hand go through the attentional processes for selection. Only a subgroup of the attended stimuli, however, will reach consciousness at the “access” level. In the current study, though, it is shown that some aspects of the object can reach access awareness even before attentional processes are involved.

This leads us towards the more fundamental questions such as whether attention and consciousness are each a unitary phenomena or whether they each consist of several different aspects. To address these questions, before proposing detailed functional imaging studies, careful examinations of phenomenological and behavioural effects are warranted. This is because differential brain processes do not necessarily mean differences in subjective phenomenology and behaviour. Only after we sort out phenomenological and behavioural effects can we map those into brain processes.

References

Atkinson, J. & Braddick, O. J. (1989). 'Where' and 'what' in visual search. Perception, 18, 181-189.

Block, N. (1996). How can we find the neural correlate of consciousness. Trends in Neurosciences, 19, 456-459.

Breitmeyer, B. G. (1984). Visual masking: An integrative approach. New York: Oxford University Press.

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. Journal of Experimental Psychology: Human Perception and Performance, 21, 109-127.

Dehaene. S., Changeux, J-P., Naccache, L. (2006). Conscious, preconscious, and subliminal processing: A testable taxonomy. Trends in Cognitive Sciences, 10, 204-211.

Farah, M. J. (2000). The cognitive neuroscience of vision. Oxford, England: Blackwell.

temporal order and motion sensation. Vision Research, 33, 1219-1240.

Hikosaka, O., Miyauchi, S., & Shimojo, S. (1993b). Voluntary and stimulus-induced attention detected as motion sensation. Perception, 22, 517-526.

Hikosaka, O., Miyauchi, S., & Shimojo, S. (1993a). Focal visual attention produces illusory

Hikosaka, O., Miyauchi, S., & Shimojo, S. (1996). Orienting of spatial attention - its reflexive, compensatory, and voluntary mechanisms. Cognitive Brain Research, 5, 1-9.

Huang, L. & Pashler , H. (2007). A boolean map theory of visual attention. Psychological Review,114, 599-631.

Kanwisher, N. (2001). Neural events and perceptual awareness. Cognition, 79, 89-113.

Kawahara, J. (2002). Facilitation of local information processing in the attentional blink as indexed by the shooting line illusion. Psychological Research, 66, 116-123.

Koch, C. & Tsuchiya, N. (2007). Attention and consciousness: two distinct brain processes. Trends in Cognitive Sciences, 11, 16-22.

Lamme, V.A.F. (2003). Why visual attention and awareness are different. Trends in Cognitive Sciences, 7, 12-18.

Mack, A., & Rock, I. (1998). Inattentional Blindness. MIT Press.

Miyauchi, S. (1997). Attentional systems and consciousness. In N. Osaka (Ed.), Brain and Consciousness, pp. 146-164. Tokyo: Asakura Shoten. (In Japanese).

O'Regan, J.K, Deubel, H., Clark, J.J., & Rensink, R.A. (2000). Picture changes during blinks: looking without seeing and seeing without looking, Visual Cognition, 7, 191–211.

Potter, M. C., Chun, M. M., Banks, B. S., & Muckenhoupt, M. (1998). Two attentional deficits in serial target search: The visual attentional blink and an amodal task-switch deficit. Journal of Experimental Psychology: Learning, Memory, and Cognition, 24, 979-992.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? Journal of Experimental Psychology: Human Perception and Performance, 18, 849-860.

Rensink, R.A. (2000). Seeing, Sensing, and Scrutinizing. Vision Research, 40, 1469-1487

Rensink, R.A., O'Reagan, J.K., & Clark, J.J. (1997). To see or not to see: The need for attention to perceive changes in scenes, Psychological Science, 8, 368-373.

Sagi, D. & Julesz, B. (1985). "Where" and "What" in vision. Science, 228, 1217-1219.

Schmidt, W.C. & Klein, R.M. (1997). A spatial gradient of acceleration and temporal extension underlies three illusions of motion, Perception, 26, 857-874.

Sergent, C., Baillet, S., & Dehaene, S. (1995). Timing of brain events underlying access to consciousness during the attentional blink, Nature Neuroscience, 8, 1391-1400.

Sergent, C., & Dehaene, S. (2004). Is consciousness a gradual phenomenon: Evidence for an all-or-none bifurcation during the attentional blink, Psychological Science, 15, 720-728.

Simons, D.J. & Levin, D.T. (1997). Change Blindness, Trends in Cognitive Sciences, 1, 261-267.

Simons, D.J., & Rensink, R. (2005). Change blindness: Past, Present, and Future, Trends in Cognitive Sciences, 9, 16-20.

Supèr, H., Spekreijse, H., Lamme, V.A.F. (2001). Two distinct modes of sensory processing observed in monkey primary visual cortex (V1). Nature Neuroscience, 4, 304-310.

Taylor, J.G., & Fragopanagos, N. (2007). Resolving some confusions over attention and consciousness. Neural Networks, 20, 993-1003.

von Grunau, M., Saikali, Z., Faubert, J. (1995). Processing speed in the motion-induction effect. Perception, 24, 477-490.

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