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Attention encourages directional suppression in bivectorial motion fields*

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Two experiments were performed to examine attentional suppression in transparently moving dot fields. One of the dot groups were moving coherently in a single direction (effector) and the other were moving randomly (contender). A proportion of the random dot group occasionally moved coherently in the orthogonal direction to the effector during motion adaptation period. In 'passive' condition, observers viewed the stimulus without performing any task. In 'attentive' condition, they were asked to attend to the occasional coherent motion in the contender by reporting the motion direction. The motion aftereffect for the effector was significantly reduced in the attentive condition compared to that in passive condition. This reduction was present even when the proportion of coherent dots in the contender was zero. The similar results were observed when the occasional coherent motion in the contender was 30 deg apart from the effector, which is well within the range of motion integration. These results show that attention to one component of bivectorial motion results in strong suppression of the unattended component as well as enhancement of the attended one. Such suppression in the small angle difference implies that attention to one of the superimposed motion components encourages segregation between different directions rather than integration.

Key words : attention, bivectorial motion, motion aftereffect

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Although the vast majority of objects in ordinary environments are stationary most of the time, the ones that move grab our attention immediately and more forcefully than other things (Palmer, 1999). Detecting motion requires neither foveal fixation nor mental effort. Partly because of this automatic and immediate perception of motion, visual motion processing has been traditionally considered as a low-level, pre-attentive process, differentiated from the higher, cognitive processes that are influenced by observers' attention (Treisman and Gelade, 1980; Nakayama and Silverman, 1986). However, people can experience different percepts when looking at the same moving object, depending on their current goals. For example, imagine two people viewing a tree swaying in the wind. One is attempting to measure the force of the wind and the other is planning to take a photograph of the landscape. The former will have attention focused mainly on the local movement of leaves, whereas the latter will look at the more global movement of the tree. Even though the visual images on the retinas of these two people are the same, their awareness of the tree's motion would be different (Raymond, 2000).

During the last two decades, there has been an enormous body of psychophysical (e.g., Chaudhuri, 1990; Lankheet & Verstraten, 1995; Raymond, O'Donnell, & Tipper, 1998; Alais & Blake, 1999; Sohn, Papathomas, Blaser, & Vidyánszky, 2004), electrophysiological (e.g., Treue & Maunsell, 1996; Treue & Maunsell, 1999; Busse, Katzner, & Treue, 2008; Wanning, Rodríguez, & Freiwald, 2007), and imaging (e.g., O'Craven, Rosen, Kwong, Treisman, & Savoy, 1997; Rees, Frith, & Lavie, 1997) studies revealing attentional modulation in motion perception. Among these, the studies that used multiple motion directions in the same visual location (e.g., Lankheet & Verstraten, 1995; Alais & Blake, 1999; Treue & Maunsell, 1996; 1999; Valdés-Sosa, Cobo, & Pinilla, 1998; 2000; Sohn et al., 2004; Wanning et al., 2007) demonstrated that particular directional signals can be attentional targets. When two sets of randomly located dots drifting in different directions are presented within the same visual space, one perceives two separate global motions that are superimposed in a transparent manner (Snowden & Verstraten, 1999). Such stimulus prevents the possibility that the observers select one of the motion components based on different spatial distribution of resources. Limited dot lifetime that is common in such displays also makes it difficult for observers to relate each dot element to a fixed location. As for properties other than spatial distribution, using simple random dots eliminates the difference in features such as spatial frequency, orientation, or color. The two sets of dots are differentiated only in terms of motion direction, and the attentional targets in a bivectorial dot field are perceptual groups defined by moving directions.

To probe the visual system's response to motion depending on attetntional states, I used a phenomenon called motion aftereffect (MAE). The MAE refers to the illusory motion percept following prolonged observation of a regularly moving stimulus (Wohlgemuth, 1911; Wade & Verstraten, 1998). The MAE involves the perceived motion of a stationary stimulus in the opposite direction to the previously observed motion. It can also cause a change in the apparent velocity of a moving stimulus. One common explanation of visual aftereffects is that multiple analyzers are tuned to different values along the dimension of interest, and that aftereffects are the result of selectively desensitizing analyzers that are sensitive to the adapting stimulus (Graham, 1989). In the case of motion perception, adaptation to a certain motion direction desensitizes direction-selective neurons that are sensitive to that particular direction. This causes an imbalance between responsiveness of the neurons tuned to multiple directions, resulting in illusory motion perception in the direction opposite to that of the adapting motion. The strength of the MAE can be measured by its duration, the directional shift away from the adapted direction, or the amount of contrast or coherence that is needed in the opposite direction to the MAE to abolish the illusory motion. It is generally agreed that the larger the MAE is, the more the observed directional component has been processed. In the current study, using the motion aftereffect (MAE) as a tool, I attempted to characterize two aspects of attentional effects in the perception of bivectorial motion.

Enhancement and suppression in attentional modulation

In bivectorial dot fields, attending to one motion direction during adaptation changes the resulting MAE strength (Lankheet & Verstraten, 1995) or direction (Alais & Blake, 1999) toward the opposite direction to the attended motion component relative to the unattended one. These MAEs reflect relative strength in the processing of two motion components during adaptation, depending on the locus of attention. Alais & Blake (1999) argued that the attentional effects measured by the MAE direction in their study were the results of the enhanced neural responses that are selective to the attended direction. In their experiment, observers adapted to a dot field, where the half of dots were moving in one direction and the other half moving randomly. During adaptation, they were asked to detect a briefly inserted motion component among the randomly moving dot group. The direction of resulting MAE was shifted toward the opposite direction to the attended direction of the two adapting vectors, compared to the passive viewing condition. The amount of MAE shift depended on the strength of the attended motion component: attentional effects were the highest around the signal strength that was just detectable, whereas little effects were observed when the signal strength of the attended direction was below detection threshold or when the motion direction was detected very easily. The authors concluded that attention can effectively enhance the processing of directional signals with intermediate strength (22% directional coherence in their study), and that attention cannot have much effect on strong signals that are easily detected without allocating much attention, or on motion signals that are not perceptually detectable.

It has been proposed that attention may not only enhance the processing of the attended stimulus, but it also suppresses that of the unattended stimulus at the same time, especially when two stimuli are competing within the same visual space (Desimone & Duncan, 1995). Let us reconsider the results of Alais & Blake (1999) from the viewpoint of suppression effects of attention. Suppose that observers were trying to detect brief dot bursts by engaging considerable amounts of attention, even when the signal strength was zero or below the detection threshold (conventionally the signal strength where observers' detection performance was at 75%). In this case, even though there is no percept of a direction that can be enhanced by attention, observers ' attention may still be drawn away from the unattended motion component and neural responses to the unattended component may be reduced. This potential suppression without enhancement of the attended directional component might not be well demonstrated in the MAE direction. When the signal strength of the attended component is 0%, since there exists no physical directional component to alter the resulting MAE direction, any observed directional MAE would be opposite to the unattended directional component in both passive and attentive viewing conditions. Therefore, the MAE direction would remain unchanged in the attentive condition compared to the passive, but the strength of the MAE for the unattended direction may have been reduced because attention was still drawn away from the unattended component. The processing of the unattended component may be assessed by measuring MAE strength selectively for the unattended direction.

Using the MAE nulling method (Hiris & Blake, 1992), the two experiments were designed to measure the processing of the unattended motion component in a bivectorial dot field. I introduced a similar stimulus configuration as the one used in Alais & Blake (1999). During adaptation, there were two populations of random dots. Half of them drifted in one direction (0 deg) throughout the adaptation, and the other half moved randomly without any biased direction. However, occasionally, a subset of dots in the latter population moved in the direction of either +90 or -90 deg for a brief period as a burst (figure 1). When the attended direction was balanced over the adaptation period, unlike in the study by Alais & Blake (1999), the resulting MAE direction would be always opposite to the motion in 0 deg (180

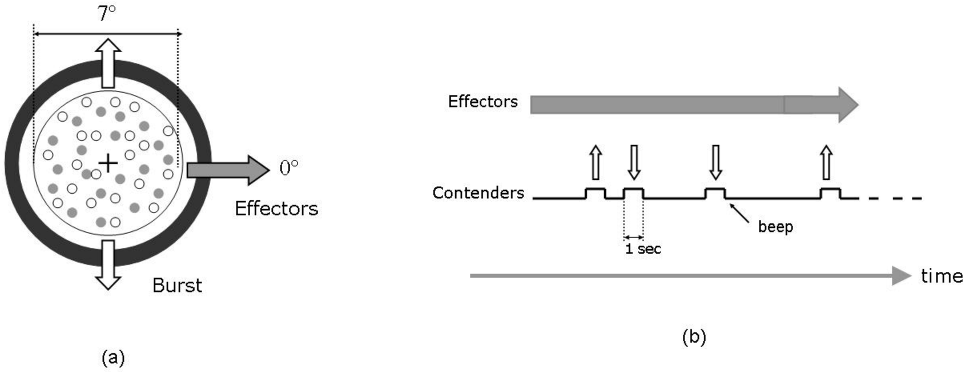


Figure 1. Schematic diagrams of stimuli used in experiment 1.(a) The adapting stimulus. Half of random dots (effectors), shown as gray, moved in one direction (0°) coherently with a speed of 2.5° per sec. The other half (contenders), shown as white dots, moved incoherently, but occasionally a proportion of this group moved as a burst coherently either in +90° or in -90° (±30°,in experiment 2), for a brief duration. The background inside the aperture was actually black. (b) Changes in effectors and contenders throughout the adaptation. The grey arrow indicates the effector dot group, and the small white arrows indicate the direction of bursts. Each burst lasted for one sec. Only ±90° burst in experiment 1 are shown here. In the attentive conditions, a short auditory beep was presented after each burst, in order to induce observers' responses.

deg). In such display, the MAE nulling strength for the direction of the aftereffect reflects the strength in the processing of the unattended directional component. If there is an attentional suppression regardless of the presence of the attended direction, one should observe attentional effects even when there is no perceived motion in the attended direction.

Directional separation between two vectors

I employed two different kinds of bursts in experiment 1 and 2. Whereas the attended and unattended directions were orthogonal in experiment 1, they were differed by 30 deg in experiment 2. Interactions between different directional components in various ranges have been often questioned in superimposed dot fields. Watamaniuk and his colleagues (1989) showed that the mean direction of a random dot display could be judged with a high accuracy, in the distribution of the motion vectors over a range of up to 120 deg. Interestingly, Snowden (1989) showed that direction discrimination was strongly hampered by the simultaneous presence of orthogonal motion, which falls in the range of global directional integration in Watamaniuk et al. (1989). The difference in directional interactions in different studies may be due to different tasks. Depending on what they are asked to do, integrating or segmenting, observers show high accuracy in detecting the mean or individual directions (Braddick & Qian, 2001). However, even when observers performed a task on global directions, they were aware of diverse local motions existing within the global flow, as in the real-world example of a flock of flying birds. The human visual system may have access to the whole distribution of local motion vectors, and can perform different operations upon it, depending on the visual task the observer is currently performing.

The perception of two superimposed vectors forming an acute angle is particularly interesting. Humans successfully perceive two distinct transparent directions not only at an angle difference of 90 deg or larger, but also at an angle as small as 10 deg (Mather & Moulden, 1980). However, population responses in motion processing area MT to transparent motion patterns appear differently, depending on whether the vectors are apart by amounts larger or smaller than 90 deg. Population activity of MT cells to perceptually transparent directions at an acute angle produces a merged unimodal distribution as a function of cells' preferred directions, while it generates a bimodal distribution to patterns containing two directions at an angle larger than 90 deg (Treue, Hol, & Rauber, 2000). This implies that, although two directions are perceptually well distinguished with an angle difference both smaller and larger than 90 deg, neural responses to these motion components may interact in a manner dependent on the amount of directional difference between the two components.

Suppressive interactions in MT cells may exhibit the kind of dynamics that depend on the directional difference of multiple vectors. Snowden et al. (1991) measured tuning curves of the suppressive effect on responses of MT cells to dots moving in the preferred direction, from another set of dots moving in a different direction. The suppression tuning curves had a width of 90 deg, which implies that MT cells show strong suppression for two directions differing by more than 90 deg and less suppression when the angular difference is smaller (Braddick & Qian, 2001). Interestingly, the direction that was apart less than 90 degree from the preferred direction caused the cell to reduce its responses when the two directions were presented together, but the very same direction generated considerable amount of activation when presented alone.

When attending to one of the superimposed vectors at a small angle such as 30 deg (experiment 2), which process would be facilitated, integration or suppression? If attention operates on directions with fine scales as the perceptual segmentation does (down to 10 deg difference according to Mather & Moulden (1980)), suppression mechanisms, rather than integration, would be facilitated. In this case, attention to one of the two adapting vectors will enhance the processing of the attended direction and suppress that of the unattended at the same time. As a result, the observed strength of the MAE for the unattended component would be smaller than that from the passive condition. Alternatively, if attention functions on the population responses of MT cells to multiple directions (Treue et al., 2000), integration processing may be facilitated by attention to one of the motion components that are apart at an acute angle. This integration mechanism will enhance the processing of the unattended direction as well as the attended one, because the two vectors are within a range that generates a single peak of the population activities in MT. If this is the case, the reduction in MAE strength for the unattended component would not be observed with attention to the directional burst.

General Method

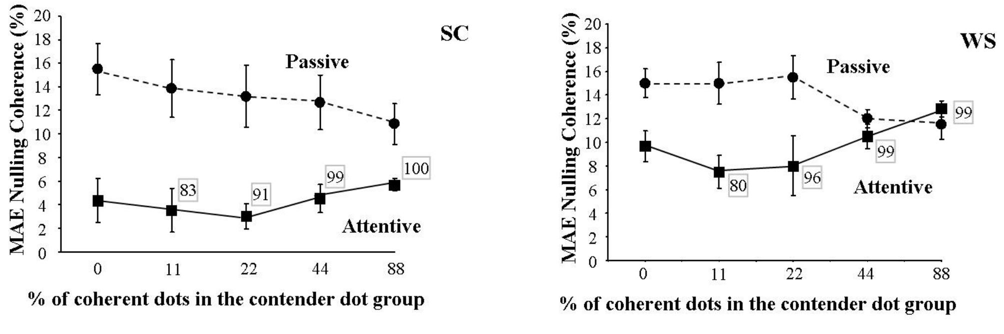
Observers Two observers, including the author (WS), participated in experiment 1 and 2. Both observers had previous experience in psychophysical experiments, and observer SC was not aware of the purpose of the experiments.

stimuli Each trial consisted of two parts: Motion adaptation and MAE test. During adaptation, an aperture (7 deg diameter in visual angle) surrounded by a bullseye pattern (Day & Strelow, 1971) contained a central fixation cross and two populations of random dots, moving with the same speed (2.5º per sec) in different directions (figure 1). Each dot was 2.1 min arc in visual angle and had limited life time (104 msec). After each dot's life time expired, it was re-located in a random position within the aperture. Half of the dots (8.5 cd per m^2; n=100) moved coherently in one of four directions; up, down, left, or right. This group of dots was named "effector" because it is responsible for generating any directional MAE during the test interval. The other half, 'contender' (17cd per m^2;n=100) moved randomly most of the time. However, occasionally a subset of contender dots moved coherently for a brief duration (1s) as a 'burst'. Burst direction was ±90 deg (experiment 1) or ±30 deg (experiment 2) (figure 1a), with respect to the effector's direction. The proportion of the burst dots within the contender dots was varied from 0 to 88% with a logarithmically spaced interval with respect to the known threshold for burst detection in a similar display (Alais & Blake, 1999). The number of bursts in the direction of +90 and of -90 (+30 and -30 in experiment 2) were the same during adaptation, so as not to bias the global direction of the moving dots over time (figure 1b). After adapting to this display, the resulting MAE direction is opposite to the effector's direction. Stimuli during the MAE test consisted of randomly moving dots and biased dots in the same direction as the motion of the effector population. All dots had the same luminance (8.5 cd per m^2;n=200).

procedure Observers viewed the superimposed motions of the two populations of dots during the adaptation period. There were eight bursts during the 32 sec of the initial adaptation period and four during the 16 sec of following re-adaptations. In the passive condition, observers simply fixated at the central cross without performing any task. In the attentive condition, observers reported the burst's moving direction, e.g., either +90 deg or -90 deg (+30 deg or -30 deg in experiment 2) in the case when effector's direction was 0 deg. Right after each burst was presented, a brief auditory beep was presented to compel the observers to report the direction of the burst even when they were not certain (figure 1b). A blank screen was presented for 600 ms between adaptation and test stimuli. After a 1.5 sec of the test interval, observers reported the direction of the test stimulus in a two-alternative forced-choice (2AFC) paradigm; the same direction of the effector population, or the opposite. The MAE nulling threshold was obtained by a staircase procedure (Levitt, 1971). Specifically, when observers reported the direction of the test stimulus in the opposite direction to the effector, the number of the coherent dots moving in the effector direction was increased. Conversely, when the observer's response was in the same direction as the effector, the number of coherent dots was decreased. The percentage of coherent dots that were adequate to null the MAE (i.e., where a half of observers responses favored effector direction and the other half favored the opposite direction) was taken as the nulling threshold and considered as the MAE strength. Six staircases per each condition were carried out for each observer.

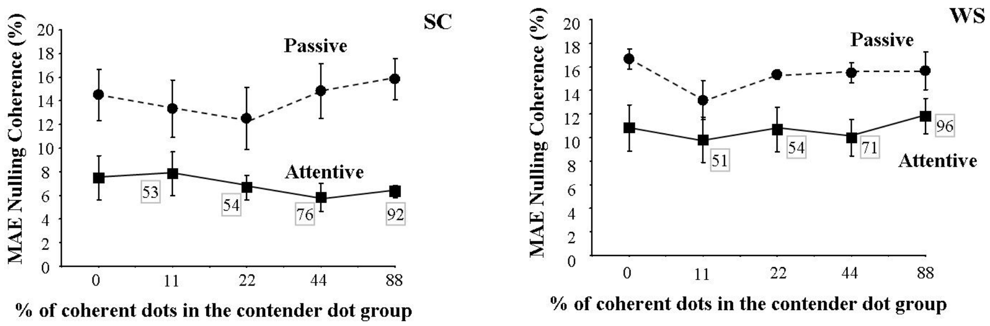
Results

There was no significant effect observed due to the direction of the effectors (up, down, left, or right), and therefore, the data from the same burst conditions with different effector directions were combined. In the passive condition of the two experiments, the mere presence of the bursts had little influence on the MAE strength for the effectors as a function of the burst coherence (The slope of the regression lines were not significantly different from 0, except for 90 deg burst condition in observer WS. $b = -0.05$, $p < .05$). In both experiments with ±90 and ±30 deg bursts, observers showed different amounts of the MAE for the effector direction, depending on attentional states (solid and dotted lines in figure 2 and 3). The MAE of the effectors was generally reduced when observers attended to the bursts in either ±90 deg or ±30 deg, compared to the passive viewing condition. This reduction was present even when the proportion of burst dots was zero (A two-tailed t-test on six thresholds for each subject showed significant difference, $p < .05$). The average attentional effects measured by the difference in log thresholds between the passive and attentive conditions were larger in experiment



(a) (b)

Figure 2. The results of experiment 1. The MAE nulling strength is shown as a function of burst coherence within the contender dot group. The vertical bar on each dot point is the standard error of the mean from six staircases. Dotted line indicates passive viewing condition and solid line shows attentive condition. The numbers inside the small boxes indicate the accuracy in direction discrimination for the bursts. Results from two subjects (SC and WS) are shown in (a) and (b).



(a) (b)

Figure 3. The results of experiment 2. The notations and formats are the same as in figure 2.

1 (.50 and .18 for SC and WS respectively) than those in experiment 2 (.34 and .15 for SC and WS) for both observers. The burst condition where both observers showed the largest attentional effects is 22% condition in experiment 1 and 44% in experiment 2.

The direction discrimination performance in attentive conditions was generally lower with 30 deg bursts (the average performance was 68.8% for both observers), compared to that for orthogonal bursts (the average performance was 93.3 and 93.5% for the observer SC and WS respectively).

Discussion

When attention is allocated to a certain stimulus in the visual field, it facilitates the processing of the attended stimulus and inhibits the unattended stimulus at the same time. In the above two experiments, I investigated the effect of attention on the unattended stimulus by measuring the MAE nulling strength for the direction of the coherent motion component (effector). In both experiments, attention drawn away from a certain directional component reduced the MAE strength for that direction even when the attended direction was not perceived. These effects were observed whether the attended component formed an orthogonal or an acute angle to the effector. In addition to the role of attention in enhancing the processing of the attended motion vector in a bivectorial dot field (Alais & Blake, 1999), the attentional effects observed in the present experiments imply that attention also takes part in suppressing the unattended motion component.

The effects of signal strength on attentional modulation

Consistent with Alais & Blake (1999), experiment 1 showed that attentional effects were the largest when the burst was presented with intermediate strength (22% in figure 2). Several studies (Martinez-Trujillo & Treue, 2002; Reynolds, Pasternak & Desimone, 2000) reported that attentional modulation is most efficient when the stimuli are at low or intermediate intensities where the evoked neural responses are not saturated. Attentional effects are also known to be influenced by attentional loads that can be manipulated by task difficulty (Rees et al., 1997; Lavie, 1995): the harder the attentional task is, and therefore consuming more attentional resources, the larger the attentional effects are. Both reports, on signal strength and on task difficulty, can explain attentional effects depending on the burst coherence observed in experiment 1. Changing the coherence of bursts may create changes in task difficulty that might lead to changes in attentional effects. When the strength of the burst is weak, it becomes harder to discriminate the direction of the burst (see the number next to each data point in figure 2 and 3, for the burst discrimination accuracy). Given the interaction between stimulus intensities and task difficulty, it is not clear which one of the two factors, the stimulus strength itself or the different amounts of engaged attention in the tasks with different difficulties, is the one that produced the difference in attentional effects at different burst coherences.

In both experiments, considerable amount of attentional effects were observed in the conditions where burst coherence was 0% or when the discrimination performance was at a chance level (the conditions with burst coherence 11% and 22% in experiment 2 for both observers. See figure 3). It is worth pointing out that the *direction* of the MAE was not affected under similar conditions (Alais & Blake, 1999). This comparison is important, not only because it demonstrates the attentional inhibition in the processing of the effector, but also because it leads to a question: what actually produced this inhibition without a percept of the attended direction? Specifically, if there did not exist any detectable (or physical) motion component in the to-be-attended direction, where was attention directed? One possibility is that observers' expectation of the appearance of the attended direction itself took some of attentional resources and limited the processing of the effector. Constant vigilance for occasional bursts during adaptation may have resulted in the decreased MAE for the effector direction.

The other possibility is that attention may have been assigned not only to the pre-instructed direction itself, but also to the randomly moving dots as a group, where the anticipated directional signal appeared. This is quite likely if observers strategically maintained considerable amount of attention on the contender. If attention was constantly directed to the whole group of randomly moving dots during adaptation, not just to the briefly inserted coherent directional signals, it explains that the processing of the effector component was reduced even when bursts were not presented or identified. According to Edwards and Nishida (1999), directionless random motion is sufficient to suppress the processing of another motion component. Randomly moving dots contain all the possible directions and therefore attention allocated to this dot group may have enhanced the neural responses selective to all directions equally, while reducing the processing of the effector direction. Recent studies on attentional modulation on bivectorial dot fields (Sohn et al., 2004; Wanning et al., 2007) suggest that attentional targets in such displays are motion-defined surfaces rather than motion direction itself. It is an interesting question whether a visual stimulus that is physically present and consciously perceived is necessary, or anticipation for a certain stimulus is enough to draw attention away from another visual stimulus.

The effects of separation between two motion vectors

In the present experiments, when attention was directed to one of the directional components, both 90 and 30 deg bursts reduced the processing of the unattended direction (solid lines in figure 2 and 3) although such reduction was hardly observed without attention (except 90 deg burst condition in observer WS where the linear regression line was significantly different from zero in the passive condition). This result may be interpreted as that attention facilitates segmentation rather than integration between multiple vectors located in the same visual space, even when the two components are within the range that can be integrated in a single global direction.

It may be worth to compare the general trends in attentional effects as a function of the burst coherence in two experiments (figure 2 and 3). The attentional effects observed in experiment 1 are the largest with the burst coherence 22%, whereas those in experiment 2 do not show much difference over different burst coherences. Such difference may be due to different interactions across various directions and accompanying different task difficulties in direction discrimination. It is reasonable to assume that two motion vectors with a 30 deg difference are more easily integrated than those with a 90 deg difference. Therefore, segregating two directions in the former case would be harder than the latter. Attentional effects are larger with difficult tasks than with easy one (Rees et al., 1997; Lavie, 1995). Observers' performances for burst direction discrimination (compare the performances with same burst coherence in figure 2 and 3) reveals that discriminating the ±30 deg component from the effector was harder in general, across various signal strengths, than discriminating ±90 deg. This may explain the relatively constant attentional effects in experiment 2, compared to the diminished attentional effects with higher burst coherence in experiment 1. In order to further investigate the influence of directional separation between two vectors on attentional suppression, one would need to equate the task difficulties with different directional bursts.

Conclusions

Although recent reports on attentional modulation in motion perception have changed the traditional views on motion as an obligatory, pre-attentive process, more specific aspects of visual motion processing that are influenced by attention have not been fully investigated. Using MAEs, the present study examined the way attention functions in processing multiple motion vectors. In two experiments, attentional effects resulting from directing attention to one of two superimposed motion vectors (contender) were assessed by measuring the processing of the unattended motion vector (effector). The reduced processing of the effector appears as the combination of enhancement of the contender and inhibition of the effector. The result that attention to the 0% coherent contender still reduced the MAE for the effector direction suggests that random motion as a grouped surface, rather than a particular direction, was the attentional target in the current study, which is in agreement with some recent studies (Sohn et al., 2004; Wanning et al., 2007).

The reduced processing of the effector component was observed whether attention was directed to the component that was orthogonal to the effector, or one that formed a 30-deg angle. The difference in the magnitude of MAE reduction between experiment 1 and 2 may be due to the difference in directional suppression between different angle differences or to different task difficulties. Equating task difficulty in these two stimuli is necessary to differentiate these two possibilities.

Selective attention to one of the two superimposed vectors appears to bias our visual system toward segregation, rather than integration, of the two dot groups, resulting in suppression between the vectors even when they are differed by an acute angle that can be easily integrated into a single global direction.

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중첩된 운동 자극에서 주의에 의한 운동 벡터들 간의 상호 억제

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동일한 공간에 중첩된 무선점 운동 자극의 지각에서 억제적 주의 효과를 알아보기 위해 두 개의 실험을 하였다. 무선점들 중 반은 한 방향으로 움직였고(효과 집단), 다른 반은 각각 무선적인 방향으로 운동하였다(방해 집단). 운동 순응 기간 동안 간헐적으로 방해 집단의 점들 중 일부 점들은 효과 집단의 점들이 움직이는 방향과 직교하는 방향으로 움직였다. 통제 조건에서 관찰자는 운동 순응 기간 동안 아무 과제 없이 자극을 바라보았고, 주의 조건에서는 직교 방향으로 운동하는 점들을 탐지함으로써 주의를 기울이도록 지시받았다. 효과 집단 방향에 대한 운동 잔여 효과는 통제 조건에 비하여 주의 조건에서 감소하였다. 두 주의 조건 간 잔여 효과의 차이는 방해 집단 점들 중 0%가 직교 방향으로 움직이거나 관찰자가 방향을 전혀 탐지하지 못했을 때에도 관찰되었다. 이러한 결과들은 방해 집단의 점들이 효과 집단과 30도 떨어진 방향으로 운동했을 때에도 관찰되었다. 본 연구의 결과들은 두 개의 중첩된 운동 방향 중 하나의 방향에 주의를 기울였을 때 주의를 기울인 방향의 처리가 활성화됨과 동시에 주의를 기울이지 않은 방향의 처리가 억제된다는 것을 보여주었다. 두 방향의 차이가 운동 방향의 통합이 잘 일어나는 범위 내에 해당했을 경우에도 주의에 의한 억제 효과가 관찰된다는 사실은 중첩된 운동 자극에서의 선택적 주의가 운동 방향들의 통합 보다는 분리를 유발한다는 점을 시사한다.

주제어 : 주의, 중첩된 운동, 운동 잔여 효과