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Attentional Distribution Affects Motion-Induced Blindness

In motion-induced blindness (MIB) salient static dots "disappear" when superimposed onto a moving mask. In this article, the modulating effect of voluntary task-divided attention on MIB disappearances is investigated. Two types of tasks were used in turn as the primary and the secondary ones: to detect target dots disappearances (the MIB task) and to detect subjective changes in the direction of mask rotation caused by the motion aftereffect (the MAE task). Thus the allocation of central attention was manipulated while the MIB display remained unchangeable. The focused attention condition (a single task to detect MIB disappearances) and two divided attention conditions (detecting MIB as primary and secondary tasks) were compared. In the focused attention condition, detection of MIB disappearances had the highest task priority and evoked the greatest number of disappearances. The allocation of attention to different tasks led to the dramatic decrease of MIB occurrences and the more so the more priority the second (MAE) task had.

Motion-induced blindness (MIB) refers to perceptual disappearance when salient stimuli superimposed on a moving mask fluctuate in awareness (Bonneh, Cooperman, and Sagi, 2001). It has been shown that a number of factors influence the target disappearances in MIB. Depth ordering (Graf, Adams, and Lages, 2002), boundary

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adaptation (Hsu, Ye, and Kramer, 2006), learning (Bonneh, Sagi, and Cooperman, 2005), or dichoptical viewing (Devyatko, 2007) can increase target disappearances, while an abrupt onset cue leads to immediate return of a target to awareness (Kawabe and Miura, 2007; Kawabe, Yamada, and Miura, 2007). Target dots tend to disappear and reappear simultaneously when being grouped according to Gestalt laws (Bonneh, Cooperman, and Sagi 2001; Mitroff and Scholl, 2005) though the semantic grouping seemingly does not affect the simultaneity of targets' disappearance and reappearance under MIB (Devyatko and Falikman, 2008).

At least five different accounts[1] of MIB can be distinguished (see New and Scholl, 2008, for details). The very first explanation of MIB, based on the idea of attentional competition, was proposed by Y. Bonneh and colleagues (2001). According to this account, under MIB conditions the visual system operates in a winner-takes-all mode. This mode could be described as disruption or slow down of fast attentional switching between the moving mask and target objects in the scene. This disruption might occur, in Bonneh and colleagues' words, "because attentional mechanisms can't be allocated or divided between [sensory] dissociated or 'unfused' elements at the same time and location" (Bonneh, Cooperman, and Sagi, 2001, p. 800). Hence, disappearances during MIB are due to the rivalry that might occur either between competing object representations modulated by attention, or between attention mechanisms assigned to objects in space. Concerning the first part of this account, Donner et al. (2008) have recently obtained neurophysiological evidence for competing object representations in the dorsal and ventral visual cortex. They found a decrease in fMRI response in visual ventral area V4 during subjective disappearances of a target and an increase in mask subregions (V3AB, pIPS) (ibid., p. 10306). The increase in the brain area corresponding to the mask could not be caused by bottom-up influences because objectively nothing had changed in the stimulation (neither the mask's nor the targets' behavior). The aforementioned attentional modulation may serve as a possible explanation of these findings. Geng et al. (2007) investigated the influence of spatially distributed attention on MIB. They compared MIB characteristics in two different situations: when spatial attention was focused on one of the targets and when spatial attention was divided between two targets. Their results show that the disappearance of a target enhances under the focused-attention condition and that the modulation of MIB by spatial attention has different patterns in upper and lower visual fields. Olivia Carter and colleagues obtained similar results on the role of attention using another experimental paradigm (Carter et al., 2008). Taken together, these results indicate the necessity of a further search for evidence for or against Bonneh's hypothesis on attentional modulation of perceptual rivalry as a principal mechanism of MIB. Although Geng et al. hypothesized that precisely spatial attention captured by salient MIB targets enhances perceptual rivalry, in my opinion the spatial attention is unlikely to solely modulate it.

Donner and colleagues, in turn, conclude that "The spatially specific response increases in V3AB and pIPS during target disappearance suggest that spontaneous fluctuations of endogenous attention may have caused the target to disappear" (Donner et al., 2008, p. 10309), but their findings do not contain empirical data concerning a spatially nonspecific component of endogenous attention.

In the present study,[2] I explored the modulating effect of voluntary task-divided attention on MIB. I wanted to elucidate the role of shared attention, which may supplement the results of Geng et al. and further specify the contribution of higher attentional mechanisms to the emergence of MIB earlier assumed by Bonneh, Cooperman, and Sagi (2001). I used two subjective change detection tasks with varying attentional load (one or two tasks at a time with different priorities) while a stimulation used in two experimental conditions remained invariable. I manipulated the task priority in order to show that task-driven attention to target objects (dots) is a necessary condition for MIB to arise.

If central attention modulates MIB, I expected to obtain significantly different MIB characteristics (i.e., amount of disappearances and accumulated duration of disappearances in a given period of time) in two conditions: the first, when observers performed just one task (*focused attention condition*) and the second, when observers performed two tasks at a time (*divided attention condition*). Otherwise the characteristics would be the same in these two conditions. In addition, I expected that if attention enhances MIB, there would be more disappearances of target dots when detection of their disappearance was a primary task compared to a condition when it was a secondary task.

General method

My experimental design combined features of Neisser's "selective looking" study (Neisser and Becklen, 1975) and Duncan's (1984) object-based divided attention experiment. In both experiments two different objects or dynamic patterns were presented superimposed at the same location. Neisser's participants successfully reported on events in one movie at a time and failed to report on events in two movies at a time; Duncan's participants were asked to report either on two features of one object or on the same feature of two objects at one location. In my study participants were asked to perform a dual task, that is, two tasks at a time, both requiring detection of a subjective change in objectively invariable visual stimulation.

Two types of tasks were used in turn as the primary and the secondary tasks: the first was to detect subjective target dots' disappearances/reappearances (the "classical" MIB task), whereas the second was to detect subjective (i.e., illusory) changes in the direction of mask rotation. The latter effect usually emerges at a relatively high speed of mask rotation and, presumably, may be considered as a kind of dynamic motion aftereffect (MAE) (Hiris and Blake, 1992). In a recent study on illusory motion reversal (IMR), Klein and Eaglemen proposed that "MAE can be superimposed on a moving stimulus, creating a *motion during-effect* that can lead to illusory motion reversal" (Klein and Eaglemen, 2008, p. 4).

The illusory motion reversal effect for the moving MIB mask (coherently moving dot pattern) has never been reported in publications on MIB, but I discovered it in my previous experiments, and it has shown good reproducibility while using appropriate instruction.

In a first experimental condition (M+D), participants were instructed to attend to the mask and to report about all changes in direction of its rotation (see Table 1). Additionally, they were asked

Table 1

Tasks Performed by Observers in Experimental and Baseline Conditions

	Priority of the task		
Observer's tasks	Single	Primary	Secondary
Detect changes in direction of the mask rotation	Baseline for MAE	M+D	D+M
Detect the target dots' disappearances	Baseline for MIB	D+M	M+D

Notes: An example of instruction (for M+D condition): "Your task is to keep your eyes fixed on the white cross in a center of the screen and attend to the mask. Every time you see that the mask has changed its direction of rotation press this button (F). Also, please report all disappearances and reappearances of dots by pressing corresponding buttons (J for the left dot and K for the right dot). Please keep the button pressed and release it only when the dot (dots) reappears."

to observe two yellow dots and to report on their possible disappearances/reappearances. In the second experimental condition, I asked the participants to attend to target dots and to report about all their disappearances/reappearances and, second, I also asked them to report about changes in direction of mask rotation if any in the (D+M) condition. In a baseline condition for MIB, participants were simply asked to report on target dots' disappearance and reappearance. In a baseline condition for MAE, subjects were asked to report only about illusionary direction reversals of mask rotation (there were no target dots on the display). I also included a setting condition which always came first when participants performed M+D instruction. I added this condition in order to check whether the participants can experience and report about both phenomena (MIB and MAE).

Stimuli

The stimuli were created using Macromedia Flash MX 2004 and presented with Macromedia Flash Player 7. All stimuli were viewed from 57 cm, with the observer's head restrained by a chinrest. The stimulation for M+D, D+M, and baseline for MIB conditions consisted of a white fixation cross and two yellow dots superimposed on a blue moving mask on a black background (luminance 1.13 cd/m²). Target dots (0.4 degrees in size, luminance 31.55 cd/m², color RGB coordinates: R255 G255 B0, α = 100 percent) were located 1 degree above and with 1.2 degree of eccentricity to the left and to the right of a white fixation cross (0.3 degrees × 0.3 degrees, luminance 28.48 cd/m²) in the center of the screen. Targets were surrounded with a circular protection zone (0.5 degrees). The blue clockwise moving mask (a 2D rectangle 21.2 degrees × 18.1 degrees, with rotation speed 240 degrees/sec, luminance 3.88 cd/m², color RGB coordinates: R0 G0 B255, α = 100 percent) consisted of 1,589 coherently moving dots (0.1 degrees each). The stimulation for the setting condition was the same except a speed of mask rotation (360 degrees/sec).

Apparatus

Stimuli were displayed on a Samsung Sync Master 757 DFX 17 inch' monitor (1024 × 768, Athlon 2000, NVidia GeForce 4MX). Key presses were recorded from the keyboard (BTC model 52 01, input +5V,170mH) connected with a second PC (Intel Pentium 4 CPU 2.40 Ghz 514, 608 kb RAM, operating system was Microsoft Office Windows 2000 Professional [5.0, build 2195], Service Pack 4) using custom software.

Participants

Twenty-one participants (six of them were male) aged from eighteen to twenty-five with normal or corrected-to-normal visual acuity took part in the experiment.

Design and procedure

The within-subject design was employed in my experiment.

Each session consisted of four three-minute-long trials with thirty-second between-trial intervals (one trial per condition). The order of presentation for four conditions was randomized (except the setting condition, which always came first). In all conditions participants reported on observed changes by pushing and releasing three buttons assigned to changes in a mask rotation and to disappearances/reappearances of two target dots correspondingly.

Results

To compare the number and duration of target disappearances and number of perceived changes in the direction of the mask rotation, I used a paired-samples *T*-test (the distributions of these variables for all experimental conditions were normal). The results of *T*-test comparisons are summarized in Table 2. The total duration of the disappearance period for target dots and the total number of disappearances reached maximum under the baseline MIB condition and minimum under the M+D condition (Figures 1 and 2; Table 2), which means that sharing attention between two different tasks decreases the number of MIB-evoked target disappearances compared to the "standard" MIB condition, that is, the more one concentrates on looking at target dots, the more they disappear. Furthermore, I obtained significant differences between the baseline MIB condition and both experimental conditions. I also found significant differences (in terms of both number and total duration of disappearances) between both experimental conditions (M+D and D+M), showing that focusing attention on dots as a main task leads to higher disappearance rates as compared to focusing attention mainly on mask rotation.

A repeated-measures ANOVA for number and duration of tar¬get dots' disappearances with shared attention (focused attention condition and two divided attention conditions) as a factor also revealed a significant main effect ($F(1.6, 40) = 18.665$, $p = 0.00$ and $F(1.6, 40) = 14.978$, $p = 0{,}00$, correspondingly). I also compared the number of changes in perceived direction of mask rotation between M+D, D+M, and baseline MAE conditions (see Figure 1 and Table 2). There was a significant increase in the number of illusory changes in the M+D condition and the baseline MAE as compared to the D+M condition, though there was no significant difference be-

Figure 1. **Mean Number of Reported Illusory Dots' Disappearances and Mask Reversals in Different Conditions**

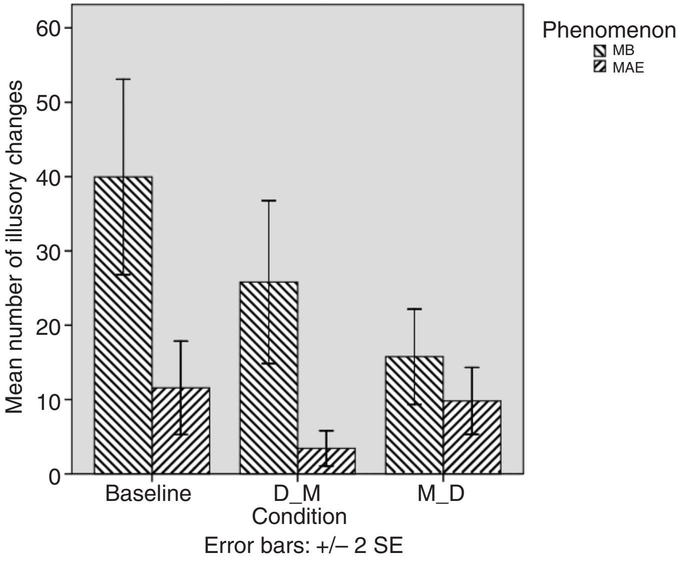

Figure 2. **Mean Total Duration of Target Dots' Disappearances in Baseline MIB, M+D, and D+M Conditions**

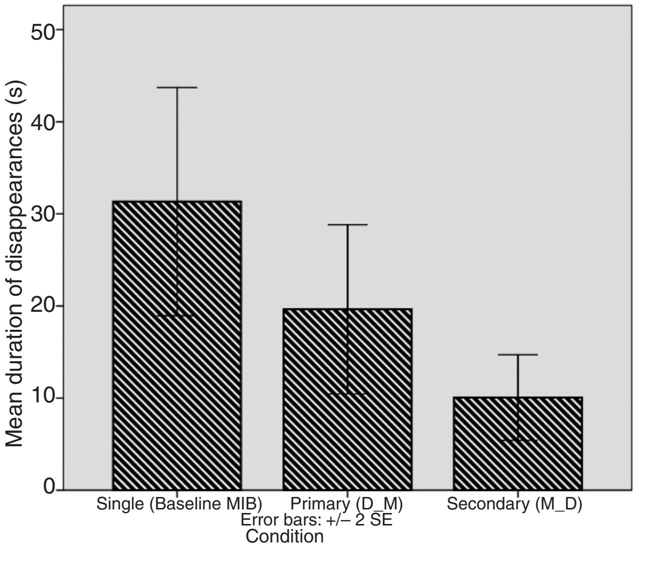

Table 2

The Results of *T*-test for Differences in the Total Number of Dots Disappearances, Total Phase Duration of Disappearance (sec), **and in a Number of Perceived Changes in the Direction of Mask Rotation: Comparison of Experimental, Baseline MIB, and Baseline MAE Conditions**

Conditions	Total number of dots disappearances	Total phase duration of disappearance (sec)	Number of changes in perceived direction of mask rotation
M+D vs. D+M	$t(20) = -2.442$, p=0,024*	$t(20) = -2.562$, $p = 0.019$*	$t(20) = 2.647$, $p = 0.015$*
M+D vs. baseline MIB	$t(20) = -5.158$, $p = 0.000$**	$t(20) = -4,556$, $p = 0.000$**	—
D+M vs. baseline MIB	$t(20) = -4.836$, $p = 0.000$**	$t(20) = -3.761$, $p = 0.001$**	—
M+D vs. baseline MAE	—	—	$t(20) = -0.858$, $p = 0.401$
D+M vs. baseline MAE	—	—	$t(20) = -2.579$, $p = 0.018$*

tween the condition in which detection of direction was a single task (baseline MAE) and the condition in which it was the first of two tasks (M+D). Probably, attention modulates MIB and MAE in different ways because mechanisms of these two phenomena differ to some degree.

Runs test statistical analysis of M+D (number of runs—141, $Z = -10.409$, $p = 0.00$) and D+M (number of runs—55, $Z = -14.297$, $p = 0.00$) conditions showed significant deviation from a chance sequence with mutually independent elements, which means that occurrences of two types of perceptual events—the illusory dots' disappearance and the illusory motion reversals—were not independent. This result could be interpreted in two ways: either MIB and MAE share common mechanisms (perhaps, a timing mechanism) or there is a limited common resource on which both phenomena are critically dependent (see the next section).

Discussion

Returning to my hypotheses, my data support both of them. My first hypothesis about the influence of shared attention on MIB is supported by the fact that characteristics of MIB significantly differ between baseline MIB and M+D and D+M conditions. The focused attention condition produces the highest number of disappearances of the target dots and the longest total phase durations of disappearances. The allocation of attention to different tasks leads to the decrease of MIB and the more so the more priority the secondary (distracting) task has.

Significant differences in MIB characteristics between M+D and D+M conditions support my suggestion that attention might enhance the phenomenon.

Although my results are in line with recent findings on attentional influences on the MIB dynamic that were presented by Schölvinck and Rees (2008), it is not an easy task to directly compare the results of these two studies. Schölvinck and Rees hypothesized that the high attentional load to an unrelated task withdrew attention from the MIB display, which would alter the competitive interactions between the target and the mask. They manipulated attentional load using different levels of difficulty in a "central task" *unrelated* to *MIB stimuli*. It was a feature-detection task that required participants to monitor an object (or two different objects) in a central stimuli stream. It should be noted that the visual input in low and high attentional load conditions was not invariant (in contrast to my experimental conditions) and could cause some uncontrollable attentional interactions between different systems of attention (e.g., between endogenous and exogenous attention). Probably, the latest fact is reflected in less salient and statistically significant differences in number and duration of disappearances under different experimental conditions in Schölvinck and Rees's second experiment. (Their first experiment reproduced the results of Geng et al. [2007], but the difference in MIB indicators used by Schölvinck and Rees [2008] somehow constrains the possibility of direct comparisons with the results obtained by Geng et al. [2007].)

My results are in good agreement with Bonneh's account of MIB mechanisms, with the results of Carter et al. (2008), and with results on the modulating role of endogenous attention obtained by Geng et al. (2007).

Geng and colleagues extended Bonneh's account of MIB. They hypothesized that the salient target dots can capture attention in a bottom-up way. This increased exogenous attention will be directed to the local space surrounding the targets and enhance processing of both the targets and the mask. As a result, the competition between them will increase. Due to the enduring priority of motion in attention capturing, in this enhanced competition there will be more attentional biases to the moving mask, which will lead to more pronounced MIB.

I assume that the conditions with voluntary divided attention lead to an increase in fast attention shifts between competing objects—the mask and the targets—in accordance with the instruction, thus reducing a number of MIB disappearances. The possible explanation of the observed decrease in disappearances in the M+D condition compared to the D+M condition is that in the M+D condition endogenous attention strongly disturbs those initial conditions for emergence of the intensified "winner-takes-all" rivalry between the dots and the mask by adding a top-down (task-determined) bias toward the mask area. These additional switches of endogenous attention to the mask preclude the intensification of the aforementioned competition leading to the dots' disappearance in a "classical" MIB experiment, which results from the widespread suppression of response to "losing" target objects. On the other hand, task-driven attention to the mask can hamper exogenous attention and thus prevent the capture of attention in a bottom-up way by the target dots. However, this hypothetical explanation needs further tests.

In the present study we aimed to show the role of a spatially nonspecific component of endogenous attention, but one may ask what the basis of the selection was. We asked participants to report on target dots' disappearances and on such a spatiotemporal feature as motion direction. In the case of detection of disappearances target offsets could be treated as a transient feature (Klotz and Ansorge, 2006). The question arises whether it was a feature- or object-based selection. I believe that in my experiment I dealt with object-based attentional selection. Arguably, even though a visual task requires detection of features, the latter belong to objects. This opinion is supported by previous research findings demonstrating that even task-irrelevant features of the attended object are selected along with task-relevant features (Scholl, 2001, p. 16; Klotz and Ansorge, 2006). Besides, there is evidence that some spatiotemporal features may be even more tightly coupled with object representations (Scholl, 2001, p. 17).

However, an alternative explanation of my data could be proposed.

One possibility was proposed by Florant Caetta (in his referee's comments on this article). Sustained attention can cause contrast adaptation (Ling and Carrasco, 2006) and thus increase the probability of the target suppression (Gorea and Caetta, 2009).

Presumably, my results showing significant difference between M+D and D+M conditions could be explained by Kahneman's limited capacity model of attention (the resource allocation model)[3] (Kahneman, 1973): within divided attention conditions (M+D and D+M), two *tasks* can compete for limited capacity. As a result, the performance of one task could deteriorate when the second task is performed at the same time. The same explanation might be applied to a significant difference between baseline MIB and M+D or D+M conditions and between baseline MAE and D+M conditions. However, the absence of a significant difference between baseline MAE and M+D conditions seemingly contradicts this explanation. Moreover, I should note that my experiment differs from Kahneman's (1973) experimental paradigm in some important aspects, limiting possible interpretations in this vein: first, I dealt with the detection of *subjective* changes in visual perception (the sensory input was invariant). In particular, defining criteria of a successful performance or a detection error in this case does not appear to be an easy task (and borders upon a metaphysical one). Second, my subjects did not mention that they had been experiencing any difficulties while performing two tasks at a time, and, finally, I did not use any kind of reinforcement or feedback to manipulate my observers' performance of the tasks. (I did not pay for or sanction their performance.)

On the other hand, I can try to apply Norman and Bobrow's (1975) model to my data. In this case, I could explain my data in terms of data and resource limitations. Performance in the dots disappearances detection task might suffer from resource limitations, which is why I obtained a reduced number of disappearances in the D+M and, especially, in M+D conditions. And vice versa, detection of illusory motion reversals suffers from data limitations and seems to be more resistant to resource limitations. This is, possibly, why I observed a significant decrease in the number of perceived motion reversals in the D+M condition and the absence of a difference between the baseline MAE and M+D conditions. But, again, I cannot be very confident regarding data limitations, because my *input was invariable*.

In summary, new evidence of the modulating role of attention in MIB has been found, which demonstrates good agreement with the results of Geng et al. (2007) on spatially divided attention's modulating effect on MIB, and strongly emphasizes the contribution of a voluntary task-driven attention distribution to the temporal and general quantitative characteristics of MIB. Taken together, these results show the important role of endogenous attention in the emergence of MIB and provide additional support to the initial idea of Bonneh et al. that under MIB conditions "the actual rivalry and suppression could occur between object representations modulated by attention or between attention mechanisms assigned to objects in space" (Bonneh, Cooperman, and Sagi, 2001, p. 800).

Notes

1. While this article was under revision two new accounts were proposed. For details see Gorea and Caetta (2009) and Wallis and Arnold (2009).

2. While this article was in preparation Schölvinck and Rees (2008) published their results on attentional influences on the MIB.

3. This possibility was brought to my attention by Maria Falikman and Ekaterina Pechenkova (oral communication).

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