

Motion-Induced Blindness and Motion Streak Suppression

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Summary

In motion-induced blindness (MIB), persistent static targets intermittently disappear when presented near moving elements [1, 2]. There is currently no consensus regarding the cause or causes of MIB [3–7]. Here, we link the phenomenon to a mechanism that is integral for normal human vision, motion streak suppression [8]. The human visual system integrates information over time [9], resulting in streaks of activity across visual brain regions when objects move [10, 11]. These “motion streaks” are usually suppressed from awareness. Our results suggest that this process shapes MIB. We show that MIB is enhanced at the trailing edges of movement and that both MIB and motion streak suppression are impaired at equiluminance. These findings suggest that an apparent failure of human vision, MIB, is at least partially driven by a functional adaptation that facilitates clear perceptions of moving form.

Results and Discussion

Experiment 1: Target Location Relative to Motion Direction

Experiment 1a: Leading versus Trailing Edges of Motion

A motion streak can be characterized as a low temporal frequency signal oriented parallel to the direction of motion and located toward the trailing edge of a moving object. Any process tasked with suppressing a motion streak from awareness should be selective for at least some of these characteristics. Psychophysical [10, 12–14] and physiological [11] studies have shown that motion streak suppression is marked by the requisite orientation selectivity. Greater luminance contrast suppression at the trailing edges of motion, compared to the leading edges, has also been shown [15, 16]. If motion-induced blindness (MIB) were related to motion streak suppression, we would, therefore, expect to see heightened MIB at the trailing edges of movement.

Observers were shown 30 s presentations of drifting dot fields surrounding two stationary targets (see Figure 1A). On each trial, the dots either drifted toward the targets, placing the targets at the leading edges of movement, or away from the targets, placing them at trailing edges (see Supplemental Data available online for demonstration video). Observers held down one of two buttons whenever a target seemed to disappear, releasing it when the target became visible again.

We found that normalized MIB (see Experimental Procedures) was enhanced when targets were located at the trailing edges of movement, rather than at the leading edges ($t_9 = 3.25$, $p = 0.01$) (see Figure 1B). These normalized disappearance

durations corresponded to 17% and 25% of the 30 s stimulus presentations for the leading and trailing conditions, respectively. The relatively greater suppression observed toward the trailing edges of movement are consistent with a link between motion streak suppression and MIB. Absolute disappearance values for subsequent experiments are provided in the Supplemental Data.

In the trailing edge condition, new dots appeared closer to target locations relative to the leading edge condition. However, these effects cannot be attributed to the proximity of onset transients; we were able to replicate the results with a grating stimulus that does not contain onset transients (see Supplemental Data for details and demonstration videos).

The greater incidence of MIB toward the trailing, as opposed to the leading, edges of movement suggests that MIB is driven by mechanisms sensitive to the trajectory of movement. Further support for this premise was provided by another supplemental experiment (see Supplemental Data), wherein we found that MIB is stronger when motion trajectories prompt integration across target locations. Both of these data sets are consistent with a streak suppression mechanism and with previous evidence of suppression along the path of apparent motion [17].

Experiment 1b: The Spatial Extent of MIB at the Leading and Trailing Edge

We also examined the spatial extent of the trailing edge bias and whether it depended on the speed of the dot field. By varying the separation distance between motion and targets, we revealed an interaction between motion direction (leading or trailing) and separation ($F_{5,35} = 2.96$, $p = 0.03$). As can be seen in Figure 1C, at smaller separations, targets at the trailing edges of motion were more suppressed than targets at the leading edges. However, both conditions were marked by diminished suppression as motion-target separations increased. There was minimal, if any, suppression overall at a distance of ~ 1.7 degrees of visual angle (dva). These data are consistent with previous findings [1], showing that MIB results from a localized process that diminishes in effect with motion-target separation. Similarly, motion streak suppression is driven by local processes, extending in influence up to ~ 0.5 dva [12, 18, 19]. The bias for greater MIB at the trailing edges of movement is consistent with this, peaking at ~ 0.43 dva and diminishing thereafter (see Figure 1D). The spread of MIB beyond this distance may be indicative of contributions from other causal mechanisms [1, 5, 6].

It is also apparent, from examining Figures 1C and 1D, that dot speed has minimal impact on the spread of MIB ($F_{1,7} = 2.34$, $p = 0.17$). This is consistent with previous data from our lab, showing that the magnitude of MIB is tuned to temporal frequency, not to retinal speed [20]. In combination, these data suggest that MIB is a temporal frequency-tuned operation.

Experiment 2: Moving Form and MIB at Equiluminance

The active suppression of motion streaks, which facilitates a clear perception of moving form, depends on neurons that are sensitive to both spatial and temporal modulation [21–23]. Such neurons are typically responsive to movement signaled

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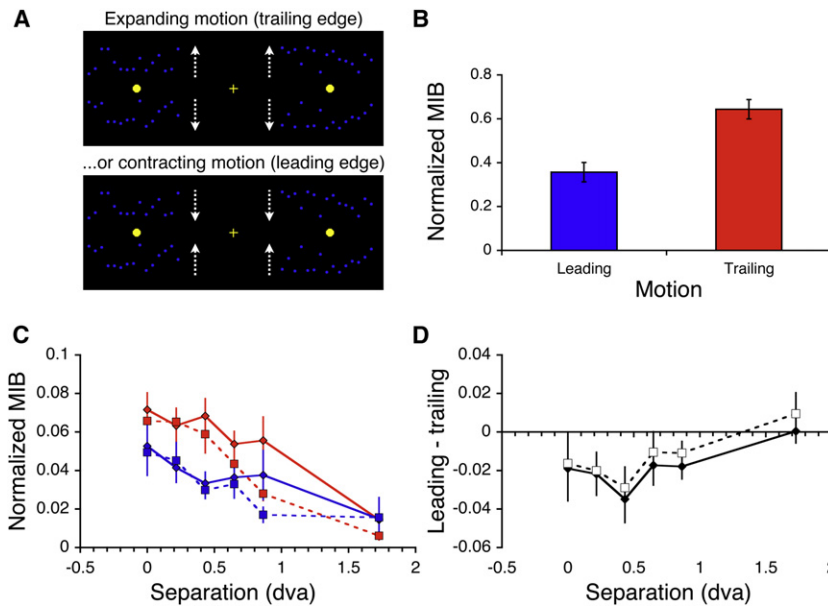


Figure 1. MIB for Targets Located at the Leading versus the Trailing Edges of Motion

(A) Depiction of the stimuli used in Experiment 1. White dotted lines depict motion direction.

(B) Bar plot showing normalized durations of reported disappearances (see [Experimental Procedures](#)) in the trailing and leading edge conditions of Experiment 1a ($n = 10$). Observers experienced more MIB for targets at the trailing edges of movement than at the leading edges.

(C) Data from Experiment 1b showing normalized MIB for leading and trailing motion conditions for two dot speeds at six target-motion separations ($n = 8$). (Red) Trailing. (Blue) Leading. (Diamonds with solid lines) 4.32 dva/s. (Squares with dashed lines) 8.64 dva/s. Note that the 0.43 separation point is comparable to data from (B).

(D) Leading minus trailing; negative values indicate more MIB at the trailing edges of movement than at the leading edges. (Solid diamonds) 4.32 dva/s. (Open squares) 8.32 dva/s. Error bars represent ± 1 SEM.

by large luminance changes but are relatively insensitive to movement defined by very small luminance changes or by chromatic contrast [24, 25]. We shall refer to such stimuli as equiluminant. Because of these factors, the ability to perceive moving form can be impaired at equiluminance [26]. If MIB is related to motion streak suppression, then motion streak suppression, moving form perception, and MIB should all be impaired at equiluminance.

Experiment 2a: Letter Identification

To demonstrate impaired moving form perception at equiluminance, observers were required to locate a particular

form (the letter “X”) (see [Figure 2A](#)). This moving form was defined by fluctuations within “signal” dots embedded in arrays of unchanging “noise” dots (see [Supplemental Data](#) for demonstration video). The X’s appeared to move vertically. In all conditions, signal dots intermittently changed color. Across conditions, signal dots also either intermittently became darker than the background, brighter, or stayed at a constant perceived brightness (the equiluminant condition). As shown in [Figure 2B](#), detection performance deteriorated around the equiluminant point in the presence of unchanging noise dots ($F_{8,56} = 15.3, p < 0.001$).

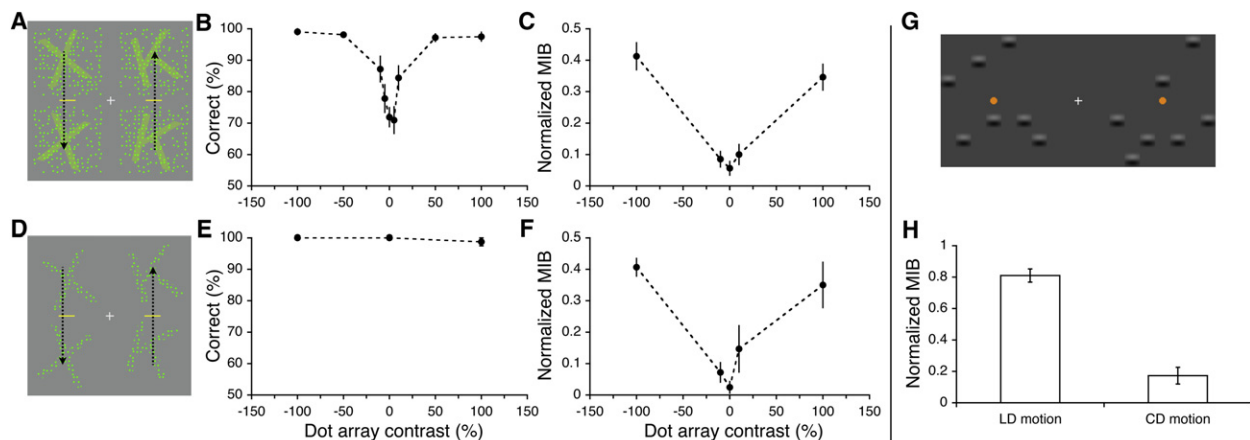


Figure 2. MIB for Luminance-Defined versus Equiluminant Motion

(A) Depiction of the stimulus used in Experiment 2. Note that the moving forms are depicted here by completed semitransparent letters. These were not present in the display. Black dotted lines depict motion direction.

(B) Letter localization performance in Experiment 2a as a function of the luminance contrast of the dot arrays ($n = 8$).

(C) Normalized MIB in Experiment 2b as a function of the luminance contrast of the dot arrays ($n = 8$).

(D) Depiction of the unmasked dotted form stimulus in Experiments 2c and 2d. This stimulus was identical to that of Experiments 2a and 2b but without noise dots.

(E) Letter localization and direction identification performance in Experiment 2c as a function of the luminance contrast of the dot arrays ($n = 4$).

(F) Normalized MIB in Experiment 2d as a function of the luminance contrast of the dot arrays ($n = 4$).

(G) Depiction of the stimuli used in Experiment 3. Gabors were displaced vertically and were either luminance or chromatic defined.

(H) Normalized MIB for luminance (LD) and chromatic (CD) motion at five times direction discrimination threshold ($n = 7$).

Error bars represent ± 1 SEM.

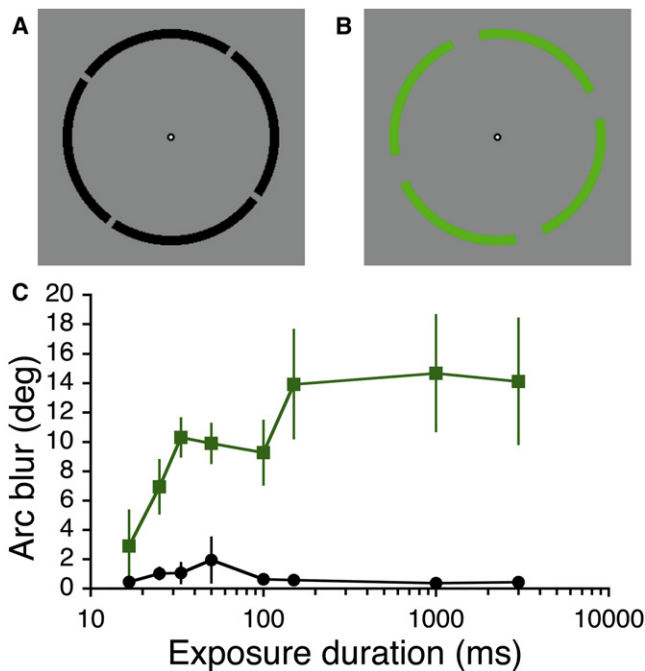


Figure 3. Motion Streak Suppression at Equiluminance
(A and B) (A) Depiction of the luminant stimulus (shown with 4° separations) and (B) the equiluminant stimulus (shown with 16° separations) used in Experiment 4.
(C) Arc blur as a function of stimulus exposure duration for luminant (black circles) and equiluminant (green squares) stimuli (n = 5). Higher values indicate larger motion streaks (see Experimental Procedures). Error bars represent ± 1 SEM.

Experiment 2b: MIB

Next, we examined disappearances of static targets in the same display. As shown in Figure 2C, observers reported robust disappearances when moving form was signaled by large luminance changes, but MIB was negligible around the equiluminant point ($F_{4,28} = 19.66, p < 0.001$).

Experiment 2c: Unmasked Letter Identification

It is possible that MIB was mitigated at equiluminance simply because observers were unable to detect, or to attend to, stimulus movements or motion-defined forms at equiluminance. To show that this was not a critical factor, we repeated Experiments 3a and 3b without noise dots (Figure 2D). In the absence of noise dots, observers were able to identify both the position and direction of moving form, even at equiluminance ($F_{2,6} = 1$) (see Figure 2E). They were, therefore, capable of attending to these signals. Interestingly, the ability to discern the direction of moving form at equiluminance has been linked to an attentional mechanism, responsive to both persistent and temporally modulated chromatic contrast [27]. If unimpeded, this mechanism can evidently facilitate perception of moving form at equiluminance. However, it is unclear whether it might also be sufficient to induce MIB and motion streak suppression.

Experiment 2d: Unmasked MIB

In the absence of noise dots, we found that MIB was still greatly reduced at equiluminance ($F_{4,12} = 9.04, p = 0.001$) (see Figure 2F). This shows that not all types of movement are equally capable of eliciting MIB. Equiluminant movement, even when it can easily be discerned and attended, results in greatly reduced disappearances.

Experiment 3: Is MIB Selectively Driven by Mechanisms Tuned to Luminance-Defined Motion?

Experiment 2 suggests that MIB is driven selectively by mechanisms tuned to luminance-defined movement. However, in these experiments, no attempt was made to equate the different types of movement in terms of motion perception. To address this, we first determined minimal contrasts for accurate direction discriminations for vertical displacements of luminance-defined and chromatic Gabors—the observer’s detection thresholds for apparent motion perception (see Figure 2G). We then examined MIB for Gabors presented at five times the observer’s detection threshold (see Supplemental Data for Experimental Procedures).

As shown in Figure 2H, luminance-defined motion produced more MIB than did chromatic motion ($t_6 = 6.78, p < 0.001$), even when the two types of motion were presented at equal multiples of the observer’s detection threshold for apparent motion perception. These data confirm that MIB is not tied to motion perception per se.

Experiment 4: Motion Streak Suppression at Equiluminance

MIB is strongly reduced at equiluminance. If MIB is related to motion streak suppression, motion streak suppression should also be mitigated at equiluminance. As of yet, this possibility has not been assessed.

The active nature of motion streak suppression can be revealed by varying the duration for which stimuli are presented. Initially, moving forms can appear more blurred as stimulus exposure increases. However, at even longer exposures, moving forms typically appear less blurred [8, 12]. We were able to replicate this characteristic pattern with movements defined by large luminance changes (see Figures 3A and 3C). However, equiluminant movement (Figure 3B) did not become less blurred. Instead, blur magnitude increased and then saturated (see Figure 3C). These data indicate a relative failure of motion streak suppression at equiluminance.

General Discussion

We have linked MIB to a process that suppresses motion streak perception by showing that MIB is enhanced at the trailing edges of movement and that MIB is sharply reduced at equiluminance. Furthermore, we have shown that motion streak suppression also fails at equiluminance. Previous data from our lab [20] has shown that MIB has a comparable temporal sensitivity to the spiking rates of V1 cells as they respond to motion streaks [11]. Taken together, these observations suggest that MIB is driven, at least in part, by a mechanism that helps to suppress motion streaks from awareness and, thereby, to facilitate the clear perception of moving form in daily life.

MIB has previously been linked to the disruption of attention [1]. To some extent, our results speak against this characterization. We have shown that an unmasked equiluminant motion signal, which can be clearly discerned and attended, induces almost no MIB. Our data, therefore, implicate a more mechanistic process, with MIB being driven more strongly by operations that are selective for luminance-defined movements. This mechanistic process may, however, be modulated by attention.

Our data suggest that MIB is shaped by a competition between two neural signals [see also 1 and 5], one responding to spatiotemporal luminance changes and another to proximate static targets. Recent brain imaging is consistent with this proposal; neural signals relating to motion and static

form fluctuate, with perceptual dominance coinciding with the instantaneously stronger signal [28]. A similar suggestion has been made to account for motion streak suppression [29]. We suggest that, during MIB, target-related signals might be intermittently treated like motion streak activity.

Suppression of the target signal in MIB and of motion streaks is likely to be driven by processes such as metacontrast [12] and temporal masking [30, 31]. However, MIB should be modulated by factors that relatively strengthen or weaken one of the two signals in the MIB competition. Such factors may include attention [1], surface completion or grouping cues [1, 5, 32], contrast facilitation along contours [6, 33], neural adaptation [3, 6], and small eye movements [34].

A recent paper has proposed a different functional explanation for MIB [7]. Static targets might be suppressed because they are mistaken for aberrations arising from within the visual system, which are normally static with regard to the retina and are suppressed from awareness. Consistent with this, it has been shown that targets that are stabilized on the retina undergo more MIB than targets that move across the retinal surface. However, motion streaks are also stabilized on the retina, which may explain this tendency. Moreover, it is unclear why the presence of a signal that is static on the retina would need to be signaled by proximate luminance movement, as opposed to chromatic movement, or why suppression during MIB should be biased toward the trailing edges of movement. These properties are consistent with a link between MIB and motion streak suppression. However, they are not predicted by any existing account of MIB.

Here, we have linked MIB to a process that is ubiquitous to human vision, the suppression of motion streaks, which facilitates clear perceptions of moving form. Thus, MIB, which could be taken for a failure of vision, may be shaped by a functional adaptation that is integral to perception in daily life.

Experimental Procedures

Stimuli were generated with either a ViSaGe (Experiment 1, Experiment 3, and Supplemental Data) or VSG 2/3F (Experiments 2 and 4) from Cambridge Research Systems. They were displayed on a γ -corrected 21" Samsung SyncMaster 1100p+ monitor or a 19" Sony Trinitron G420 monitor (Experiment 3) at a resolution of 1024 \times 768 pixels and a refresh rate of 120 Hz. Observers viewed all stimuli from 57 cm with their head placed in a chinrest.

In experiments assessing MIB, observers held down one of two buttons (one for each target) whenever a target seemed to disappear. We recorded durations for which a disappearance of at least one target was signaled. To provide comparable measures of disappearances across observers, we normalized disappearance duration by dividing the disappearance duration in each condition for each observer by the observer's total disappearance duration across conditions (the "normalized MIB").

In experiments assessing sensitivity to moving form, stimuli were presented for 1 s, and participants either indicated whether a target form was presented to the left or right of fixation (Experiment 2a) or identified both the position (left or right) and direction (up or down) of a moving target (Experiment 2c). A distractor letter ("K") moving in the opposite direction was presented to the nontarget side.

In Experiment 4, we assessed the perceptual suppression of motion streaks as a function of luminance contrast. Observers were shown rotating and static line segments separated by variable distances for a range of different durations (16.7, 25, 33.3, 50, 100, 150, 1000, and 3000 ms). On each trial, observers were asked to indicate whether the "arc segments looked clearly separated" or whether they "looked like they were joined, possibly by streaks." Responses were coded 0 (joined) or 1 (clearly separated), and cumulative Weibull functions were fitted to each observer's data to determine arc separation thresholds at which segments were clearly separated. Static thresholds were subtracted from moving thresholds to produce indices of motion-related blur. Positive values indicate a failure to suppress blur, causing physically offset segments to appear joined.

Full details concerning all of the experimental procedures can be found in the Supplemental Data.

Supplemental Data

Supplemental Data include Supplemental Experimental Procedures, Supplemental Discussion, one figure, and four movies and can be found with this article online at [http://www.current-biology.com/supplemental/S0960-9822\(09\)00605-8](http://www.current-biology.com/supplemental/S0960-9822(09)00605-8).

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