

Sensory and decisional factors in motion-induced blindness

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The processes underlying *motion-induced blindness* (MIB) are widely debated. Ultimately, however, they must reduce to a sensitivity drop and/or to an upward shift of the decision criterion. The first possibility was tested by assessing the detection threshold for a contrast (or luminance) increment applied to the MIB target under its visible and suppressed phases. This was performed over a whole range of reference target contrasts (yielding the standard Threshold vs. Contrast [TvC] function) with a 2AFC staircase procedure. The second possibility was tested with a Yes/No procedure, allowing the assessment of both the sensitivities (d') and decision criteria (c) yielded by four contrast increments applied to a fixed reference target contrast (the psychometric function). The 2AFC procedure yielded a global upward shift of the TvC function of about 5.3 dB (a factor of 1.84) under the suppressed phase. The Yes/No procedure yielded a commensurate d' drop (of about 0.8 σ) under the suppressed phase with no change in the slope of the psychometric function and an upward shift of c of about 0.7 σ . The presently observed vertical shift (in log-log coordinates) of the TvC function in the suppressed phase is indicative of a divisive inhibition occurring after the transducing stage. The invariance of the psychometric function slope under the visible and suppressed MIB phases supports this conclusion. The present experiments cannot settle the issue of whether the upward shift of the decision criteria is yet another cause of the MIB or a consequence of its underlying inhibitory process. Instead, they make clear that MIB (and perhaps other unstable perceptual phenomena) is associated with both sensory and decisional processes.

Keywords: motion-induced blindness, threshold versus contrast function, sensitivity, decision criterion

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Introduction

From a psychophysicist's point of view, the "spontaneous" disappearance of a physically present and otherwise visible stimulus can result from only two causes: a drop in sensitivity and/or an upward shift of the perceptual decision criterion—with reference to which an observer will assert that the stimulus is or is not perceived. Each of these two ultimate causes may be instantiated in a number of ways. A sensitivity drop may result from an inhibitory process, an increase of the noise level, and/or a change in the transducing process. Criterion changes can be brought about by a change of the observer's priors and/or by interference with other decision processes. Any of these internal causes can be brought about and/or modulated by a multitude of external and internal factors such as task switching, multiple tasks

and/or stimuli (contextual factors), and changes in vigilance/attentional level.

Salient visual stimuli can be blocked from conscious perception under a number of conditions such as binocular rivalry (Levelt, 1965; Wheatstone, 1838), attentional blink (Raymond, Shapiro, & Arnell, 1992), repetition blindness (Kanwisher, 1987), inattentional blindness (Mack & Rock, 1998), change blindness (Rensink, O'Regan, & Clark, 1997), or different forms of masking. The latter, and more specifically metacontrast (Stigler, 1910; see reviews by Breitmeyer, 1984; Breitmeyer & Ogom, 2000), were used to show that "invisible"/nonconscious primes may nonetheless affect the perception of their masker (Klotz & Neuman, 1999; McGinnies, 1949), as well as trigger or modulate motor behavior (Goodale & Milner, 1992; Trevarthen, 1968). Equivalent altered perceptual consciousness states have been described in stroke patients with extinction (Bender, 1952; Critchley, 1949), neglect

(Halligan & Marshall, 1993), and blindsight (Weiskrantz, 1990). Epitomes of the current empirical approach to the problem of perceptual awareness, these phenomena have been used as starting blocks for debates on what consciousness might be (e.g., Dennett, 1991; Weiskrantz, 1986), as a means of quantifying awareness-related processes such as attention (see above), signal processing disruption (e.g., Ogmen, Breitmeyer, & Melvin, 2003), or interocular and pattern competition (for a review, see Tong, 2001) and as a substantiation of the dissociation between perception and action (Goodale & Milner, 1992). While the interpretations of the above phenomena have been scrutinized both at their conceptual level and from the standpoint of their neurophysiological substrate, the particularities of the recently discovered *motion-induced blindness* (MIB; Bonneh, Cooperman, & Sagi, 2001) phenomenon defy such analyses.

MIB refers to the spontaneous perceptual vanishing (followed by reappearance) of highly salient, peripheral visual targets when superimposed on a globally moving (distracter) background. Originally, MIB was thought of as an instance of the Troxler effect (Troxler, 1804) and/or of lateral masking (by the moving background). These low-level accounts have been questioned in view of results by Bonneh et al. (2001) showing that MIB persists for (slowly) moving or flickering targets (hence preventing a local low-level adaptation—the main cause of the Troxler effect; Clarke & Belcher, 1962), as well as when the background was occluded within relatively large areas around the targets (hence impeding lateral masking). The fact that the invisible MIB targets contribute to the formation of negative aftereffects (Hofstoetter, Koch, & Kiper, 2004) and yield an orientation selective adaptation (Montaser-Kouhsari, Moradi, Zandvakili, & Esteky, 2004) was taken as evidence that the neural site of their suppression is beyond the primary visual cortex (but see Blake, Tadin, Sobel, Raissian, & Chong, 2006). This conclusion is sustained by observations that MIB is sensitive to Gestalt-like grouping effects (Bonneh et al., 2001; Hsu, Yeh, & Kramer, 2004) and to the manipulation of the depth planes where targets and distracters are presented (Graf, Adams, & Lages, 2002). The latter observation suggests that target and distracters compete for saliency, consistent with the proposal that MIB is but another form of bistable perception reflecting the competition between neural mechanisms signaling irreconcilable percepts (Funk & Pettigrew, 2003; see also Kastner, De Weerd, Desimone, & Ungerleider, 1998). All the findings above are compatible with an interpretation according to which MIB could reveal (at least in part) a disruption of attentional processing, reminiscent of a competition between object representations (Bonneh et al., 2001). However, this account is in conflict with the most counterintuitive observation that MIB correlates *positively* with the saliency of the targets (Bonneh et al., 2001; Hsu et al., 2004).

Apart from a very few neglect/extinction studies having suggested that these conditions may also reflect changes in

subjects' decisional behavior (Azzopardi & Cowey, 1997; Campion, Latto, & Smith, 1983; Gorea & Sagi, 2000, 2002; Klein, 1998), the ultimate account of a perceptual awareness impairment has been in terms of sensitivity changes. This was most extensively documented for binocular rivalry where the sensitivity of the suppressed eye was shown to be significantly deteriorated (Blake, 1989; Blake & Camisa, 1979; Blake & Fox, 1974; Fox & Check, 1972; Nguyen, Freeman, & Wenderoth, 2001; Wales & Fox, 1970; Watanabe, Paik, & Blake, 2004). Watanabe et al. (2004) measured the contrast increment threshold for the nonsuppressed and suppressed targets as a function of this target's contrast. Their results show that the Threshold versus Contrast (TvC) function (Foley & Legge, 1981; Gorea & Sagi, 2001; Legge, 1981; Legge & Foley, 1980) in the suppressed phase is just an upward shifted version of the TvC in the nonsuppressed phase.

Based on the assumption that the internal response R to contrast C is a log function of C ($R \sim \log(C)$; Fechner-Weber's law, Fechner, 1907), these authors interpreted their results as a manifestation of an inhibitory process (during suppression) occurring *after* the transducing stage (or gain control operator). Indeed, as sensitivity is modeled as the derivative of R with respect to C , a posttransducer divisive inhibition, m (i.e., $R \sim m\log(C)$, with $m < 1$), yields $\delta R/\delta C \sim m/C$ and $\delta C \sim m^{-1}C$, which is an *upward* shift of the TvC function on a log-log scale. The same conclusion would be reached if R were a power function of C ($R \sim C^\gamma$; Stevens' law, 1957), or a Naka-Rushton function ($R = R_{\max}C^\gamma/(S^\gamma + C^\gamma)$; Naka & Rushton, 1966; see Foley, 1994). For a pretransducer inhibition, the three putative transducers yield different threshold changes: no change at all for Fechner's law, a *downward* TvC shift for Stevens' law, and either an upward or a downward shift for Naka-Rushton depending on the relationship between its free parameters (s , γ) and C .¹ Hence, the processes underlying the suppression of an otherwise highly visible stimulus do not necessarily translate into a measurable sensitivity change. Although the counterintuitive option of a threshold drop under the suppressed phase was rejected for binocular rivalry, it remains possible for other oscillatory percepts such as MIB. In fact, given that, contrary to other perceptual oscillatory phenomena (see Mueller & Blake, 1989), high-contrast stimuli disappear more frequently than low-contrast stimuli under MIB conditions (Bonneh et al., 2001), this option is even plausible.

The first purpose of the present study was to compare the TvC functions (obtained with a 2AFC procedure) under MIB conditions for visible and suppressed targets. It should be stressed from the start that in no way does the present study intend to inform on the validity of one of the three transducers alluded to above over the remaining two (and even less on its putative location in the visual processing stream). In fact, the critical literature is still debating on this issue (e.g., Meese, 2004; Meese &

Holmes, 2002; Yu, Klein, & Levi, 2003). However, based on the logic developed above (see also [Footnote 1](#)), an upward Tvc shift under the suppressed state will strongly hint to the reliance on a posttransducer divisive inhibition regardless of the transducer.

The second purpose of the present study was to determine whether the MIB phenomenon also involves a decision-criterion shift (during the suppressed phase) as suggested (Gorea & Sagi, 2000, 2002; Klein, 1998) and actually observed (Azzopardi & Cowey, 1997; Campion et al., 1983; Ricci & Chatterjee, 2004) for neglect patients with extinction. To answer this question, we used, in the present study, a Yes/No experimental format and assessed d'' and decision criteria for four contrast increments applied to a highly suprathreshold MIB target under visible and suppressed phases. By so doing, it allows a rough estimation of the psychometric functions for these two perceptual states and thereby an indirect derivation of their associated internal noises (related to the slopes of these functions). Again, the observed constancy of the psychometric function slopes under suppressed and dominant binocular rivalry phases (Sanders, 1980; *passim* Watanabe et al., 2004) is no guarantee of an equivalent result under MIB conditions.

Methods

Observers

Four volunteers who were naïve to the purpose of this study and the first author (all of whom were 24–25 years old), with normal or corrected-to-normal vision, participated in the two experiments.

Stimuli

They were presented on a 19-in. gamma-corrected screen (LG Flatron 795FT Plus, $1,024 \times 750$ pixel resolution and 75 Hz refresh rate) 70 cm away from the observers in a dimly lit room. The target stimulus was a $0.3^\circ \times 1.6^\circ$ bar ([Figure 1](#)) presented at 6.4° (in the left hemifield) from a white fixation cross ($0.57^\circ \times 0.57^\circ$) and surrounded by a “mask” pattern subtending an $8.3^\circ \times 8.3^\circ$ area. The mask pattern was composed of 49 (7×7) 23.7 cd/m^2 blue crosses, $0.7^\circ \times 0.7^\circ$ each. The whole mask rotated clockwise about its center (coinciding with the center of the target) at 5.23 rad/s . Fixation of a central cross (at the center of the screen) presumably minimized eye movements. Target (also referred hereafter as pedestal) and mask were displayed on a 10.7 cd/m^2 background (L_0). The target/pedestal was set at one of five luminance levels equally spaced on a log scale between 14.1 and 40.0 cd/m^2 . Luminance increments were randomly applied

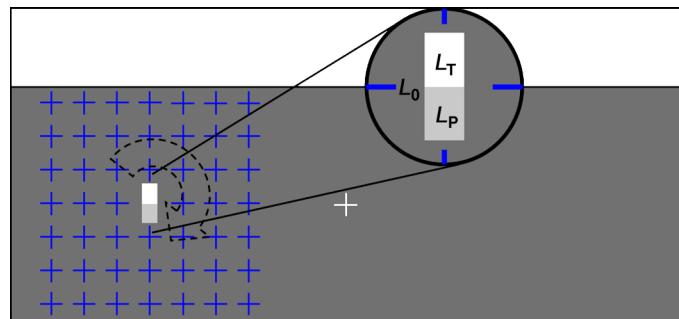


Figure 1. Experimental display (not at scale) used in the two experiments. The dotted arrow indicates the rigid rotational movement of the background crosses. The inset shows an enlargement of the target area where L_0 , L_P , and L_T refer to the luminance of the background, of the pedestal, and of the test increment, respectively.

for 100 ms to either the upper or lower half of the vertical bar pedestal and observers had to specify which of the two halves was incremented.

Procedure

Luminance (or contrast; see below) increment detection thresholds as a function of pedestal luminance (Tvc functions; [Experiment 1](#)) and d'' and decision criteria for one pedestal level ($L = 31.2 \text{ cd/m}^2$) and four increment levels ([Experiment 2](#)) were measured in independent sessions for each of the two phenomenal states of the observers, that is, target visible and suppressed. In “target-visible” sessions, observers initiated a trial at their leisure by pressing a key while the target was visible; in the “target-suppressed” sessions, they pressed the key as soon as the target vanished. In either case, a 100-ms luminance increment was applied 50 ms after the key press. The whole display (mask and target) was erased 850 ms after the offset of the increment.

In [Experiment 1](#) (run first), the Tvc function was assessed by means of a 2AFC staircase procedure. An increment was randomly applied to either the lower or the upper part of the target bar (see [Figure 1](#)), and observers indicated its location by pressing one of the two mouse buttons. The increment size at the beginning of the staircase was set, on average, at 6 dB above the actual threshold. Following three consecutive correct responses, the magnitude of the increment was decreased by 2 dB and increased by the same amount after each incorrect response—a procedure converging to 79% correct responses (Levitt, 1971), which is equivalent to a d'' of 1.14 (Macmillan & Creelman, 1991). The staircase was ended after eight reversals, and the threshold was computed as the mean of the increment amplitudes over the last six reversals. Increment thresholds for the five different pedestal levels and the two phenomenal states

were assessed in different sessions and repeated thrice. The order of the sessions (each specified by the pedestal luminance and phenomenal state) was randomized for each repeat and observer.

In **Experiment 2**, only one pedestal luminance (31.2 cd/m^2) was used throughout, and d' values, together with decision criteria, were assessed in separate sessions for four increment magnitudes by way of a Yes/No procedure with the increment randomly applied to either the lower or the upper part of the bar in 50% of the trials. The four increment amplitudes (1.24, 1.37, 1.50, and 1.62 dB) were chosen based on preliminary sessions so that the smallest and largest increments yield for all observers d' values not lower than 0.4 and not higher than 3.5. One session (specified by the increment magnitude and by the observer's phenomenal state) consisted of 100 trials and was repeated thrice so that d' values and decision criteria (defined as $c = 0.5(z_H + z_{FA})$, where z_H and z_{FA} are the z scores of hits and false alarms²) were computed from 300 trials per observer. The order of the sessions was randomized for each observer.

It should be noted that both the stimulation setup and some aspects of the procedure were finalized after a long series of preliminary experiments meant to maximize the duration and stability of the individual MIB durations and, hence, the reliability of the threshold/ d' measurements. Originally, these measurements were made with a “standard” MIB configuration where the rotating mask was presented at the center of the screen and where the target (a $0.9^\circ \times 0.9^\circ$ cross) was presented 2.7° from fixation in the upper left corner along the main diagonal. This configuration yielded relatively short MIB periods (<1.5 s), which, together with a 100-ms delay between an observer's key press and the target's luminance increment, produced small and unstable threshold increments (compared to those assessed with visible targets). Postexperimental interviews revealed that, in the target-suppressed perceptual states, observers frequently experienced premature target reappearance, that is, before or within milliseconds after the increment was applied. Premature target reappearances can be triggered both by the abrupt luminance increment (Kawabe, Yamada, & Miura, *in press*) and by microsaccades set off by an observer's intention to press the key while focusing his attention on the target location; such premature target reappearances are most likely favored under shallow suppression states. Hence, the preliminary trial-and-error manipulations were meant to find the stimulation parameters that strengthen the suppression states. In addition to those, preliminary observations indicated that the first target disappearance within each trial tended to last less and be more easily terminated by the test increment than subsequent disappearances (presumably because of a shallower adaptation state). Hence, observers were encouraged to refrain from signaling it and await the second or even the third disappearance in a trial. These observations

are of importance as they point at the difficulty of obtaining reliable threshold or d' assessments during MIB and at the particular care needed to choose the optimal stimulating and response recording conditions (for a comprehensive discussion of the topic, see Kim & Blake, 2005).

Results

Observations on MIB phenomenology

The time lapse between the beginning of a trial and an observer's key press to signal a target's disappearance was not measured as observers were encouraged to ignore the first or even the first two disappearances (see the **Methods** section). This instruction was based on our long-lasting experience with MIB: The duration of a disappearance tends to increase with inspection time and practice (Bonneh, Sagi, & Cooperman, 2005), suggesting the incremental contribution of an adaptation process. For one observer (out of five), the time lapse before the first disappearance was consistently longer (up to 1 min) than usually reported. Observers occasionally signaled partial target disappearances (i.e., of the upper or lower part of the pedestal) and were instructed to ignore them. All observers signaled the reappearance of the suppressed pedestal as if triggered by the test increment when this increment was large (at the start of the staircase) but not when it was close to threshold. Target reappearance was also reported on almost all occasions where observers were aware of their inadvertent eye movements. Two observers reported that their perception of the rotating mask alternated between a state where its components (crosses) appeared as individualized items and a state where they were grouped to form a unitary rotating surface. Interestingly, they also reported an increased likelihood of a target's disappearance concomitant with the transition to a latter state. A potentially related phenomenon was reported by Graf et al. (2002).

Experiment 1: TvC functions

The appropriate way of representing luminance increment thresholds as a function of the pedestal luminance, L_P , has been a matter of debate (e.g., Kingdom & Moulden, 1991; Whittle, 1986). For the present stimulus configuration where the reference pedestal was itself displayed on a nonnull background, L_0 , two data display formats are equally legitimate whereby (a) the liminal *luminance* increment, $\Delta L_\theta (= |L_T - L_P|)$, is plotted as a function of the pedestal *luminance* relative to the background luminance, that is, $L_{P,\text{relative}} (= |L_P - L_0|)$, or

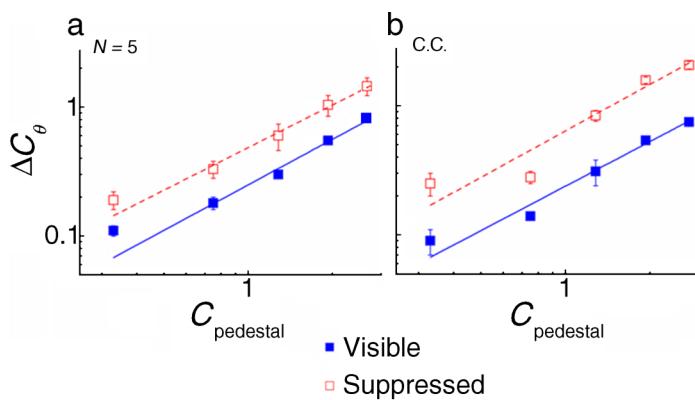


Figure 2. Increment ΔC_θ thresholds averaged over the five observers (a), and for one of them (b), for visible (filled symbols) and suppressed targets (open symbols) as a function of pedestal contrast, C_{pedestal} . Solid and dashed straight lines are best power function fits for the visible and suppressed conditions, respectively. Vertical bars are ± 1 SE across observers (a) and over the three repeats for one observer (b).

(b) the liminal *contrast* difference, ΔC_θ , is plotted against the pedestal *contrast* (C_P ; relative to the background luminance, Tvc function); that is,

$$\Delta C_\theta = \frac{|L_T - L_0|}{L_0} - \frac{L_P - L_0}{L_0} = \frac{|L_T - L_P|}{L_0} \quad (1a)$$

and

$$C_P = \frac{|L_P - L_0|}{L_0}. \quad (1b)$$

As it can be noted, the contrast representation is but a normalized (by L_0) version of the luminance representation. Inasmuch as the incremental threshold is a linear function of the pedestal magnitude in log–log coordinates (e.g., Foley & Legge, 1981; Gorea & Sagi, 2001; Legge, 1981; Legge & Foley, 1980; Watanabe et al., 2004), the

two representations yield the same log–log slopes but different intercepts. For the sake of comparison with Watanabe et al.’s (2004) equivalent study in binocular rivalry, the data below are displayed in the second format above (Tvc; Equations 1a and 1b).

Figure 2 displays Tvc functions averaged over the five observers (Figure 2a), and for one of them (Figure 2b), under target-visible (filled symbols) and target-suppressed (open symbols) conditions. The mean suppressed-to-visible ΔC_θ ratio is 1.84 (0.26 log units), which is close to that obtained in binocular rivalry (Watanabe et al., 2004).³

A two-factor (pedestal contrast and phenomenal state) repeated measures ANOVA performed on the $\log(\Delta C_\theta)$ data shows a significant effect of phenomenal state, $F(1, 4) = 20.1, p < .05$, and pedestal contrast, $F(4, 16) = 144.9, p < .001$, with no significant interaction between the two, $F(4, 16) = 0.1, p = .99$. This lack of interaction implies that the visible and suppressed phases yield equivalent Tvc slopes (i.e., exponents of the fitted power function; see below).

Whether the target was perceived or not, contrast thresholds (ΔC_θ) are well fit by power functions of the pedestal contrast, C_P ($\Delta C_\theta = k_C C_P^\omega$; solid and dashed straight lines in Figure 2 for visible and suppressed phenomenal states, respectively). Table 1 displays the exponents, ω (slopes in the log–log plots of Figure 2), and the gain (i.e., intercept) parameters as estimated from the data when expressed as contrast, k_C , and as luminance, k_L , thresholds (see above) for each observer together with their means. The mean ω is close to unity (Weber’s law), which is substantially higher than the exponents obtained for spatially modulated gratings (e.g., Foley & Legge, 1981; Gorea & Sagi, 2001; Henning & Wichmann, 2007; Legge, 1981; Legge & Foley, 1980; Nachmias & Sansbury, 1974) but close to the exponents inferred for luminance discrimination thresholds with spatially localized stimuli (e.g., Cornsweet & Teller, 1965; Hood & Finkelstein, 1986).

As suggested by the analysis above, the gain parameter (k_C or k_L) increases in the suppressed phase (by an average factor of 1.92 and 2.33, depending on whether it is computed for the contrast or luminance data formats, respectively), whereas the ω exponent is equivalent for the

Observer	ω (Tvl and Tvc)		k_C (Tvc)		k_L (Tvl)	
	Visible	Suppressed	Visible	Suppressed	Visible	Suppressed
F.C.	1.19	1.24	0.22	0.30	0.14	0.17
C.C.	1.15	1.20	0.24	0.64	0.18	0.41
P.C.	1.09	0.85	0.32	0.76	0.27	1.10
D.G.	1.05	1.14	0.25	0.41	0.23	0.29
M.T.	1.41	1.32	0.21	0.28	0.08	0.13
M	1.17 ± 0.06	1.15 ± 0.08	0.25 ± 0.02	0.48 ± 0.10	0.18 ± 0.03	0.42 ± 0.18

Table 1. Exponents (ω) and gains (k_C , k_L) of the power functions fitted to the Tvl and/or Tvc data formats (Figure 2) for visible and suppressed phenomenal states.

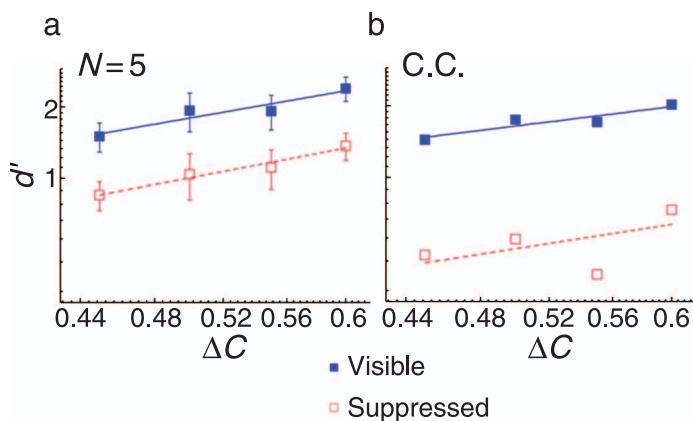


Figure 3. d' averaged over the five observers (a), with bars indicating $\pm 1\text{ SE}$, and for one of them (b), as a function of stimulus change (ΔC) for visible (full symbols) and suppressed targets (open symbols). Standard errors are not shown for the individual data (as in Panel b) because individual d' values were computed from the 300 trials run by each observer.

two phenomenal states. A linear regression analysis performed on the $\log(\Delta C_\theta)$ data of all observers confirmed the parallelism between the visible and suppressed Tvc functions as the difference between their slopes is not significant, $F(1, 6) = 0.022$, whereas their intercepts differ significantly, $F(1, 7) = 44.56, p < .0001$. Linear regression analyses performed on each observer's data yield equivalent effects with the exception of observer M.T. whose intercepts for the visible and suppressed states do not differ significantly.

Overall, the present results and statistical analyses point to a global vertical shift of the Tvc function during MIB and are in line with Watanabe et al.'s (2004) binocular rivalry data. As argued in the [Introduction](#) section, this shift is compatible with a form of divisive inhibition operating during MIB and occurring after the transducing stage whether this transducer is of the form of a log, power, or Naka-Rushton function (see also [Footnote 1](#)).

Experiment 2: Sensitivity (d') and decision criteria (c)

To cite from Green and Swets (1966, p. 108), "the principal value of the forced-choice task is that it practically eliminates the need to deal with the observer's decision criterion." The main purpose of the present Yes/No experiment was precisely *not* to eliminate this parameter as our concern was to assess its relation to the observer's decisional behavior under visible and suppressed MIB states. To do so, we fixed the target/pedestal luminance at 31.2 cd/m^2 and assessed d' values and decision criteria for four increment levels. The experimental format allows the assessment of the psychometric

functions obtained under the two phenomenal states and, most critically, the test of the conjecture that the suppression phase in MIB reflects, at least in part, an upward decision-criterion shift with respect to the visible phase.

[Figure 3](#) shows d' values averaged over the five subjects ([Figure 3a](#)), and for one of them ([Figure 3b](#)), under target-visible (filled symbols) and target-suppressed (open symbols) conditions as a function of the target increment magnitude (in contrast units, ΔC). Solid and dotted lines are power function fits ($d' = k(\Delta C)^\beta$; Pelli, 1985; for a d' derivation based on a Naka-Rushton transducer type, see Yu et al., 2003). Observers show an overall sensitivity drop in the suppressed phase by an average factor of 1.77 (an average of 0.84σ). A two-way repeated measures ANOVA (with phenomenal state and ΔC as factors) shows a significant effect for the two factors, phenomenal state: $F(1, 4) = 7.09, p < .05$; $\Delta C: F(3, 12) = 19.39, p < .001$, with no significant interaction between them, $F(3, 12) = 0.84, p = .50$. This lack of interaction implies that the visible and suppressed phases yield psychometric functions with similar slopes (see below).

The average psychometric function fits yield slightly larger exponents/slopes (β) but smaller elevations (k) for the suppressed ($\beta = 1.58; k = 3$) than for the visible ($\beta = 1.45; k = 4.9$) MIB states. A linear regression analysis performed on the mean $\log(d')$ indicates that these slopes are not significantly different, $F(1, 4) = 0.15, p = .72$, whereas the elevations are, $F(1, 5) = 200.37, p < .001$. Equivalent analyses performed on the slopes and elevations of the psychometric functions for each observer yield similar effects except for observer P.C. whose elevations do not differ significantly. This shift of the psychometric function along the ordinate without changes in slope is indicative of a divisive reduction of signal strength rather than of an increase in the internal noise. The preservation of the psychometric function slopes under visible and suppressed states has also been observed for binocular rivalry (Sanders, 1980; *passim* Watanabe et al., 2004).

The mean ΔC_θ values derived from the fitted d' functions ($\Delta C_{\theta,\text{Exp } 2} = (d'/k)^{1/\beta}$) for a $d' = 1.14$ (the theoretical sensitivity at the detection threshold, θ , as assessed with the 2AFC 1-up–3-down staircase procedure of [Experiment 1](#)) are globally lower than those actually measured in [Experiment 1](#) with the 31.2 cd/m^2 pedestal for both the visible ($\Delta C_{\theta,\text{Exp } 1} = 0.55; \Delta C_{\theta,\text{Exp } 2} = 0.37$) and the suppressed ($\Delta C_{\theta,\text{Exp } 1} = 1.13; \Delta C_{\theta,\text{Exp } 2} = 0.59$) MIB states. These differences are substantially larger than those previously reported (Green & Swets, 1966, p. 112). The only account we can offer is that the lower thresholds derived from the Yes/No data reflect a learning effect as this experiment was run after the 2AFC one. As the 2AFC experiment was run with five intermingled pedestal levels (as opposed to the one pedestal level used in the Yes/No experiment), it is also possible that the 2AFC thresholds were relatively increased due to this additional "noise" factor.

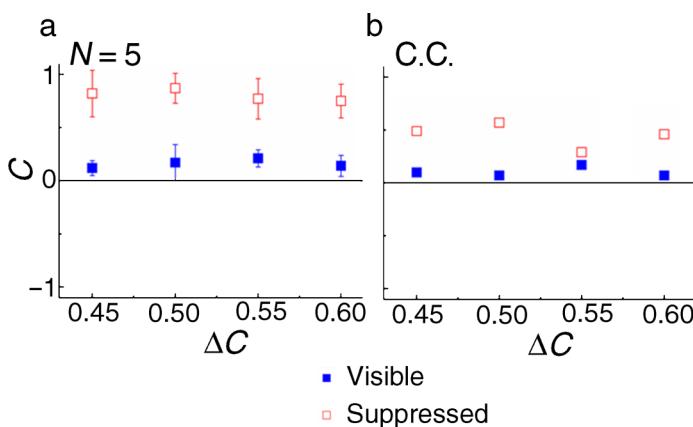


Figure 4. Criteria averaged over the five observers (a), with bars indicating ± 1 SE, and for one of them (b), as a function of stimulus increment (ΔC) for the visible (solid symbols) and suppressed targets (open symbols).

Figure 4 displays criterion (c) values averaged over the five observers (Figure 4a), and for one of them (Figure 4b), for visible and suppressed targets (filled and open symbols, respectively) as a function of the target increment magnitude (ΔC). The horizontal dotted line at $c = 0$ denotes the optimal behavior. Under the visible state, as expected, all observers but one (M.T.; $c = .49$) use a criterion close to optimal (mean $c \pm 1$ SE = 0.08 ± 0.04). Under the suppressed state, all observers raise their criterion by an average of 0.68σ (mean $c \pm 1$ SE = 0.83 ± 0.14), barely below the average d' drop (0.84σ). A two-way repeated measures ANOVA on the c data (with phenomenal state and ΔC as factors) reveals a significant effect of the phenomenal state, $F(1, 4) = 15.57, p < .05$, but not of the ΔC factor, $F(3, 12) = 0.49, p = .70$, with no significant interaction between the two, $F(3, 12) = 1.00, p = .42$. The present data and analysis clearly demonstrate that MIB is associated with a conservative decision behavior although they cannot specify whether this behavior is one of its causes or a consequence of the depleted sensitivity assessed in Experiments 1 and 2.

Discussion

The present results indicate that MIB is associated with both a sensitivity drop and a decisional criterion shift to higher values. In Experiment 1, the Tvc functions for the suppressed phase yielded an average upward shift (relative to the nonsuppressed phase) of 0.26 log units (Figure 2), congruent with the results obtained in an equivalent binocular rivalry study by Watanabe et al. (2004). This sensitivity drop is confirmed by the second experiment showing that the psychometric functions assessed under the suppressed phase are shifted downward compared to the nonsuppressed phase without a change in slope

(Figure 3). This behavior suggests that the sensitivity loss observed during MIB results from a divisive reduction of the signal strength (gain) rather than from an increase in the internal noise.

The upward shift of the Tvc function is compatible with a posttransducer divisive inhibition (see the Introduction section and Footnote 1). As noted a while ago by Dealy and Tolhurst (1974) and originally modeled by Foley (1994) and Foley and Chen (1997), such an inhibition may result from prolonged adaptation, a process invoked at least since Kohler (1940) to account for unstable perception phenomena (for a recent review, see Blake, Sobel, & Gilroy, 2003). At the same time, this same literature also posits a mutual target-distracter short-lived inhibition (i.e., not due to prolonged inspection) reflecting the antagonism between competitive processes (for a review, see Lankheet, 2006). Although this competition is readily understood for unstable phenomena such as binocular rivalry or Necker cube, its substrate remains a matter of debate for the MIB phenomenon. A number of studies suggest that the relevant competition in MIB occurs at high processing levels between incompatible perceptual representations of the static targets and the moving distracters (e.g., Funk & Pettigrew, 2003; Graf et al., 2002; Kanai, Paffen, Gerbino, & Verstraten, 2004). The possibility remains that the MIB target is transiently inhibited at an earlier processing stage by the moving background (e.g., Breitmeyer, Love, & Wepman, 1974; Gorea & Fiorentini, 1982; Kanai et al., 2004; Yantis & Nakama, 1998) via lateral interactions (Baloch & Grossberg, 1997; Finkel & Edelman, 1989; Grossberg & Rudd, 1992; Tononi, Sporns, & Edelman, 1992; Zeki & Shipp, 1988) and/or feedback loops (Angelucci et al., 2002; Felleman & Van Essen, 1991; Zeki & Shipp, 1988). Funk (cited by Funk & Pettigrew, 2003) actually showed that TMS of area MT (hence disruption of motion processing) decreases the MIB effect. Libedinsky and Livingstone (2006) proposed that both low- and higher level suppression processes ("downstream of V1 and upstream of inferotemporal cortex") are at work in MIB. Be it as it may, the MIB effect is most likely contributed to by both long-lived (due to adaptation, as in the Troxler effect; e.g., Hsu, Yeh, & Kramer, 2006; Wilke, Logothetis, & Leopold, 2003) and short-lived inhibition (Wilke et al., 2003).

Experiment 2 shows that, in addition to a sensitivity loss, the suppression stage in MIB is also subtended by a change in observer's decisional behavior. Response criteria during this phase are about 0.68σ larger than during the visible phase (Figure 4). Whether this criterion change is a (partial) cause of MIB or rather the consequence of the related sensitivity loss remains undecided. The first alternative could be related to attentional variations triggering the suppressed phases in MIB (via a criterion shift; see Gorea & Sagi, 2005) but is short of a firm theoretical ground and requires further investigation. The second alternative is reminiscent of Gorea and coll. (Gorea & Sagi, 2000, 2001, 2002, 2005;

Gorea, Caetta & Sagi, 2005) findings that lower saliency sensory events are more frequently ignored when presented together (whether simultaneously or in sequence) with more salient ones than without. In the present context, the two saliency levels tally with the two phenomenal states. In any event, the decisional behavior of observers presented with perceptually bistable stimulations has not been previously documented and deserves further examination.

In summary, the present study points to the fact that the MIB phenomenon is concomitant with a sensitivity drop (most likely due to a posttransducer divisive inhibition), as well as with a shift toward higher values of the decision criterion. The present experimental paradigm does not allow deciding whether these changes are its (exhaustive) causes or consequences. While the sensitivity drop is most likely a cause, the fact that the criterion shift may well be one of its side effects is consistent with Gorea and Sagi's (2000, 2001, 2002, 2005) observation that criterion shifts result from a saliency imbalance between simultaneous or intermingled sensory events.

The question of whether or not the relatively mild sensitivity changes presently observed (very similar to those observed during binocular rivalry; Watanabe et al., 2004) may, by themselves, account for the MIB remains unsettled. That this could be so is consistent with a number of studies having demonstrated the perceptual suppression (Kanai & Kamitani, 2003) or the perceptual alternation (Kanai, Moradi, Shimojo, & Verstraten, 2005) of suprathreshold targets subsequent to the transient stimulation with more salient stimuli. Kanai and Kamitani (2003) and, more recently, Simons et al. (2006) also demonstrated that the brief removal or contrast reduction of a target causes its subsequent fading, an indication that offset transients per se are sufficient to induce fading. The point made here is that, in addition to a sustained target adaptation process, the sudden drop in the saliency of the MIB target (due to the sudden change in the transducer's gain) could, by itself, result in its total suppression (e.g., Wilke et al., 2003). The criterion shifts presently revealed would reinforce and prolong the phenomenal disappearance of the target during MIB.

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Footnotes

¹For Steven's law, $R \sim C^\gamma$ (with γ typically below 1; e.g., Foley & Legge, 1981; Gorea & Sagi, 2001; Legge, 1981); the derivative of R with respect to C is $\delta R/\delta C \sim \gamma C^{\gamma-1}$. A divisive inhibition m (<1) applied *after* the transducer yields $R \sim mC^\gamma$ with $\delta R/\delta C \sim m\gamma C^{\gamma-1}$, that is, an *upward threshold shift* ($\delta C \sim m^{-1}\gamma C^{1-\gamma}$). The same is true for an inhibited Naka–Rushton transducer ($R = mR_{\max}C^\gamma/(s^\gamma + C^\gamma)$, where R_{\max} and s are the saturation and semisaturation constants, respectively, and where γ is the maximum steepness of the function; but see Meese & Holmes, 2002; Yu et al., 2003) as its derivative with respect to C is $m(pR_{\max}C^{\gamma-1}s^\gamma/(s^\gamma + C^\gamma)^2)$ so that δC is again proportional to m^{-1} . The case of an inhibition *before* the transducer can be written as $R \sim (mC)^\gamma$, $\log(mC)$, and $R_{\max}(mC)^\gamma/(s^\gamma + (mC)^\gamma)$ for Stevens, Fechner, and Naka–Rushton, respectively. The corresponding derivatives with respect to C are $(mC)^{1-\gamma}$, $1/C$, and $(\gamma R_{\max}m^\gamma C^{\gamma-1}s^\gamma)/(s^\gamma + m^\gamma C^\gamma)^2$. Hence, a pretransducer inhibition should yield a *threshold drop* for Stevens ($\delta C \sim (mC)^{1-\gamma}$), an *unaffected threshold* for Fechner ($\delta C \sim C$), and a threshold that may either increase or drop for Naka–Rushton depending on the relationship between C and the free parameters s and γ (the proof of the latter is beyond the scope of this study; for a detailed discussion of these parameters, see Meese & Holmes, 2002 and Yu et al., 2003).

²According to this notation (Green & Swets, 1966), an unbiased decision behavior yields $c = 0$ with negative and positive values corresponding to "liberal" and "conservative" behaviors, respectively.

³One of our reviewers was concerned with the fact that the transition from the suppressed to the visible states may have occasionally occurred during the 100-ms presentation of the test increment, thereby reducing its effectiveness and, hence, accounting (at least partly) for the larger thresholds under the suppressed phase. To answer this concern, we have reduced the increment duration to 10 ms and measured the suppressed and visible thresholds for one target contrast (1.28, i.e., 13.6 cd/m²). For the two tested observers, the suppressed thresholds were 1.93 and 1.43 times larger than the visible ones, an increase practically identical to the one observed with 100-ms increment durations.

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