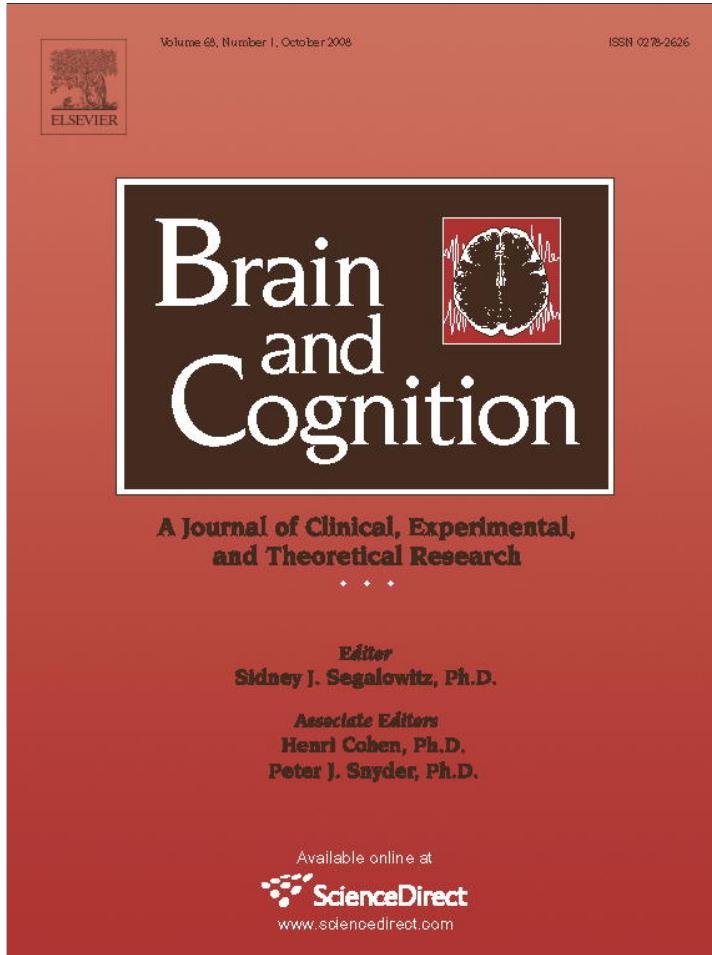


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The role of the magnocellular and parvocellular pathways in the attentional blink

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Abstract

The attentional blink refers to the transient impairment in perceiving the 2nd of two targets presented in close temporal proximity in a rapid serial visual presentation (RSVP) stream. The purpose of this study was to examine the effect on human attentional-blink performance of disrupting the function of the magnocellular pathway—a major visual-processing pathway specialized in temporal segregation. The study was motivated by recent theories that relate the attentional blink to the limited temporal resolution of attentional responses, and by a number of poorly understood empirical findings, including the effects on the attentional blink of luminance adaptation and distraction. The attentional blink was assessed for stimuli on a red background (Experiment 1), stimuli on an equiluminant background (Experiment 2), and following flicker or motion adaptation (Experiment 3), three psychophysical manipulations known to disrupt magnocellular function. Contrary to our expectations, the attentional blink was not affected by these manipulations, suggesting no specific relationship between the attentional blink and magnocellular and/or parvocellular processing.

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1. Introduction

An important question addressed by cognitive psychologists is how much time our cognitive system needs to turn relevant perceptual information into a representation that can be remembered or acted upon, before the system is available again for the next piece of information. Much of the research addressing this question has used the *attentional-blink* paradigm. In the standard version of this paradigm, participants are asked to report two targets that are embedded in a rapid serial visual presentation (RSVP) stream of distractor stimuli. All items are presented in the same location at a rate of about 10 items per second. Participants usually have no difficulty with reporting the first target (T1). However, if the second of the two targets (T2) is presented at temporal positions within about 500 ms

of T1, report of T2 is considerably impaired—a phenomenon that is referred to as the attentional blink (Raymond, Shapiro, & Arnell, 1992). The attentional blink suggests that under the perceptually demanding conditions imposed by an RSVP stream, our cognitive system is rather limited in the rate at which durable representations of distinct perceptual stimuli can be formed.

One class of theories that have attempted to explain the mechanism underlying the attentional blink has emphasized the limited temporal resolution of our attentional system (Bowman & Wyble, 2007; Nieuwenstein, Chun, van der Lubbe, & Hooge, 2005; Olivers, van der Stigchel, & Hulleman, 2007; Raymond et al., 1992). For example, Olivers (2007) has proposed that the attentional responses to RSVP stimuli are sluggish, generally lagging behind the stimuli that elicit them. As a result, they bias the processing not (just) of the eliciting stimulus, but also of the subsequent stimulus: Stimuli following targets receive a high attentional weight, and stimuli following distractors receive

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a low attentional weight. If T1 is followed by a distractor, the processing of the distractor is potentiated, which may in turn lead to a strong suppressive response that, if sufficiently long-lasting, may cause an attentional blink for subsequent stimuli (Raymond et al., 1992). This type of account can also explain various other results, including the finding that T2 performance is typically spared if T2 immediately follows T1 (Nieuwenhuis, Gilzenrat, Holmes, & Cohen, 2005; Raymond et al., 1992), or if T2 is immediately preceded by a third target or a distractor sharing the target-defining property (Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Nieuwenstein et al., 2005; Olivers et al., 2007).

The goal of the present research was to investigate whether the limited temporal resolution of the attentional system, as expressed in the attentional blink, might be mediated by some of the main characteristics of the visual system. Physiological and anatomical studies have revealed that the primate visual system consists of several parallel information-processing channels. The two major channels, the parvocellular and magnocellular pathways, originate in the retina, have distinct projections to the lateral geniculate nucleus, and remain in part segregated in cortical visual areas. The cells in the two pathways have very different physiological and functional properties (for reviews see Livingstone & Hubel, 1988; Schiller & Logothetis, 1990): Parvo cells respond in a relatively slow and sustained manner to visual stimulation, have a small receptive field, and are specialized in analyzing the color, shape, and other static surface properties of objects. Therefore, facilitation of the parvocellular pathway leads to increased *spatial segregation* (due to the small receptive field size) and increased *temporal integration* (due to the sluggish response profile). In contrast, magno cells respond much faster and more transiently, have larger receptive fields, and are specialized in analyzing movement and low-frequency information. As a result, facilitation of the magnocellular pathway promotes *spatial integration* and *temporal segregation*, an influence that opposes and complements that of the parvocellular pathway. In line with this physiological interaction, psychophysical tests have demonstrated that experimental manipulations that induce focused spatial attention cause a concurrent decrement in temporal resolution (Yeshurun & Levy, 2003).

We hypothesized that the usual instruction to identify targets within an RSVP stream places the cognitive system in a processing mode that shifts the relative contribution of the parvocellular and magnocellular pathways toward the former. However, although parvo cells are presumably more sensitive to the detailed features of the stimuli typically used in attentional-blink tasks, their prolonged neural response periods render them unsuitable for segregating the individual stimuli. That is, when two stimuli are separated by a brief interval, the corresponding neural responses are likely to be integrated over time, resulting in decreased temporal resolution. In contrast, magno cells respond instantly and vigorously to the type of luminance flicker presented

by an RSVP stream, leading to distinct neural representations for each of the individual stimuli. Together, this suggests that performance in the attentional-blink task might benefit from experimental manipulations that favour a more dominant contribution of the magnocellular pathway to the processing of the RSVP stream. In contrast, performance might be impaired by manipulations that disrupt magnocellular function.

There are several lines of (indirect) evidence for this hypothesis. Perhaps the most supportive evidence concerns the effect of luminance adaptation on the attentional blink. Giesbrecht and colleagues compared performance on an attentional-blink task after 40 min of dark adaptation (scotopic viewing condition) and after 40 min of adaptation to ambient light (photopic viewing condition; Giesbrecht, Bischof, & Kingstone, 2004). An attentional blink was observed only in the photopic viewing condition. Interestingly, physiological and psychophysical experiments have demonstrated that under scotopic viewing conditions, visual processing is dominated by the magnocellular pathway (Benedek, Benedek, Keri, Letoha, & Janaky, 2003; Purpura, Kaplan, & Shapley, 1988), presumably because there is strong rod input to the magnocellular pathway, but negligible rod input to the parvocellular pathway. Rods are retinal cells that form the primary source of information under scotopic viewing conditions. According to our hypothesis, the dominant contribution of the magnocellular pathway under scotopic viewing conditions is consistent with the absence of an attentional blink under such conditions.

The parvo/magno hypothesis would also offer an intriguing explanation of the counter-intuitive finding that the attentional blink is ameliorated by manipulations that promote divided visual attention. For example, Olivers and Nieuwenhuis (2006) found that the attentional blink is smaller following explicit instructions to participants to “concentrate a little less”, and to “pay a little less attention” to the RSVP stream. Similarly, the attentional-blink magnitude is much reduced if T2 is presented at an unattended location quite far away from T1 (Kristjánsson & Nakayama, 2002). These and other distraction manipulations (Arend, Johnston, & Shapiro, 2006) may be assumed to reduce the attentional focus on the RSVP stream. Importantly, as discussed above, there is evidence indicating that increases in focused spatial attention cause a concurrent decrement in temporal resolution, possibly as a result of the mutual trade-off between spatial and temporal sensitivity of the parvo- and magnocellular pathways (Yeshurun, 2004; Yeshurun & Levy, 2003). This raises the possibility that the reduction in attentional-blink magnitude under distracting conditions reflects the increased magnocellular involvement and accompanying increase in temporal resolution associated with a reduction in focused spatial attention.

There are various other striking similarities between the attentional blink and properties of the magnocellular system. For example, magno cells show maximal sensitivity

to flicker at around 10 Hz (Lee, Martin, & Valberg, 1989), which is more or less the same frequency as the RSVP stream in most attentional-blink experiments. Furthermore, backward masking of the targets by subsequent RSVP items is crucial for the occurrence of an attentional blink (Brehaut, Enns, & Di Lollo, 1999). This is consistent with the observation of an increased effect of backward masking under task conditions that attenuate magnocellular activity (Okubo & Nicholls, 2005). Finally, there is some evidence that the magnitude of the attentional blink varies with stimulus size and with the requirement to identify either the global aspects or the local details of RSVP stimuli (Lawson et al., 2002). Although the exact influence of these factors, and in particular their interaction, requires further investigation, the broad pattern of results appears consistent with the well-documented role of the magnocellular pathway in processing low spatial frequencies and global aspects of a scene (Breitmeyer & Breier, 1994; Chikashi, Okubo, & Mugishima, 1999).

Here we report three experiments that were designed to test the possible influence of the relative contribution of parvo- and magnocellular activity on the attentional blink. Each of the experiments capitalized on the differential sensitivity of the magno- and parvocellular pathways, by using psychophysical manipulations shown to be successful in previous behavioral and neurophysiological research.

A subset of cells in the magnocellular pathway is inhibited by red diffuse light, due to an inhibitory surround that is selectively sensitive to long wavelengths. Therefore, the use of a red background disrupts performance on tasks requiring high temporal resolution (e.g., Breitmeyer & Williams, 1990; Wiesel & Hubel, 1966). In Experiment 1, we exploited this property to manipulate the relative involvement of the parvo- and magnocellular pathways in an attentional-blink task. On each trial, participants were required to identify the two digits that were embedded in an RSVP stream of letter distractors. In one condition the stimuli were presented against a red background, and in another condition they were presented against a green background. The conditions were identical in terms of the luminance contrast between stimuli and background, and in terms of general luminance. Our prediction was that the magnitude of the attentional blink would be larger with a red than with a green background, because the red light was assumed to weaken magnocellular involvement in processing the RSVP stream.

In Experiment 2, we made use of another property of the magno- and parvocellular pathways: Stimuli with low luminance contrast and equal color to the background preferentially activate the magnocellular pathway, whereas stimuli that are equiluminant but of a different color than the background preferentially activate the parvocellular pathway (Kaplan & Shapley, 1986; Schiller & Logothetis, 1990; Steinman, Steinman, & Lehmkuhle, 1997). Accordingly, we compared the attentional blink under conditions of (low) luminance contrast vs. color contrast. On the basis of pilot work, we selected a set of colors such that in a sta-

tionary setting, the stimuli were perceived as slightly better visible in the color-contrast condition than in the luminance-contrast condition (cf. Omtzigt, Hendriks, & Kolk, 2002). Therefore, if the attentional blink would be more pronounced in the color-contrast condition, this finding could be unambiguously ascribed to a weaker involvement of the magnocellular pathway.

Finally, in Experiment 3, we used extended periods of flicker adaptation or motion adaptation as a way of fatiguing the magno cells and disrupting the function of the magnocellular pathway (Clifford & Wenderoth, 1999; Green, 1981; Pantle, 1971). Each block of RSVP trials was preceded by a 2-min period of adaptation to flicker or motion, using parameters shown to be successful in previous research (Green, 1981). The control condition began with 2 min of adaptation to a stationary gray field. In all three task conditions, a re-adaptation period of 2 s was presented between the RSVP trials (Chapman, Hoag, & Giaschi, 2004). Our prediction was that the attentional blink would increase in size following flicker and motion adaptation, due to disruption of magnocellular function.

To foreshadow the results, in none of the three experiments our predictions were confirmed: The attentional blink was not systematically affected by manipulations that changed the relative involvement of the magno- and parvocellular pathways.

2. Experiment 1

2.1. Method

2.1.1. Participants

Sixteen students (12 female, age 18–27 years) from Leiden University participated in the experiment in return for €6, or course credit.

2.1.2. Stimuli, design, and procedure

Each trial started with a $0.4 \times 0.4^\circ$ fixation cross, presented for 1000 ms in the center of the display. Subsequently, the fixation cross was replaced by an RSVP stream of 21 uppercase letters, each measuring approximately $0.5 \times 0.5^\circ$. Each letter was randomly drawn (without replacement) from the alphabet and presented for 74 ms, followed by a 26-ms blank interval. “I”, “O”, “Q”, and “S” were left out as they resemble digits too much. On each trial, two of the letters were replaced with digits, randomly drawn without replacement from the set 2 to 9. T1 was presented at positions 10–13 in the stream. The temporal distance between T1 and T2 was systematically varied between 1, 2, 3, and 7 items, corresponding to lags of 100, 200, 300, and 700 ms. The participant's task was to identify both T1 and T2 by typing the digits in order on a standard keyboard, following the end of the RSVP stream. Participants were instructed to guess whenever they failed to identify a digit. The two keyboard entries were followed by the presentation of a feedback stimulus for 150 ms (e.g., ‘+ –’ to indicate that T1 was correct and

T2 was incorrect). After a 500-ms blank screen the next trial started.

There were two experimental conditions. In one condition, the stimuli were presented in dark red ($\text{RGB} = 192, 0, 0$; CIE x -, y -coordinates = .617, .346; luminance = 15.8 cd/m²) against a bright red background ($\text{RGB} = 255, 0, 0$; luminance = 29.0 cd/m²). The colors used in this condition were the same for all participants. In the other condition, the stimuli were presented in dark green against a bright green background. The green colors were each luminance-matched with respect to the corresponding colors in the red condition. Therefore, a potential difference in performance between the two conditions could not be attributed to differences in luminance contrast. Isoluminance was established individually for each participant using heterochromatic flicker photometry (Ives, 1912). The resulting color parameter values were generally within the range of ($\text{RGB} = 0, 152, 0$; CIE x -, y -coordinates = .290, .603; luminance = 30.6 cd/m²) – ($\text{RGB} = 0, 168, 0$; luminance = 38.0 cd/m²) for the background, and ($\text{RGB} = 0, 122, 0$; luminance = 19.6 cd/m²) – ($\text{RGB} = 0, 138, 0$; luminance = 25.4 cd/m²) for the stimuli. The visual field surrounding the computer monitor was dark.

The experiment started with twelve practice trials, six for each condition, randomly intermixed. This was followed by six blocks of 60 trials each, with each block containing 15 repetitions of each lag, randomly intermixed. To counteract the confounding effects of task practice, the task conditions were varied across blocks in an ABABAB-order, with half of the participants starting with the red condition and the other half starting with the green condition. To minimize potential carryover effects, there was a 1-min break between blocks.

2.2. Results

Fig. 1 (left panel) shows average T2 accuracy (contingent on correct T1 identification) as a function of Condition (red, green) and Lag (1, 2, 3, and 7). A similar pattern of results was found if T2 accuracy was averaged across correct and incorrect T1 trials. Trials on which T1 and T2 were accurately identified but in the wrong order were treated as correct. The two T2 accuracy curves show a pattern that is characteristic of attentional-blink research: Lag-1 sparing, followed by a drop in performance for lags 2 and 3 (i.e., the attentional blink itself), followed by a recovery of performance at lag 7. This pattern was expressed in a significant effect of Lag, $F(3, 45) = 28.10$, $MSE = 0.044$, $p < .001$. Most important for the present purposes is the finding that T2 accuracy in the red condition (78.0%) and the green condition (78.2%) was very similar, $F(1, 15) = .02$, $MSE = 0.006$, $p = .90$. The Condition \times Lag interaction was also not significant, $F(3, 45) = 1.31$, $MSE = 0.007$, $p = .29$. T1 accuracy was roughly the same in the red (82.9%) and green condition (84.0%).

3. Experiment 2

3.1. Method

3.1.1. Participants

Seventeen students (15 female, ages 18–24 years) from Leiden University participated in the experiment in return for €6, or course credit.

3.1.2. Stimuli, design, and procedure

All details were as in Experiment 1, except for the following. The RSVP items were presented for 74 ms and were separated by a blank interval of 46 ms, resulting in a 120-ms item onset asynchrony. All stimuli were presented against a bright yellow background ($\text{RGB} = 199, 199, 0$; CIE x -, y -coordinates = .401, .519; luminance = 74.2 cd/m²). In the luminance-contrast condition, the stimuli were presented in a yellow color that was only slightly brighter than the background ($\text{RGB} = 216, 216, 0$; CIE x -, y -coordinates = .402, .518; luminance = 87.5 cd/m²). The stimulus color used in this condition was the same for all participants. In the color-contrast condition, the stimuli were presented in a bright green color that was equiluminant with the yellow background. The individual color parameter values, as determined by heterochromatic flicker photometry, were within the range of ($\text{RGB} = 72, 216, 0$; CIE x -, y -coordinates = .304, .593; luminance = 70.6 cd/m²) – ($\text{RGB} = 76, 226, 0$; CIE x -, y -coordinates = .302, .595; luminance = 77.9 cd/m²). Note that the selection of colors on the basis of this procedure provided independent support that our color-contrast manipulation was successful at disrupting magnocellular function (Lee, Martin, & Valberg, 1988).

Before the task practice phase, the participants were shown a (stationary) bright yellow and a bright green 'O', next to each other, in the stimulus colors and against the background color used in the experiment. They were asked to indicate on a 5-point scale whether the bright yellow 'O' was (1) much less visible, (2) a little less visible, (3) equally visible, (4) a little more visible, or (5) much more visible than the bright green 'O', by typing in the corresponding number on the keyboard. The resulting average was 2.76 ($SD = 1.03$), suggesting that, in general, participants found the equiluminant color-contrast stimulus slightly better visible than the luminance-contrast stimulus. Therefore, if we observed a performance impairment in the color-contrast condition, this impairment could be unambiguously attributed to a weaker involvement of the magnocellular pathway.

3.2. Results

Fig. 1 (middle panel) shows average T2 accuracy (contingent on correct T1 identification) as a function of Condition (luminance contrast, color contrast) and Lag (1, 2, 3, and 7). The attentional blink was expressed in a significant effect of Lag, $F(3, 48) = 22.37$, $MSE = 0.027$, $p < .001$.

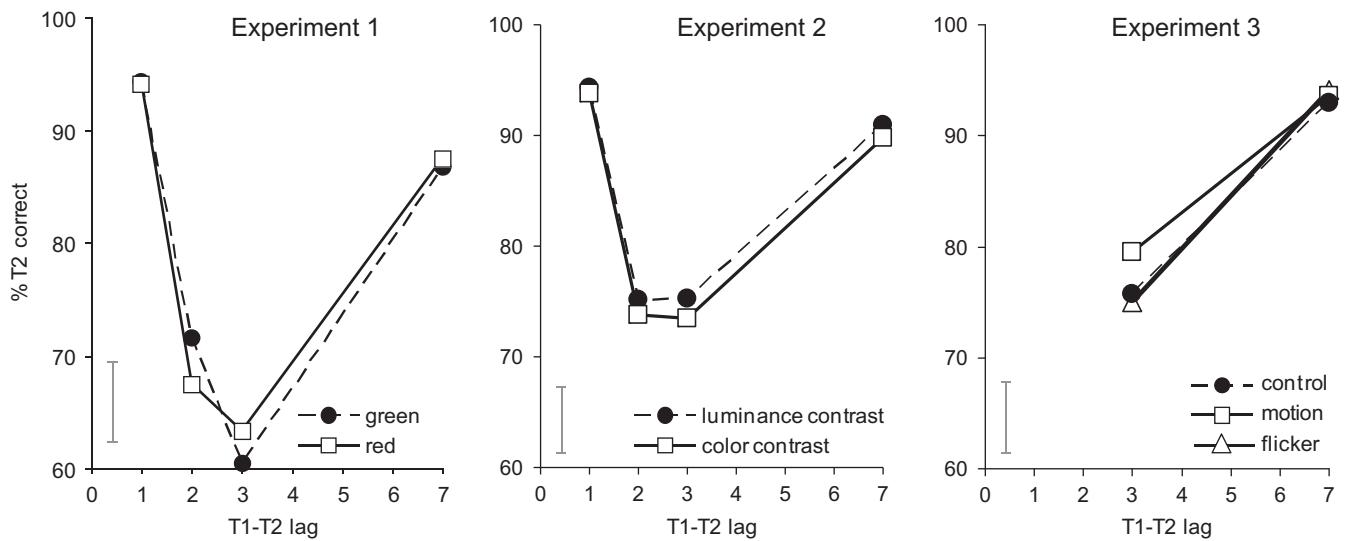


Fig. 1. Mean percentages of trials on which the second target (T2) was correctly identified, given accurate identification of the first target (T1), as a function of condition and the lag between T1 and T2. Error bars indicate, for each experiment, the within-subject 95% confidence interval associated with the main effect of Condition and the Condition \times Lag interaction (according to Loftus & Masson, 1994).

Importantly, although T2 accuracy in the color-contrast condition was somewhat lower than in the luminance-contrast condition (82.7% vs. 83.9%), this difference was far from significant, $F(1, 16) = .97$, $MSE = 0.005$, $p = .34$. The Condition \times Lag interaction was also not significant, $F(3, 48) < 1$. T1 accuracy was numerically lower in the color-contrast condition compared to the luminance-contrast condition (86.3% vs. 88.3%), but this difference was not significant, $F(1, 16) = 1.65$, $MSE = 0.008$, $p = .22$.

4. Experiment 3

4.1. Method

4.1.1. Participants

Twelve students (nine female, ages 18–24 years) from Leiden University participated in the experiment in return for €10, or course credit.

4.1.2. Stimuli, design, and procedure

All details were as in Experiment 1, except for the following. The stimuli were presented in black against a gray background ($RGB = 128, 128, 128$; CIE x -, y -coordinates = .279, .304; luminance = 34.2 cd/m^2). To make the task more difficult, the blank interval between RSVP items was shortened to 19 ms, resulting in a 93-ms item onset asynchrony, and no trial-to-trial feedback was provided. Furthermore, only two lags were used: Lag 3 (279 ms) and lag 7 (651 ms). The experiment started with twelve practice trials, followed by six blocks of 40 trials each, with each block containing 20 repetitions of each lag, randomly intermixed.

There were three experimental conditions, which were varied across blocks of trials in an ABCCBA-order, with the order of conditions counterbalanced across parti-

pants. In the motion condition, each block began with two minutes of pre-adaptation to motion, and each trial began with a 2-s re-adaptation period, followed by a 400-ms blank screen before the start of the RSVP stream. The motion stimulus consisted of a 0.6 c/deg, black-and-white, sine-wave grating which drifted leftward at 10 Hz (black $RGB = 32, 32, 32$; luminance = 3.3 cd/m^2 ; white $RGB = 223, 223, 223$; luminance = 103.2 cd/m^2). In the flicker condition, the adaptation stimulus consisted of the same grating, but now, instead of moving, it alternated with an unpatterned gray background (see control condition) at 10 Hz. The parameters of the motion and flicker stimuli have been shown to be effective in causing adaptation of the magnocellular pathway (Green, 1981). In the control condition, the adaptation stimulus was a stationary gray screen ($RGB = 128, 128, 128$). To ensure that participants were exposed to the pre-adaptation stimulus, they were instructed to fixate a red '+' presented in the center of the screen during each pre-adaptation period. They were told to count the number of times the '+' changed briefly to an 'x' (for 120 ms), which happened on average 6.6 times (range 2–9) per pre-adaptation period. At the end of the pre-adaptation period, participants were to enter the counted number on the keyboard. This was followed by a 2-s display that indicated the start of the RSVP task. The average difference between the actual and reported number of changes was 0.54 (range across participants 0.17–1.83).

4.2. Results

Fig. 1 (right panel) shows average T2 accuracy (contingent on correct T1 identification) as a function of Condition (motion, flicker, control) and Lag (3, 7). The attentional blink was expressed in a significant effect of Lag,

$F(1,11) = 15.67$, $MSE = 0.032$, $p = .002$. Importantly, there was no reliable difference in T2 accuracy between the three conditions (motion 86.5%, flicker 84.5%, control 84.4%, $F(2,22) = 1.46$, $MSE = 0.002$, $p = .26$), and no reliable Condition \times Lag interaction, $F(2,22) = 1.03$, $MSE = 0.004$, $p = .37$. Finally, T1 accuracy was not significantly different between the three conditions (motion 87.8%, flicker 90.1%, control 86.4%, $F(2,22) = 1.30$, $MSE = 0.009$, $p = .29$).

5. General discussion

We tested the prediction that experimental manipulations that disrupt magnocellular processing and bias parvocellular processing should affect attentional-blink magnitude. This prediction was based on the notion that the neural response profile of magno cells (i.e., short-latency, transient) is more suited for resolving the challenges posed by an RSVP stream than the response profile of parvo cells (relatively slow and sustained). We suggested that our hypothesis is consistent with, and provides a possible neurophysiological basis for recent proposals that have related the attentional blink to limitations in temporal resolution, and in particular to the notion that attentional responses are too slow to keep up with the pace of an RSVP stream (Nieuwenstein et al., 2005; Olivers, 2007; Olivers et al., 2007). The hypothesis would also provide an explanation for a number of hitherto poorly understood phenomena in the attentional-blink literature, such as the effects of scotopic vs. photopic viewing (Giesbrecht et al., 2004) and distraction (Arend et al., 2006; Olivers & Nieuwenhuis, 2006).

The three attentional-blink experiments reported here did not confirm this prediction. In each of the experiments we used an experimental manipulation known to differentially influence the parvo- and magnocellular pathways, as determined by neurophysiological and psychophysical studies. Critically, the magnitude of the attentional blink was not larger in task conditions associated with attenuated magnocellular activity. To further address this issue, we carried out an omnibus t -test, including all 45 participants in this study, that compared performance in the “magno-reducing” task conditions (in Experiment 3: The average of performance in the motion and flicker conditions) with performance in the control or “parvo-reducing” conditions, averaged across lags. There was essentially no difference in performance between these two task conditions (81.2% vs. 82.0%, $t(44) = .37$, $p = .36$, one-sided), which further indicates that we did not obtain any empirical support for our hypothesis. Of course, this conclusion leaves open the possibility that the attentional blink is due to delayed *attentional* responses (Nieuwenstein et al., 2005; Olivers, 2007), which represent an interaction between perceptual input and target representations held in working memory. Indeed, although the importance of perceptual factors has been sufficiently demonstrated (e.g., Brehaut et al., 1999), explanations of the attentional

blink in terms of attentional mechanisms are dominating the literature.

The parameters of our manipulations were based on previous research that obtained significant effect sizes in different tasks. Furthermore, our results were consistent across experiments, in that three different experiments, each with a different type of magno/parvo manipulation, failed to find an effect of such manipulations on the attentional-blink task. One possible explanation for these null results is that the employed psychophysical manipulations may have been unsuited for addressing the central research question. In particular, in all three experiments we used a manipulation that disrupted magnocellular function (red background, color contrast, flicker and motion adaptation) and expected to find impaired attentional-blink performance. However, it is possible that performance would have been more sensitive to manipulations that increased rather than decreased the relative contribution of the magnocellular pathway. As we have discussed, performance improvements have been reported under scotopic viewing conditions (Giesbrecht et al., 2004) and for conditions that promote divided visuospatial attention (Arend et al., 2006; Kristjánsson & Nakayama, 2002; Olivers & Nieuwenhuis, 2006)—circumstances in which visual-processing is dominated by the magnocellular pathway. Interestingly, in Experiment 2 we found a hint of a reduced attentional blink in the luminance-contrast condition, our only manipulation that preferentially activated the magnocellular pathway.

It is of course also possible that our manipulations were appropriate but not sufficiently strong to produce effects in the attentional-blink task, or that the (rather standard) version of the attentional-blink task we used was not sufficiently sensitive. In this context it is worth noting the practical limitations of psychophysical research on the contribution of the parvo- and magnocellular pathways to human perception and performance. In particular, there are no psychophysical manipulations that completely inhibit one or the other pathway, and many of the manipulations affect both pathways, though to a different degree (cf. Maunsell, 1992). The fact that strong psychophysical tests are lacking is reflected in the typically modest behavioral effect sizes. Accordingly, it is generally desirable to complement psychophysical tests with more direct methods, such as the creation of selective lesions to the parvo- and magnocellular layers of the monkey lateral geniculate nucleus (Schiller, Logothetis, & Charles, 1990). Definitive assessment of the parvo/magno hypothesis proposed here will have to await the application of such methods in the context of the attentional-blink task.

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References

- Arend, I., Johnston, S., & Shapiro, K. (2006). Task-irrelevant visual motion and flicker attenuate the attentional blink. *Psychonomic Bulletin & Review*, 13, 600–607.
- Benedek, G., Benedek, K., Keri, S., Letoha, T., & Janaky, M. (2003). Human scotopic spatiotemporal sensitivity: A comparison of psychophysical and electrophysiological data. *Documenta Ophthalmologica*, 106, 201–207.
- Bowman, H., & Wyble, B. (2007). The simultaneous type, serial token model of temporal attention and working memory. *Psychological Review*, 114, 38–70.
- Brebaud, J. C., Enns, J. T., & Di Lollo, V. (1999). Visual masking plays two roles in the attentional blink. *Perception & Psychophysics*, 61, 1436–1448.
- Breitmeyer, B. G., & Breier, J. I. (1994). Effects of background color on reaction time to stimuli varying in size and contrast: Inferences about human M channels. *Vision Research*, 34, 1039–1045.
- Breitmeyer, B. G., & Williams, M. C. (1990). Effects of isoluminant-background color on metacontrast and stroboscopic motion: Interactions between sustained (P) and transient (M) channels. *Vision Research*, 30, 1069–1075.
- Chapman, C., Hoag, R., & Giaschi, D. (2004). The effect of disrupting the human magnocellular pathway on global motion perception. *Vision Research*, 44, 2551–2557.
- Chikashi, M., Okubo, M., & Mugishima, Y. (1999). Effects of background color on the global and local processing of hierarchically organized stimuli. *Journal of Cognitive Neuroscience*, 11, 1–8.
- Clifford, C. W., & Wenderoth, P. (1999). Adaptation to temporal modulation can enhance differential speed sensitivity. *Vision Research*, 39, 4324–4332.
- Di Lollo, V., Kawahara, J., Ghorashi, S. M. S., & Enns, J. T. (2005). The attentional blink: Resource limitation or temporary loss of control? *Psychological Research*, 69, 191–200.
- Giesbrecht, B., Bischof, W. F., & Kingstone, A. (2004). Seeing the light: Adapting luminance reveals low-level visual processes in the attentional blink. *Brain and Cognition*, 55, 307–309.
- Green, M. (1981). Psychophysical relationships among mechanisms sensitive to pattern, motion and flicker. *Vision Research*, 21, 971–983.
- Ives, H. E. (1912). On heterochromatic photometry. *Philosophical Magazine*, 24, 845–853.
- Kaplan, E., & Shapley, R. M. (1986). The primate retina contains two types of ganglion cells, with high and low contrast sensitivity. *Proceedings of the National Academy of Sciences USA*, 83, 2755–2757.
- Kristjánsson, Á., & Nakayama, K. (2002). The attentional blink in space and time. *Vision Research*, 42, 2039–2050.
- Lawson, M. L., Crewther, S. G., Blume-Tari, A., Guminsky, M., Perdikeas, N., Roebuck, G., et al. (2002). Temporal processing of global and local information varies with global precedence. *Clinical and Experimental Ophthalmology*, 30, 221–226.
- Lee, B. B., Martin, P. R., & Valberg, A. (1988). The physiological basis of heterochromatic flicker photometry demonstrated in the ganglion cells of the macaque retina. *Journal of Physiology*, 404, 323–347.
- Lee, B. B., Martin, P. R., & Valberg, A. (1989). Sensitivity of macaque retinal ganglion cells to chromatic and luminance flicker. *Journal of Physiology*, 414, 223–243.
- Livingstone, M., & Hubel, D. (1988). Segregation of form, color, movement, and depth: Anatomy, physiology, and perception. *Science*, 240, 740–749.
- Loftus, G. R., & Masson, M. E. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin and Review*, 1, 476–490.
- Maunsell, J. H. (1992). Functional visual streams. *Current Opinion in Neurobiology*, 2, 506–510.
- Nieuwenhuis, S., Gilzenrat, M. S., Holmes, B. D., & Cohen, J. D. (2005). The role of the locus coeruleus in mediating the attentional blink: A neurocomputational theory. *Journal of Experimental Psychology: General*, 134, 291–307.
- Nieuwenstein, M. R., Chun, M. M., van der Lubbe, R. H., & Hooge, I. T. (2005). Delayed attentional engagement in the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, 31, 1463–1475.
- Okubo, M., & Nicholls, M. E. (2005). Hemispheric asymmetry in temporal resolution: Contribution of the magnocellular pathway. *Psychonomic Bulletin & Review*, 12, 755–759.
- Olivers, C. N. L. (2007). The time course of attention: It is better than we thought. *Current Directions in Psychological Science*, 16, 11–15.
- Olivers, C. N. L., & Nieuwenhuis, S. (2006). The beneficial effects of additional task load, positive affect, and instruction on the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, 32, 364–379.
- Olivers, C. N. L., van der Stigchel, S., & Hulleman, J. (2007). Spreading the sparing: Against a limited-capacity account of the attentional blink. *Psychological Research*, 71, 126–139.
- Omtzigt, D., Hendriks, A. W., & Kolk, H. H. (2002). Evidence for magnocellular involvement in the identification of flanked letters. *Neuropsychologia*, 40(12), 1881–1890.
- Pantle, A. (1971). Flicker adaptation. I. Effect on visual sensitivity to temporal fluctuations of light intensity. *Vision Research*, 11, 943–952.
- Purpura, K., Kaplan, E., & Shapley, R. M. (1988). Background light and the contrast gain of primate P and M retinal ganglion cells. *Proceedings of the National Academy of Sciences, USA*, 85, 4534–4537.
- Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance*, 18, 849–860.
- Schiller, P. H., & Logothetis, N. K. (1990). The color-opponent and broad-band channels of the primate visual system. *Trends in Neuroscience*, 13, 392–398.
- Schiller, P. H., Logothetis, N. K., & Charles, E. R. (1990). Functions of the colour-opponent and broad-band channels of the visual system. *Nature*, 343, 68–70.
- Steinman, B. A., Steinman, S. B., & Lehmkuhle, S. (1997). Transient visual attention is dominated by the magnocellular stream. *Vision Research*, 37, 17–23.
- Wiesel, T. N., & Hubel, D. H. (1966). Spatial and chromatic interactions in the lateral geniculate body of the rhesus monkey. *Journal of Neurophysiology*, 29, 1115–1156.
- Yeshurun, Y. (2004). Isoluminant stimuli and red background attenuate the effects of transient spatial attention on temporal resolution. *Vision Research*, 44, 1375–1387.
- Yeshurun, Y., & Levy, L. (2003). Transient spatial attention degrades temporal resolution. *Psychological Science*, 14, 225–231.