Dividing attention in the flash-lag illusion

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Abstract

A dual-task paradigm was used to examine the effect of withdrawing attentional and/or cognitive resources from the flash-lag judgment. The flash-lag illusion was larger, and performance in a detection task was generally poorer, under dual-task conditions than in single-task control conditions. These effects were particularly pronounced when decisions in the two tasks were required simultaneously, as compared to when they could be made sequentially. The results suggest that a time consuming process is involved in the flash-lag decision, of such a nature that prolonging the process increases the magnitude of the illusion.

1. Introduction

The *flash-lag illusion* occurs when a smoothly moving stimulus is displayed aligned with a briefly flashed stimulus. The moving stimulus is perceived to be further along its trajectory than the point of alignment with the flash, at the perceived time of the flash. Since Nijhawan (1994) re-discovered this illusion, much experimental work has ensued and several competing accounts have been proposed and tested (see reviews by Krekelberg & Lappe, 2001; Nijhawan, 2002; Ögmen, Patel, Bedell, & Camuz, 2004; Schlag & Shlag-Rey, 2002; Whitney, 2002).

Early on in this debate Baldo and Klein (1995) suggested that attention might play a role in this illusion. They argued that the flash might be responsible for bottom-up (i.e. stimulus driven) attentional capture, but their account was immediately challenged (Khurana & Nijhawan, 1995), and the literature remains inconclusive regarding the involvement of bottom-up attentional processes in the flash-lag illusion (for reviews see Chappell, Hine, Acworth, & Hardwick, 2006; Kreegipuu & Allik, 2003). Conversely, there is evidence that by directing the allocation of attention in a top-down fashion before each trial begins, the magnitude of the flash-lag illusion may be manipulated (Baldo, Kihara, Namba, & Klein, 2002; Brenner & Smeets, 2000; Namba & Baldo, 2004; Vreven & Verghese, 2005), despite early indications to the contrary (Khurana, Watanabe, & Nijhawan, 2000).

Using a dual-task paradigm (Pashler, 1994) in order to gain greater control over the direction of attention, the current study found what effect dividing attention, and thus removing processing resources from the flash-lag task, had on the magnitude of the flash-lag illusion. We expected that, if less resources were available under dual-task conditions, then processing the flash and assessing its and the moving objects' positions were likely to take longer (Carrasco & McElree, 2001). This being the case, the moving object's position, assessed under dual-task conditions, would be a later one than that used when the flash-lag illusion was measured alone (cf. Baldo, et al., 2002; Kanai, Sheth, & Shimojo, 2004). Therefore, the flash-lag illusion would have a larger magnitude when a detection task was performed concurrently than when the flash-lag task was performed alone. Note that this argument would not hold if the latencies of perception of the moving object and the flash at their respective positions were simply both increased by the same amount[1]. It is implicit in our reasoning that additional information accumulated by the visual system during the delay affects perception, particularly of the moving object's position (cf. *temporal integration*, Lappe & Krekelberg, 1998). Indeed finding this predicted difference would support our assumption that such a process occurs.

Another way to derive this prediction is to regard the perception of a flash-lag illusion as an error in perception and a larger flash-lag illusion as representing poorer performance by the visual system. Then our prediction here is simply in line with other research that shows that accuracy declines when attention is withdrawn from a task (e.g. Carrasco & McElree, 2001). We expected this effect to be most pronounced when the flash-lag flash appeared at about the same time as the decision was required in the dual-task, and thus also varied the Inter-Stimulus Interval (I.S.I.) between these events to test this.

2. Methods

2.1. Observers

Fourteen naive participants were tested. All participants possessed normal or corrected-to-normal vision. One participant withdrew from the study for medical reasons. Another,

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[1] We thank an anonymous reviewer for pointing this out to us.

during their pilot session, yielded a large confidence interval segment[2] (1.5º) in one of the dual-task conditions. Examination of their data indicated that their responding was inconsistent, so they were excluded from further testing, leaving 12 participants in the final statistical analysis.

2.2. Stimuli

Stimuli were displayed in a darkened room on a 15-inch computer monitor with a refresh rate of 60 Hz and 640 × 480 pixel resolution. A chin rest was used to assist participants with maintaining a constant viewing distance of 84.2 cm. The moving triangular object (luminance: 104 cd/m^2, Tektronix J18 1º luminance probe) in Figure 1 was 2.8º on each of its shorter sides and moved horizontally with a speed of 3º/sec, randomly from the left or the right. The flash was the same size (115 cd/m^2).

Insert Fig. 1 about here.

The detection task stimulus was presented two degrees below the fixation point. This stimulus changed to a target for 2 frames (33 ms) at one of five I.S.Is. These I.S.Is were -583, -117, -67, 0 and 117 ms. (-35, -7, -4, 0 and 7 frames)[3]. The monitor background luminance was below the probe's resolution (0.3 cd/m^2).

2.3 Procedure

Participants underwent a one-hour pilot session and two experimental sessions. The pilot session consisted of two segments: 1) tuning of the detection task stimuli for each participant and 2) a pilot test of the flash-lag stimuli. The goal of the tuning segment was

[2] The distance from their point of subjective equality to the limit in one direction of their confidence interval.

to find a detection stimulus luminance for each participant at which their detection performance was between 50% and 75% when the detection and flash-lag tasks were performed together (as piloting showed that performance varied widely for a fixed luminance). A fixed I.S.I. of 117 ms was used for tuning, and Table 1 shows the target luminances used as a result of this piloting. Once the target luminance was determined, the remainder of the pilot session was used to give participants practice on the dual-task, and the flash-lag alone task. Data gained here was also used to set initial moving object-flash offsets for the main experimental sessions.

Insert Table 1 about here.

Both experimental sessions consisted of two blocks of trials, always in the same order. The first block contained flash-lag only trials, and dual-task trials. In the flash-lag only trials, participants reported if the flash was to the left or the right of the moving object, using arrow keys. In the dual-task they also did this, and additionally reported what numeral the placeholder stimulus briefly changed to represent, via the number keypad. Participants were instructed that the spatial alignment of the flash and moving object in the flash-lag task was of primary interest, not target detection. A 2 sec response period was allowed. Feedback was provided on the accuracy of responses in the detection task after each trial. The two trial types were randomly interleaved, but onscreen instructions prompted participants before each trial as to the type of judgement to be made (i.e. a flash-lag task alone, or a dual-task). The second block of trials consisted of

[3] A negative I.S.I means that the detection target appeared *before* the flash whereas a positive I.S.I. means that the detection target appeared *after* the flash.

detection task only trials, as it was judged to be too confusing for participants if all judgment types were interleaved. Feedback was also given to participants after each of these trials.

To measure the magnitude of the flash-lag illusion throughout the pilot and experimental sessions, an adaptive method of constant stimuli was used. An initial set of nine generic moving object-flash offsets was first adopted (chosen to span most participants' illusions). After approximately every nine trials per condition, a logistic regression (Finney, 1971) was performed within the presentation software for each participant-condition. This statistical procedure estimated the point of subjective alignment based on the data gathered so far. The nine moving object-flash offsets were then moved so as to be centred on this point of subjective equality and a further set of trials was performed with these offsets.

Approximately 162 trials contributed to each participant-condition's point of subjective alignment. A negligible number of trials were timed out after 2 sec. Conditions were fully randomized within each block.

3. Results

Means for all conditions are shown in Figure 2. Considering first performance on the flash-lag task, a planned comparison revealed that under dual-task conditions the flash-lag magnitude was larger on average (by 0.089º) than when this task was performed alone ($F(1, 11) = 7.80$, $p = 0.018$, $\eta^2 = 0.42$). Posthoc paired comparisons between the control condition and each of the dual-task conditions ($\alpha = 0.01$, one-tailed) revealed significant differences for I.S.I = -117 ms ($t(11) = -3.32$), and I.S.I = 0 ($t(11) = -2.82$) only.

Insert Fig. 2 about here.

Amongst the five dual-task conditions, a one-way analysis revealed a quadratic effect[4] ($F(1, 11) = 9.29$, $p = 0.011$). Comparing the average of the middle three means (-117, -67, 0 ms) against the average of the outer two also revealed a significant difference; $F(1, 11) = 8.54$, $p = 0.014$. Table 2 shows pairwise comparisons between endpoint means and middle means. It can be seen that all comparisons except the last are significant ($p < 0.05$) (although only that comparing –117 and 117 ms would be if a Bonferroni control were used ($\alpha = 0.0083$)).

Insert Table 2 about here.

Turning now to the detection task, on average participants' performance was worse (mean difference = 0.057) under dual-task conditions than in the control condition ($F(1, 11) = 84.06$, $p < 0.001$, $\eta^2 = 0.88$). Posthoc tests revealed that performance was significantly worse in all dual-task conditions than in the control condition ($t(11) > 4.7$, $p < 0.01$ for all tests).

For the five dual-task conditions, a quadratic main effect was again in evidence ($F(1, 11) = 13.10$, $p = 0.004$). The average of the middle conditions (-117, -67 and 0 ms) was significantly less than the average of the two outer conditions

($F(1, 11) = 33.28$, $p < 0.001$). Table 3 shows pairwise comparisons between endpoint means and middle means.

Insert Table 3 about here.

All comparisons displayed in Table 3 are significant ($p < 0.05$). If a Bonferroni control were applied ($p < 0.0083$) only comparisons of –583 and –117 ms, –583 and –67 ms, –67 and 117 ms, and 0 and 117 ms would be significant.

4. Discussion

Disregarding the effect of I.S.I for the moment, we found poorer detection performance, and a larger flash-lag illusion, when both tasks were performed simultaneously, compared to when each of the tasks was performed alone (cf. Pashler, 1994). Upon consideration of I.S.I however, comparison of dual-task performance to control performance revealed that, while poorer detection was evident across all I.S.I.s, the effect on the flash-lag was restricted to two small I.S.I.s; -117 ms and zero ms. Given that the flash-lag task was designated as primary, this asymmetry is understandable.

The overall decrements in performance are attributable to the effects of dividing top-down attentional resources so as to monitor both tasks (Gobell, Tseng, & Sperling, 2004, have confirmed that disjoint regions of space can be covertly attended to), and

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[4] Using a metric (1, 29, 32, 36, 43) in SPSS GLM that took account of the unequal spacing amongst levels of I.S.I.

generally to the effects of dividing cognitive resources between them. The detection task alone condition would also have benefited by not being blocked with other conditions, as for example the flash-lag alone condition was. Additional attentional resources would have been required to switch between tasks in the latter situation[5].

The larger decrements when decisions in both tasks must be made around the same time (when I.S.I.s are small) suggest that both tasks require additional resources at this time. The finding of poorer detection performance under dual-task conditions particularly suggests that the flash-lag decision requires an allocation of top-down attentional resources, or cognitive resources generally, for its execution.

The complementary finding that withdrawing resources from the flash-lag task increases the magnitude of the flash-lag illusion supports an account in which some time consuming process is involved in the flash-lag spatial judgement. An example would be the temporal integration process; whereby the moving object's position is computed by averaging positional information for it over some temporal window (Lappe & Krekelberg, 1998). Withdrawing resources, attentional or otherwise, prolongs the time consuming process and, in the context of temporal integration, we assume extends the temporal window. As a consequence, the positional estimate for the moving object, used to make the flash-lag spatial judgement, is further along the trajectory than it would have been if resources had not been withdrawn (cf. Baldo, et al., 2002; Kanai, et al., 2004). This finding does not, however, support the proposal that the latency to perception of the flash

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[5] The data in Figure 2, showing a larger difference between dual- and single-task conditions for the detection than for the flash-lag task, support this interpretation, and indeed the effect size for the former contrast was about twice that for the latter. We thank a reviewer for bringing this issue to our attention.

and moving object are simply both being increased by the same amount, due to the withdrawal of resources.

We (Chappell, et al., 2006) have noted that the flash-lag flash, being the sudden onset of a stimulus, is particularly suited to capture attention (Egeth & Yantis, 1997; Yantis, 1996), but this situation cannot fit the usual definition of attentional capture as the flash is task-relevant. Attentional movement to it is thus likely to be prompted in a bottom-up fashion, as well as due to top-down attentional settings – what we termed *task-relevant attentional capture*. Such movement is likely to be happening in our dual-task, and contributing to the quadratic effects of I.S.I. that we observed.

The experiment reported here is the first to explicitly manipulate attention in the flash-lag paradigm via a dual-task procedure. Our results contribute to the growing body of evidence pointing to the involvement of attentional processes in the flash-lag illusion. Whilst attentional processes alone are unlikely to be sufficient to account for the full magnitude of the illusion (cf. Baldo, et al., 2002; Chappell, et al., 2006; Namba & Baldo, 2004), they will need to be included in a comprehensive model of it.

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Figure and Table Captions

Figure 1. Stimuli used in the experiment. In the dual-task condition, the die placeholder was visible below the fixation point whilst the moving object horizontally traversed the screen. A flash was presented for one frame above the moving object. During this time (i.e., at one of five I.S.Is) the die placeholder transformed into a target. The die placeholder was absent in the flash-lag task only condition. In the detection task only condition, the die placeholder was presented below the fixation point and changed to a target. No flash-lag stimuli were employed in this condition.

Figure 2. Average flash-lag magnitude and performance on the detection task across twelve naïve participants under the five dual-task and two control conditions. A. Mean magnitudes of the flash-lag effect obtained across participants under dual-task conditions and the flash-lag control condition. B. Mean performance across participants in the detection task under dual-task conditions and the detection task control condition. Error bars display the upper and lower 95% confidence limits of each average result.

Table 1. *Number of participants assigned to each target luminance*

Table 2. *Pairwise comparisons amongst selected dual-task conditions for flash-lag magnitudes*

Table 3. *Pairwise comparisons amongst selected dual-task conditions for detection performance*

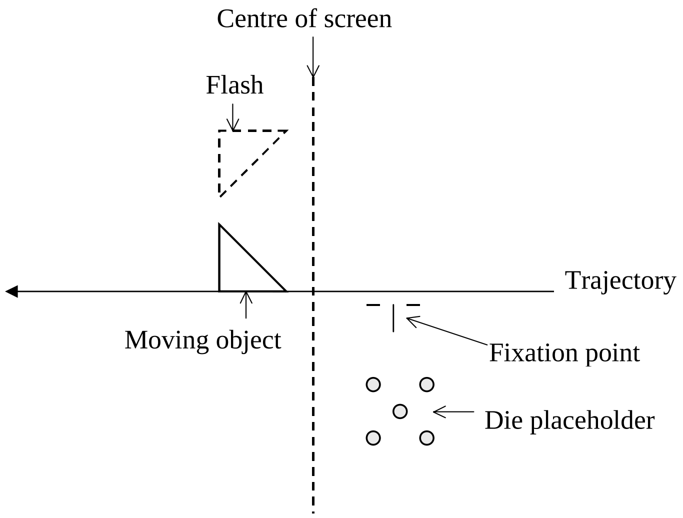
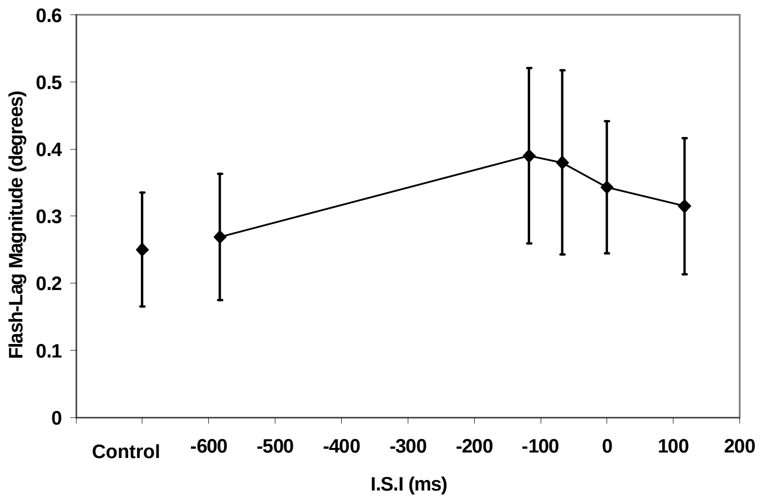
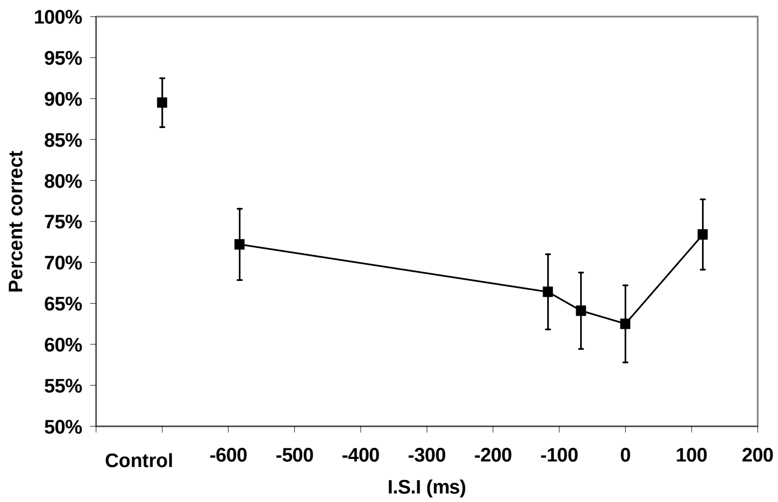


Fig. 1.



A. Average results across participants for flash-lag magnitude



B. Average results across participants for performance on detection task

Fig. 2

Table 1. *Number of participants assigned to each target luminance*

Luminance (cd/m^2)	No. of Ps
42.58	6
14.89	3
2.06	2
< 0.3	1

Table 2. *Pairwise comparisons amongst selected dual-task conditions for flash-lag magnitudes*

Between	Mean	*t*	*p* (1-tailed)
-583 and -117	-0.121	-2.68	0.011
-583 and -67	-0.111	-2.27	0.023
-583 and 0	-0.074	-2.43	0.017
-117 and 117	0.075	3.40	0.003
-67 and 117	0.065	2.59	0.013
0 and 117	0.028	1.78	0.052

Table 3. *Pairwise comparisons amongst selected dual-task conditions for detection performance*

Between	Mean	*t*	*p* (1-tailed)
-583 and -117	0.057	2.83	0.008
-583 and -67	0.080	3.24	0.004
-583 and 0	0.095	2.70	0.010
-117 and 117	-0.069	-2.16	0.027
-67 and 117	-0.092	-2.96	0.007
0 and 117	-0.107	-8.67	< 0.001