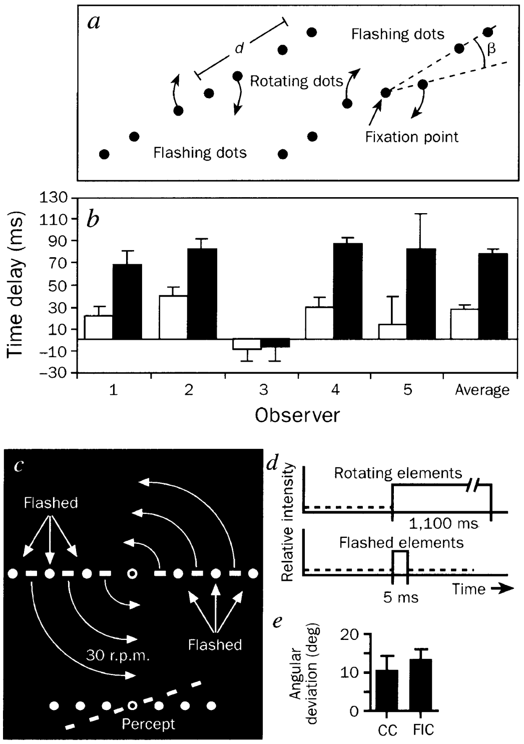

Experimental design and results of: *a, b,* Baldo and Klein, and *c–e,* Khurana and Nijhawan. *a, Left,* the stimulus, a pair of dots 1.3° apart in the visual field, rotating at 25 r.p.m. about a central dot (fixation point). Two pairs of dots were flashed in perfect alignment with the central and rotating dots. Distances, *d*, from the central dot to the midpoint between each pair of flashing dots, used in our tests, were 1.45° and 4.74°. *Right,* The situation as reported by most observers: the rotating dots are seen ahead of the flashing dots. The perceived misalignment, *β*, was assessed by letting the observer adjust the flashing dots until they appeared in alignment. *b,* The misalignment as a time delay and the mean time delay from five naive observers measured at two different distances (data averaged over all observers and weighted by inverse variance). Two other observers, under a similar experimental set-up, offered similar results concerning the original experiment (average time delays: 33 ± 9 ms and 83 ± 7 ms for closer and farther flashing (outer) dots, respectively). A switched version of the experiment was also used where the outer dots moved and the inner dots flashed. The perceptual effect was qualitatively the same, but the strong dependence on the location of the outer (moving) dots was not observed (average misalignment: 24 ±14 ms and 19 ± 9 ms for the closer and farther locations, respectively). These values are comparable to those found in the original experiment, when the flashing (outer) dots were closer to the fixation point. ❑, 1.45°; ■, 4.74°. *c,* The observer fixated the central dot while attentively tracking[6] a line (length = 6.9°) composed of 6 rectangles rotating at 30 r.p.m. A horizontal line (length = 7.8°), composed of 6 circles interleaving the rotating line, was flashed for 5 ms. Observers reported the perceived relative positions of the two lines by varying the angle between two adjustable lines. A strong flash-lag effect was reported (percept). *d,* The intensity profiles of the rotating and flashed elements as a function of time in the FIC condition. *e,* Of 10 observers, 5 viewed the FIC condition first and the complete cycle (CC) second; the order was reversed for the remaining five. A paired *t*-test showed no significant difference between the angle means for the CC and FIC conditions; mean FIC − mean CC = 2.8, $t(9) = 1.70$, $P > 0.10$. The average ($n = 10$) angular deviations for the CC and FIC conditions yield time delays of 58.61 and 74.17 ms, respectively.

fixation point in the original experiment (see figure legend).

These findings support the idea that the perceptual effect is mainly involved in the location of the flashing dots in the visual field. We hypothesize that some amount of time, dependent on eccentricity, is required to bring the flashing dots to a sufficiently high level of sensory awareness for a 'snapshot' of the moving dots to be taken. Such a time delay would be related to the abrupt onset of the flashing dots and might involve attentional mechanisms, either in capturing attention[2] or in shifting the focus of attention from one place to another across the visual field[3,4].

Purely sensorial mechanisms, operating preattentively and depending on eccentricity, cannot yet be discarded. More experiments are needed to distinguish between these possibilities, but we believe that an attentional hypothesis should be examined further.

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KHURANA AND NIJHAWAN REPLY — Baldo and Klein's hypothesis involves the 'shift' or 'capture' of attention from moving elements to flashed elements of abrupt onset. We used two experimental manipulations to distinguish between this and the hypothesis that the lag of predictably moving objects is 'corrected' by the visual system through extrapolation[1], or through some form of neural facilitation applied along the inferred trajectory of moving objects. Neural responses for inferred motion, where an explicit motion signal from the retina is absent, have been observed[5]. Flashed objects, on the other hand, are unpredictable and subject to expected neural delays, which cause their apparent lag.

We addressed the 'attention shift' hypothesis by spatially interleaving the moving and flashed elements. In this condition, observers attentively tracked[6] a rotating line composed of six rectangles. A horizontal line composed of six circles was flashed for 5 ms (*c* in the figure). As the flashed elements occupy the spaces between the attended rotating elements, attention shifts should be negligible and the flash-lag effect should not be observed. However, this display produced a strong effect (*e* in the figure).

Delays due to 'attention capture' were tested by the abrupt onset of both the moving and flashed elements. The display was modified such that the flashed and rotating elements came on simultaneously for 5 and 1,100 ms, respectively. In this 'flash-initiated' cycle (FIC), the rotating and flashed elements have an equally abrupt onset (*d* in the figure), and thus both capture attention equivalently. If delays due to attention capture cause the effect, then none should be observed in this condition. The effect we found, however, did not significantly differ in strength from that observed in the 'complete' cycle (*e* in the figure). When flashed and moving objects are equated in terms of the shift-time or capture-time of attention, observers continue to report the flash-lag effect.

We explain the FIC results on the basis of parallel processing in the visual system[7,8]. The neural processing of both the rotating and the flashed lines begins simultaneously, but the observer does not perceive either stimulus for approximately 100 ms (ref. 9). During this time, the retinal image of the line rotating at 30 r.p.m. has moved through 18°, triggering a motion signal in the magnocellular stream. We suggest that lag-correction, which probably occurs in the fast magnocellular stream, is implemented within that period. The correction process is complete within the time window required for neural signals to yield visual awareness, and before the onset of attentional processing[10].

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