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The attentional modulation of the flash-lag effect

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Abstract

If a dot is flashed in perfect alignment with a pair of dots rotating around the visual fixation point, most observers perceive the rotating dots as being ahead of the flashing dot (flash-lag effect). This perceptual effect has been interpreted to result from the perceptual extrapolation of the moving dots, the differential visual latencies between flashing and moving stimuli, as well as the modulation of attentional mechanisms. Here we attempted to uncouple the attentional effects brought about by the spatial predictability of the flashing dot from the sensory effects dependent on its visual eccentricity. The stimulus was a pair of dots rotating clockwise around the fixation point. Another dot was flashed at either the upper right or the lower left of the visual field according to three separate blocked situations: fixed, alternate and random positions. Twenty-four participants had to judge, in all three situations, the location of the rotating dots in relation to the imaginary line connecting the flashing dot and the fixation point at the moment the dot was flashed. The flash-lag effect was observed in all three situations, and a clear influence of the spatial predictability of the flashing dot on the magnitude of the perceptual phenomenon was revealed, independently of sensory effects related to the eccentricity of the stimulus in the visual field. These findings are consistent with our proposal that, in addition to sensory factors, the attentional set modulates the magnitude of the differential latencies that give rise to the flash-lag phenomenon.

Key words
• Attention
• Flash-lag effect
• Vision
• Psychophysics

A moving object is generally perceived as spatially leading a brief flash presented adjacent to it, therefore shifted forward along its trajectory (Figure 1A). Over the past eight years, this so-called flash-lag effect has received several explanations, including motion extrapolation (1,2), differential latencies (3-5), attentional modulation (6-8), and postdiction (9).

Apart from the influence of the physical attributes of the stimulus, perceptual latencies have also been shown to be modulated by the differential allocation of attention (10,11). When attention has not been shifted to a visual target prior to its appearance, additional processing time would be required, either for the attentional shift to be completed, or because the target must be processed with reduced attentional facilitation. Recently, we have shown that the magnitude of the flash-lag effect depends on the predictability of the flashing dot's location (8). This dependence strongly suggests that the attentional set modulates the extent to which differential visual latencies determine the flash-lag phenomenon. However, in a previous study by our group (8), the spatial predictability of the flashing dot was coupled with the stimulus' visual eccentricity.

The aim of the present study was to uncouple the attentional effects brought about by the spatial predictability of the flashing dot from the sensory effects dependent on its visual eccentricity. Twenty-two students from the University of São Paulo, naive with respect to the particular hypothesis being tested, and the two authors participated as volunteers in three experimental situations. The experimental procedure was reviewed and approved by the Committee on Research Involving Human Subjects, Institute of Biomedical Sciences, University of São Paulo. All participants, aged 20 to 39 years, had normal or corrected-to-normal vision. The stimulus (Figure 1B) was a pair of dots, 2º apart in the visual field, rotating clockwise at 36 rpm around the fixation point. Another dot was flashed at either the upper right or the lower left part of the visual field, at an eccentricity of 2.2º, according to three separate experimental situations: A) the flashing dot was presented at the upper right part of the visual field in one half of the trials and at the lower left part in the other (fixed); B) the flashing dot was alternated between locations from trial to trial (alternating); C) the location of the flashing dot (either upper right or lower left) was randomly chosen from trial to trial (random). The task, in all three situations, was to judge the location of the rotating dots in relation to the imaginary line connecting the flashing dot and the fixation point at the moment the dot was flashed. By pressing one of two designated keys on the computer's keyboard, this judgment was reported as a lag or a lead of the rotating dots in relation to the flashing dot, corresponding to negative or positive angles between those imaginary lines, respectively. The next trial was started immediately after a response key had been pressed.

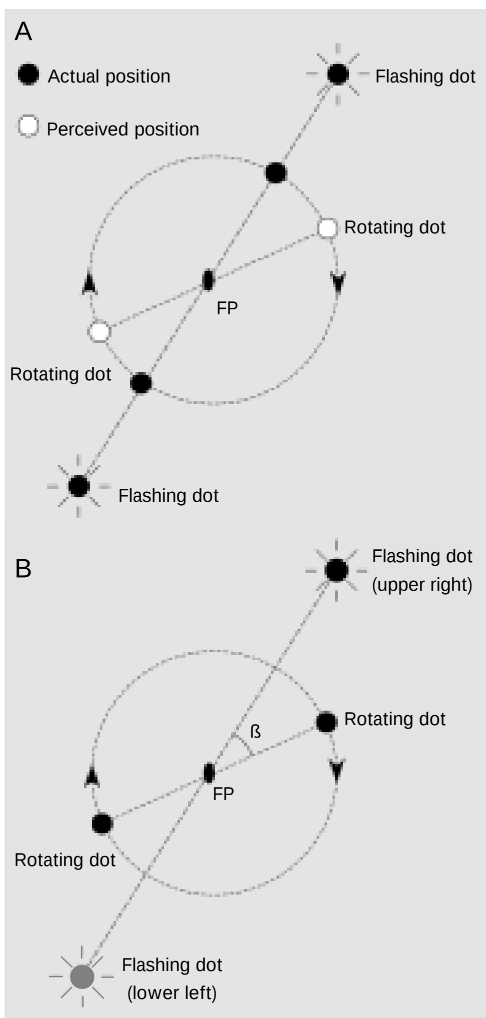

Figure 1. *A*, The perceptual misalignment between moving and flashing stimuli (flash-lag effect) as reported by most observers. The rotating dots, moving around the fixation point (FP), are seen ahead of the flashing dots when the latter are flashed in perfect alignment with the former set of dots. *B*, The visual stimuli utilized in all three experimental situations. Two rotating dots 2º apart in the visual field, diametrically opposed to each other, rotate clockwise at 36 rpm around the FP. The observer's task was to report the perceived angle ß as a lead (ß>0) or a lag (ß<0) of the rotating dots in relation to the flashing dot at the moment it was flashed in the visual field. Only one flashing dot was presented at a time, with fixed, alternating or random locations (fixed, alternate or random situation, respectively).

The rotating and flashing dots subtended 0.11º and 0.23º of the visual angle, respectively. The luminance of all dots was 20 cd/m^2, displayed on a dark background. Stimuli were generated on a 486-based PC and displayed on a Sony Multiscan 17 sf II monitor with a 60-Hz vertical refresh rate. A chin rest was used to maintain a constant viewing distance of 57 cm, and the experiments were conducted in a dimly lit room. Participants used the dominant eye, with the contralateral eye occluded by an eye-patch. Eye movements were monitored with a video camera.

Each experimental session lasted approximately 45 min, comprising 200 trials divided into four blocks. Three psychometric curves were obtained for each participant (fixed, alternate and random). Data points in each empirical psychometric curve were approximated by a cumulative Gaussian function, and the point of subjective equality (PSE) was determined as the horizontal position of the psychometric function measured by the location of the 0.5 point. The calculated PSE corresponds to the angle, converted to milliseconds, needed to generate a perception of alignment between moving and flashing dot, and is expressed as the negative of the perceived angle. Therefore, negative (positive) values mean a perceptual lead (lag) of the moving dot in relation to the flashing dot. The PSE values were computed for every participant and each situation separately. The results for the experimental situations were entered into a one-way repeated-measures analysis of variance (ANOVA) followed by pairwise comparisons (Turkey's HSD test). The level of significance was set at 5%.

Figure 2 shows the mean PSE obtained in all three experimental situations. Analysis showed a significant effect ($F(2,46) = 4.99$, $P = 0.011$) and pairwise comparisons showed a significant difference between fixed and random situations ($P = 0.008$). As expected, the flash-lag effect could be observed in all three situations. Yet, a clear influence of the spatial predictability of the flashing dot on the magnitude of the perceptual phenomenon was demonstrable. Moreover, the influence of the stimulus predictability was independent of sensory effects related to the eccentricity of the stimulus in the visual field.

Comparing fixed and random situations, which differed only with respect to the predictability of the flashing dot's location, led us to conclude that the difference in the magnitude of the flash-lag effect may depend on attentional mechanisms. A higher location predictability of the flashing dot (fixed) allowed attention to become more narrowly allocated, leading to a greater focalization of attentional resources on the expected location of the stimulus appearance. Benefits of advanced information about stimuli have often been termed perceptual set effects (12). The alternate situation, although offering as much predictability about the flashing dot's location as the fixed situation, yielded an intermediate magnitude for the flash-lag effect, midway between fixed and random situations. We can understand this result if we consider that, despite having as much spatial information as the fixed situation, in the alternate situation the volunteer must repeatedly shift his/her focus of visual attention in order to keep track of the location of the flashing dot's appearance.

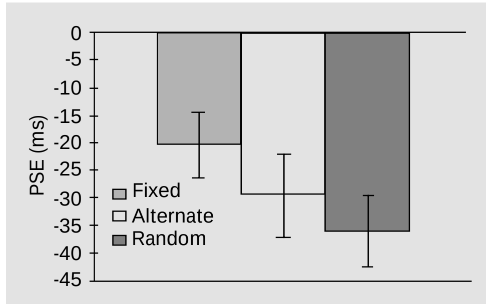

Figure 2. Point of subjective equality (PSE) obtained in all three situations. The PSE values are reported in milliseconds (by dividing the misalignment angles by the angular velocity of the rotating dots) ± SEM. Negative values for the PSE mean that the rotating dots had to be lagging behind the flashing dot in order to be perceived as aligned with them, i.e., the rotating dots were perceived as leading the flashing dot when they happened to be in perfect alignment with each other. The opposite holds for positive PSE values.

These findings are consistent with our proposal that besides several sensory factors, such as stimulus luminance and eccentricity, the observer's attentional set modulates the magnitude of the differential latencies that give rise to the flash-lag phenomenon (8). These results strengthen our present conceptual framework whereby the flash-lag effect can be accounted for by a generalized latency model composed of intrinsic sensory delays and an attentional modulatory component.

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