



Letter to the Editor

Induced Motion May Account for the Illusory Transformation of Optic Flow Fields Found by Duffy and Wurtz

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Duffy and Wurtz [(1993) *Vision Research*, 33, 1481-1490] found an illusory shift in the position of the focus of expansion (FOE) of random dot patterns when planar motion was superimposed on expanding radial motion. Subjects indicated that this illusory shift was in the direction of the planar motion. This is the opposite direction to a true shift in the FOE that is perceived when the planar motion is vector summed with the expanding motion. We account for this illusion by suggesting that planar motion induces opposite motion on the expanding dots which after vector summation produces the illusory shift in the FOE. We use a matching technique with a method of adjustment to measure induced motion and perceived FOE in moving random dot patterns and present the results in support of our assertion.

Optic flow Focus of expansion Induced motion Illusion

INTRODUCTION

Simple optic flow patterns can be easily simulated in the laboratory by applying structured motion to a random dot pattern. For example, each dot in an expanding pattern (Fig. 1a) can be described by

$$\mathbf{v} = k \cdot \mathbf{x}, \quad (1)$$

where \mathbf{v} is the instantaneous velocity vector of the dot, k is the rate of expansion and \mathbf{x} is the instantaneous position vector. This position vector indicates the instantaneous location of the dot relative to the focus of expansion (FOE). These kinds of flow patterns have generated interest in the vision community because in the real world, optic flow is rich in information about surface structure and observer locomotion (Gibson, 1950; Koenderink, 1986). For example, the optic flow described by equation (1) is essentially that for an observer approaching a plane from the direction normal to that plane and with fixed locomotory heading.

Duffy and Wurtz (1993) pointed out that if an expanding pattern [e.g. equation (1)] is vector summed with horizontal planar motion, then the FOE of the resultant pattern is displaced to the side opposite that of the direction of planar motion (Figs 1a-c). Further, Duffy and Wurtz found that naive observers were able to locate this displaced FOE fairly accurately. A second result reported by these authors was for a condition where

planar motion was superimposed on an expanding pattern. In other words, a compound stimulus was made from two sets of random dots, one translating laterally and the other expanding. In this condition, observers once again reported a spatial shift in the FOE, but this time, in the same direction as that of the planar motion (e.g. Figs 1b, e). In considering this result, Duffy and Wurtz reject an explanation in terms of induced motion (Dunker, 1929; Gogel, 1979) by arguing that their illusion was a positional shift (i.e. a shift in the location of the FOE) rather than a distortion in perceived motion.

Although we do not dispute the results of Duffy and Wurtz, we do content their rejection of an explanation in terms of induced motion (IM) because as Duffy and Wurtz point out, and as is illustrated in Fig. 1, such positional shifts are exactly what one would expect from the summation of two components of appropriate motion. Our own explanation of the illusory shift in the FOE is this: planar motion in one direction induces planar motion in the opposite direction on the expanding pattern. This induced motion is vector summed with the expansion (cf. Post & Chaderjian, 1988) and shifts the position of the FOE in the opposite direction to the induced motion and thus in the same direction as the original inducer (Fig. 1). Note that when the inducing pattern and the test pattern are both moving, as was the case in the displays of Duffy and Wurtz (1993), the phenomenon of induced motion has been referred to as simultaneous motion contrast, (e.g. Loomis & Nakayama, 1973).

Here we use a matching method to measure the magnitude of IM induced by one set of translating dots

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on a second set of more slowly translating dots moving in either the same or opposite direction to the inducer. Next, we use these data to make approximate predictions of the direction and magnitude of the illusory shift in the FOE for the same subjects.

METHODS

Subjects

Sixteen undergraduate volunteers with normal or corrected to normal vision served as subjects. Each sat at a viewing distance of 57 cm from both the test and response screens and performed the experiment with their head in a chin and forehead rest using natural pupils and binocular vision.

Stimuli and tasks

Test stimuli were random dot patterns of up to 381 bright dots generated by a 486 PC computer and displayed via a CED 501*plus* on a dark screen of an oscilloscope (Hewlett-Packard 1304, P31 phosphor) at a frame rate of 60 Hz. Response stimuli were presented on an Elonex VGA graphics monitor that was placed to the left of the oscilloscope, and at an angle such that the screen was normal to the observers direction of gaze.

For all conditions and tasks, the dots in the test stimuli were split roughly evenly between a set of test dots and a set of inducing dots and were presented simultaneously for a duration of 400 msec through a fixed circular aperture of 18 deg of visual arc.

FOE task

The test dots were always an expanding pattern described by equation 1, with $k = 1.125/\text{sec}$. This gave a median dot velocity of approx. 5 deg/sec. In experimental blocks, the inducer dots moved either leftwards or rightwards with a velocity of 10 deg/sec or were static (a total of three blocks). In a practice block, inducer dots were presented at half of their normal velocity and vector summed with the test dots. This produced a flow pattern with a FOE shifted either to the left or right of centre by 4.5 deg.

The response stimulus consisted of a dark response region bounded by a white circle of 18 deg diameter, and contained a small white cross that could be moved around with a mouse. The subjects task was to move the cross to the point that corresponded with the perceived location of the FOE in the test stimulus. In accordance with Duffy and Wurtz (1993), only the horizontal component of this response was recorded and we use a sign convention to indicate whether this component was to the left (negative) or right (positive) of true centre.

Each block consisted of six trials and the horizontal starting position of the response cross was randomised from trial to trial.

IM task

The test dots moved either leftwards or rightwards with a velocity of 5 deg/sec. (i.e. this velocity was matched to

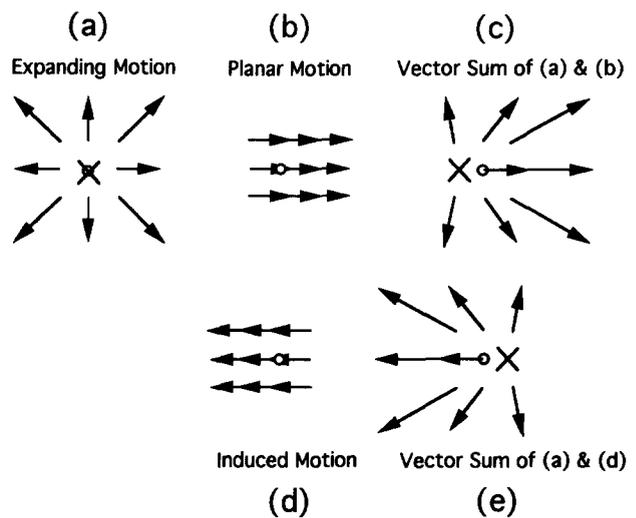


FIGURE 1. Example optic flow patterns. The crosses and small circles are for purposes of exposition only, and indicate the FOE and a static reference point respectively. (a) An expanding flow pattern [see equation (1) in the main text], (b) Rightward planar motion, and (c) the vector summation of these two components. In (c) the FOE is shifted to the left of the reference point. This is a direction opposite to that of the planar motion (b). If the two components (a, b) are not vector summed, but instead superimposed on top of each other, then we assert that the planar motion (b) will induce motion of the opposite direction (d) on the expanding pattern (a). The vector summation of the expanding pattern with the induced motion is shown in (e). In this case the FOE is shifted in the opposite direction to the induced motion (d) and so in the same direction as the inducing planar motion (b).

the median velocity of the test dots in the FOE task). The inducer dots moved either leftwards or rightwards with a velocity of 10 deg/sec, or were static. This produced a total of six different conditions for the IM task (2 test \times 3 inducer).

The response stimulus was a set of white random dots on a black background viewed through an 18 deg square window with about 50 dots always visible. These dots moved in the same direction as the test dots and were presented repeatedly with a duration of 400 msec, followed by a blank period of 400 msec. The subjects task was to match the velocity of these dots to those of the test-dots. The velocity of the response dots was controlled by two mouse buttons (one for faster and one for slower). Pressing both buttons together terminated the trial and recorded the response.

Each condition was performed in a single block consisting of eight trials, the first two of which were treated as practice and discarded. For each trial, the starting velocity of the response dots was alternated between noticeably faster and noticeably slower than the test dots.

Procedure

Half of the subjects performed the FOE task first and half performed the IM task first.

For the FOE task, the first block was always the practice block, during which subjects were allowed to ask questions. This was followed by the three experimental blocks in a random order.

For the IM task, the experimenter described the test and response patterns at the start of each block and informed the subject which set of dots in the test pattern was to be attended. For example, in blocks where the test dots and the inducer dots were moving in the same direction, subjects were told to match the velocity of the slower of the two sets of dots. The first two (practice) trials were monitored to ensure that the subjects had understood the task requirements. The six experimental blocks were performed in a random order. For half of the subjects the matching velocity of the first trial was slower than the test velocity and for the other half it was faster.

For both tasks, each trial was initiated and recorded by self paced mouse clicks. Typical experiment duration was 30 min.

Comments on our experimental design

Finally we should emphasize that no serious attempt was made to maximise the magnitude of the illusory shift in the location of the FOE. This was in part due to the experiences of one of the authors while writing the experimental software. For example, in the FOE task it was found that for several different magnitudes of expansion rate and inducer velocity, the illusion was experienced only for the first few trials. This also caused us to abandon our original plans of measuring both the location of the FOE and the magnitude of IM using a single display and an adaptive staircase (Cornsweet, 1962), which would have required many stimulus presentations. This instability in the illusion, and several equipment limitations drove us to the experimental design presented here, though a choice of different test and inducer velocities may have produced larger effects with our naive subjects.

RESULTS AND DISCUSSION

The mean perceived location of the FOE was calculated for each of the three experimental conditions by collapsing data across subjects and trials [typical within subject SE was 0.37 deg ($n=6$)]. This gave locations of 1.08 deg for the rightward inducer (SE=0.21 deg); -0.47 deg for the leftward inducer (SE=0.17 deg) and 0.23 deg for the static inducer (SE=0.13 deg). A one-way ANOVA showed a highly significant effect for inducer direction [$F(1,15)=28.93$, $P<0.001$]. The magnitude of this illusory shift in the FOE is considerably less than that found by Duffy and Wurtz (1993), who report typical results between 2 and 20 deg. However, there are several important differences between the study of those authors and ourselves. For example, Duffy and Wurtz used both different relative and absolute test and inducer dot velocities to our own (17 deg/sec compared with 10 deg/sec for the inducer; 40 deg/sec compared with 5 deg/sec for the test). They also used a considerably larger display than we did (100 × 100 deg compared with 18 deg diameter) and thus their stimuli provided a much less salient stationary reference frame.

Notwithstanding the differences in overall magnitude of the illusion and whatever its cause, we nonetheless find

strong evidence for an illusory shift in the spatial location of the FOE in our own data.

IM task

For each observer, the data from the IM task were processed as follows:

Symbolic subscripts i,t denote the inducer and test directions respectively and can be substituted by L (for leftward) or R (for rightward). In addition, i can also be substituted by S (for static). We proceed by using signed velocities to denote direction of motion, where leftward is negative and rightward is positive.

First, a matched velocity error factor, ϵ_i , is given by

$$\epsilon_i = m_{st}/V, \quad (2)$$

where m_{st} is the matched velocity for a static inducer with either leftward or rightward test dots. V is the actual velocity of the test dots and was equal to ± 5 (see Methods Section).

We assume that any systematic errors in velocity matching that may have been introduced by the experimental equipment and design are linearly related to the true test velocity. Consequently, we can derive estimates of the true magnitudes and directions of induced motion, ψ_{it} ($i \neq S$), by dividing the difference between m_{it} and m_{st} by the error factor [equation (2)] to give

$$\psi_{it} = (m_{it} - m_{st})/\epsilon_i. \quad (3)$$

Next, the average magnitude and direction of induced motion for each of the leftward and rightward inducers is given by

$$\psi_i = (\psi_{iL} + \psi_{iR})/2. \quad (4)$$

By applying equation (4) to our data, we derived a group mean IM for a leftward inducer (ψ_L) of 0.65 deg/sec (SE=0.13 deg/sec) and a group mean IM for a rightward inducer (ψ_R) of -0.66 deg/sec (SE=0.12 deg/sec).

Finally, we were able to use these IM velocities to make a rough prediction of the perceived locations of the FOE in order to compare the results from the two different tasks. However, it should be borne in mind that the radial motion component of the stimulus in the FOE task

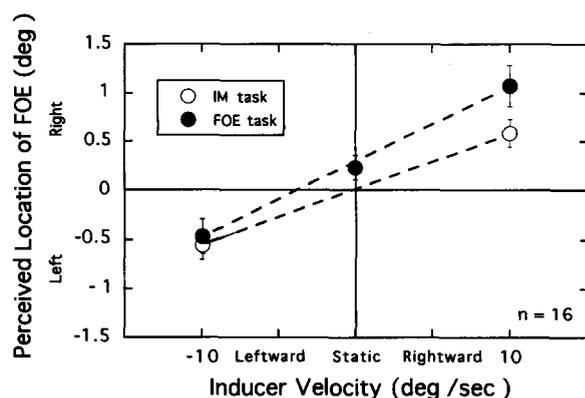


FIGURE 2. Solid symbols show group means for the perceived locations of the FOE of an expanding pattern with a superimposed inducer that travelled either leftwards, rightwards or was static. Open symbols show the locations of the FOE predicted by the results of a task that measured induced motion (see main text). Error bars show ± 1 SE.

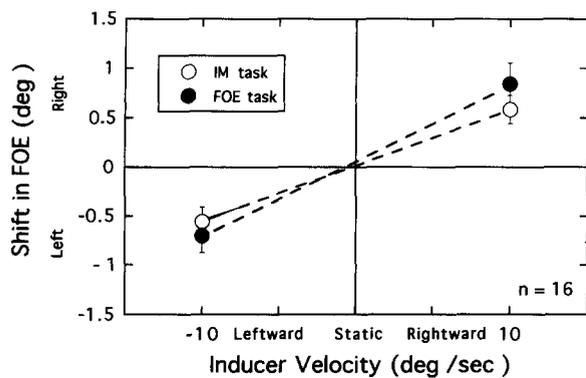


FIGURE 3. The same data as those shown in Fig. 2, but plotted as shifts in perceived location of the FOE instead of absolute locations. This was done by subtracting from the FOE data (solid symbols) the small offset in perceived location of the FOE that was measured when the inducer was static (see Fig. 2). Error bars show ± 1 SE.

contained a variety of velocities, whereas we used only two test velocities (opposite in sign, but of equal magnitude) in the IM task. As it is likely that the motion induced on each of the radially moving dots in the FOE task depended on the individual velocities of both the test and the inducer, we could not make rigorous quantitative predictions of the magnitude of the illusory shift in the location of the FOE based on our IM data. However, we were able to predict the direction of the shift, and by choosing test velocities in the IM task that were matched to the median dot velocity in the FOE task, we were also able to provide a rough approximation of its magnitude. To do this we found the radial distance from the centre of the expanding pattern where the magnitude of the instantaneous velocity was equal to that of the induced motion for each of the leftward and rightward inducers. Further, we required that the direction of local motion in the expanding pattern was opposite to that of the IM, in order that there should be a null point at that spatial location after vector summation. We found such points (x_i) by

$$x_i = -\psi_i/k, \quad (5)$$

where k is the expansion rate per second, and was 1.125 (see Method Section). This gave a predicted perceived location of the FOE of -0.59 deg for the leftward inducer and 0.56 deg for the rightward inducer. A one-way ANOVA on these data found a highly significant effect for inducer direction [$F(1,15) = 49.95$, $P < 0.001$], indicating that we were successful in subjecting our observers to induced motion.

IM data predict FOE data

A comparison of the predictions from the IM data with the true perceived locations of the FOE is shown in Fig. 2.

The first thing to note is that the predicted directions of the illusory shift in the FOE (open symbols), are the same as those found in the task that measured them directly (solid symbols). Furthermore, the magnitudes of the two data sets are roughly similar. Indeed, a two-way ANOVA found a highly significant effect for inducer direction [$F(1,15) = 55.34$, $P < 0.001$], but no significant effect of task type [$F(1,15) = 2.16$, $P = 0.163$] nor interaction [$F(1,15) = 1.16$, $P = 0.198$]. Thus, we feel confident that our IM data provide a reasonable account of our FOE data. The two data sets are seen to be even more similar in Fig. 3, where the FOE data have been adjusted by the small bias found for a static inducer (see Fig. 2), by subtracting this value from the two mean measures in the FOE task. In this figure, the IM data account for 75% of the shift in the perceived location of the FOE found in the FOE task.

CONCLUSIONS

Equipment limitations did not permit us to recreate the experimental conditions used by Duffy and Wurtz (1993) and so we were unable to make quantitative predictions for the results of those authors. Nevertheless, we have presented empirical evidence in support of our logical assertion that IM can be used to account for the illusory shift in the perceived location of the FOE originally reported by Duffy and Wurtz (1993).

We conclude, in agreement with (Gogel, 1979), that under certain conditions, induced motion behaves in a way similar to true motion, exemplified by the vector summation demonstrated in this study.

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