Fixation during pursuit eye movements for general object translations in 3D space

Helmut Glünder, Harald Frank and Wolfgang Graf

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Fixation during pursuit eye movements for general object translations in 3D space*

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Results of psychophysical experiments are reported that permit first insights to fixation strategies of humans, when confronted with composite motion of extended patterns. It appears as if pursuit eye movements not only minimize the translational component of a moving retinal pattern but also changes caused by rotations and expansions. This is achieved by pursuit fixation of a geometrically well-defined location that generally differs from the optic center of gravity of the retinal pattern.

Introduction

An object that is moving in a static surround most likely evokes visual tracking in a relaxed and uninstructed human observer. It is generally accepted that such smooth pursuit serves detailed visual analyses of the moving object, comparable to the steady fixation of static objects. Although the underlying mechanisms are known to be different, their consequence is fovealization.

We consider smooth pursuit eye movements under fixed head conditions. They compensate for fronto-parallel object translations that, in pure form, seldom occur outside of vision laboratories. Under natural conditions, the eyes track extended objects that move in space. Commonly, the retinal image of such a pursued object will not be static or stabilized but it will change according to the object's rotation in 3D space and to its motion component in depth. – Can pursuit eye movements reduce these changes and facilitate object analysis?

Obviously, changes of a pursued retinal pattern depend on the point of fixation (center of gaze) during the tracking. Consequently, the changes can be minimized by pursuing a thus defined *o*ptimum *p*oint of *f*ixation (OPF). By doing so, maximum invariance of a pursued retinal pattern under a considered geometrical transformation is achieved (cf. Glünder 1987). In the following, we report results from basic psychophysical experiments that permit first insights to fixation strategies of the human visual system when confronted with simple forms of composite motion of planar patterns.

Experiments

For our main experiment, we considered a quite natural kind of motion, namely an object approaching the observer along a straight trajectory that is inclined with respect to the head forward direction. This object motion in 3D space is simulated by a 2D pattern that expands while it translates on a fronto-parallel screen. The pattern is a chevron composed of two straight lines forming an apex. It is a self-similar shape of well-defined OPF – the apex –, that is clearly different from its optic center of gravity (centroid),[1] a location commonly assumed to be tracked.[2] Subjects were merely instructed to track the object and while they did, their eye movements were recorded.

In a supplementary experiment, subjects were confronted with another kind of composite motion, namely a wheel that rolls across a fronto-parallel screen. To again obtain an OPF that is different from the centroid, we actually presented a semicircular instead of a circular line (wheel).

Methods

Expanding chevron

A stimulus presentation (trial) starts with a horizontal left to right motion of the smallest chevron showing side lengths of 0.27°. The end position of this calibration sweep is the start position of the immediately following composite motion back to the left end, where the pattern disappears.[3] The expansion is linear – which corresponds to a decelerated approach-

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1 For binary-valued patterns, the optic center of gravity (where the gray value stands for the density) is identical to the centroid
2 Both locations coincide for a cross or a star-shaped line pattern
3 No Rashbass-steps are applied

ing object – finally reaching a 21-fold enlargement. The chevron is shaped like an isosceles triangle with a right-angled apex at the top but without a baseline. Evidently, the apex represents the OPF and the centroid is situated at half the pattern height.

Rotating semicircle
A trial starts with a horizontal left to right motion of a small cross. At the end of this calibration sweep it is replaced by a semicircular line of two degrees radius, with its virtual baseline at the top. It stays there for 200 ms before the composite motion back to the left end, where it disappears.[3] During this move, the semicircle turns 360° clockwise(!) around the midpoint of its virtual baseline, that represents the OPF. The centroid is situated at $1-\frac{2}{\pi} \approx 36\%$ ($c \approx 0.73°$) of the pattern height.

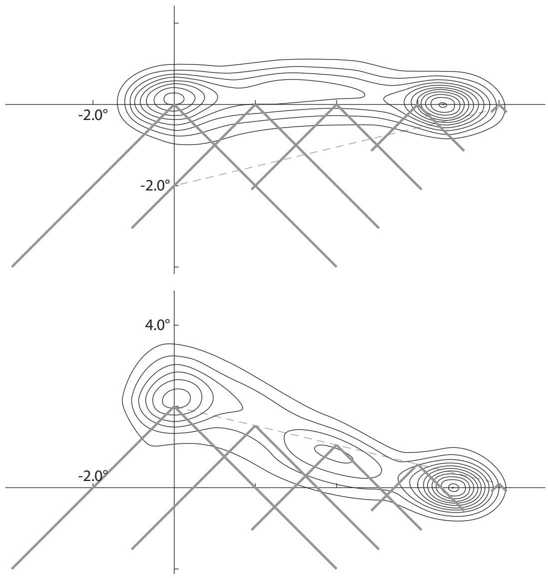
General
Either the OPF or the centroid location of the patterns move horizontally by eight degrees at a speed of 13.3°/s.[4] Both stimulus presentations are randomized during an experimental session that consists either of 80 (chevron) or 120 (semicircle) trials.

The stimuli are computer generated and stored as picture sequences in a real-time image memory system (Kürzinger & Deubel 1986). The frame rate of the black & white CRT-display is 100 Hz. The background illumination is 34 cd/mm^2 and the patterns (0.06° line widths) show constant contrast of 33%. The frame of the display (17° width) and the laboratory surround are clearly visible. Subjects are seated at a viewing distance of 1m from the screen. Viewing is free and binocular but head movements are restricted by a forehead holder and a chin rest.

During the 600 ms of composite motion, horizontal and vertical movements of the left eye are recorded by an infrared eye tracker (Bach, Bouis & Fischer 1983). The digitized data that is, the relative frequencies of the eye positions, are represented by smoothed contour plots with intervals of 20 ppm.

Results and discussion

We present results obtained from one of the authors.[5]



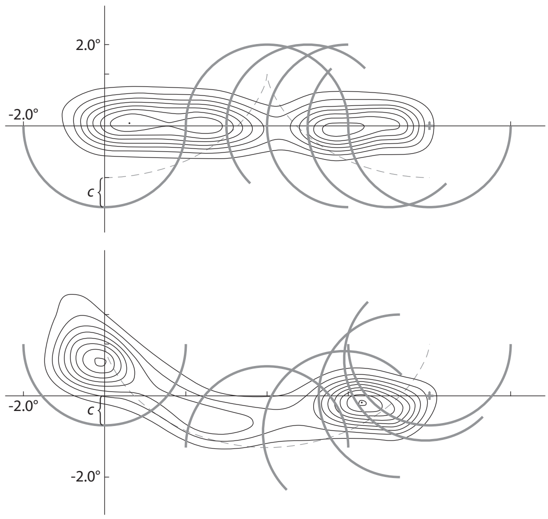
Smoothed contour plots representing the frequency of the eye positions of 40 trials per condition during pursuit of an expanding chevron with its apex (top), or centroid (bottom), translating horizontally

Expanding chevron
For both presentations, the expanding chevron is fixated on or near its OPF. Following an overshoot in the positive direction – that is caused by the calibration sweep – the eye catches up with the stimulus by at least one foveating (backward) saccade (Carl & Gellman 1987). Subsequently and despite occasional saccades,[6] the apex is nicely tracked for the remaining 500 ms of composite motion.

Rotating semicircle
For both presentations, fixation is on or near the OPF. If fixation were on the centroid, a cycloidal trajectory with a central positive peak would be expected but does not show up in the data. If fixation were on the (imagined) center of the semicircle, then a cycloidal trajectory, with a shallow negative deviation from the horizontal line, would be expected and is actually present in our data. – Following the initial pause of 200 ms, at least one foveating saccade is observed (Carl & Gellman 1987). Hereafter and despite occasional saccades,[6] the center of rotation is more or less tracked for the remaining 500 ms of composite motion.

3 No Rashbass-steps are applied
4 Below about 10°/s exploratory saccades and above foveating saccades increasingly occur
5 Earlier results of two subjects are shown in our contribution to the conference proceedings (Glünder, Frank & Graf 1989)

6 Despite the randomized stimulus presentations, habituation to the (final) pattern positions and according saccades must be expected



Smoothed contour plots representing the frequency of the eye positions of 60 trials per condition during pursuit of a rotating semicircular line with its center (top), or centroid (bottom), translating horizontally

Conclusion and conjectures

If the human oculomotor system indeed minimizes changes of a pursued retinal pattern that are caused by object motion other than fronto-parallel translations, then composite retinal pattern motion must somehow be decomposed. Neural analyzers that are selective with respect to fixed point related motion, such as rotation and expansion, could serve this purpose (Glünder 1989). Given such a mechanism, it seems likely that the fixed points of these analyzers are restricted to the foveal region. Hence, an analyzer is activated, and motion decomposition will take place, if the OPF of a pattern is fovealized. Retinal slip will lead to slow activity changes in the ensemble of analyzers that is, between systems centered on different fixed points.

We conjecture that the position (fixed point) of the currently best matching analyzer, as well as position changes that are due to retinal slip, serve as command signals for the pursuit control loop and for position-correction that is, for foveating saccades.

References

Bach M., Bouis D. and Fischer B. (1983) An accurate and linear infrared oculometer. *Journal of Neuroscience Methods* **9**: 9-14.

Carl J.R. and Gellman R.S. (1987) Human smooth pursuit: stimulus-dependent responses. *Journal of Neurophysiology* **57**: 1446-1463.

Glünder H. (1987) Invariant description of pictorial patterns via generalized auto-correlation functions. In: Meyer-Ebrecht D. (ed.) *ASST '87. 6. Aachener Symposium für Signaltheorie*. Springer, Berlin, pp. 84-87.

Glünder H. (1989) A dualistic view of motion and invariant shape analysis. In: Simon J.C. (ed.) *From pixels to features*. Elsevier, Amsterdam, pp. 323-332.

Glünder H., Frank H. and Graf W. (1989) Fixation during pursuit eye movements for general object translations in 3D space. In: Schmid R. and Zambarbieri D. (eds.) *Proc. 5. European conference on eye movements*. University of Pavia, Pavia/Italy, pp. 82-84.

Kürzinger G. and Deubel H. (1986) A versatile digital image-presentation system for research in visual psychophysics. *Perception* **15**: A30.