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FIXATION DURING PURSUIT EYE MOVEMENTS FOR GENERAL OBJECT TRANSLATIONS IN 3D SPACE.

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A single object moving through static surroundings most likely causes visual tracking behaviour of a relaxed and uninstructed human observer. Especially smooth pursuit reactions are generally assumed to serve detailed analyses of the object, in a comparable way steady fixation does in the case of static objects, although the processes are executed by different systems. In both cases fovealization and thus visual pattern analyses with high spatial resolution become feasible and one can conjecture that short periods of stabilized retinal images are necessary or at least helpful for this purpose.

Our investigations concern smooth pursuit eye movements under fixed head conditions. As is known, they are restricted to compensate essentially for translatory motion of planar objects in fronto-parallel planes, although this type of object motion alone occurs mainly under laboratory conditions. For general object motion in 3D space, however, the question arises whether there exist mechanisms or strategies that result in a minimization of impeding influences on the process of object analyses which are due to other types of motion. Obviously, the degree of momentary change of the pattern on the retina depends on the point of fixation (centre of gaze). Thus, non-translatory motion of the retinal image (pattern) of the pursued object, such as expansion and rotation, can be minimized by using the hereby defined *optimal points of fixation* (OPF) which guarantee the maximal pattern invariance under the considered type of motion (cf. Glünder 1987). In the following we report results from basic psychophysical experiments that permit first insights into the fixation strategies of the human visual system when confronted with compound motion of extended patterns.

We began with an elementary and natural kind of motion, namely that of an object towards an observer along a straight trajectory that is inclined to the Z-direction (head forward direction). For this purpose we displayed a target pattern that is expanding while it translates along a straight line on a fronto-parallel screen. We chose a chevron-shaped line-pattern because of its high degree of selfcongruence under scale changes and its well-defined OPF, which is the apex. On the other hand the centroid (centre of gravity) – another location that is suspected to serve for fixation – is sufficiently far away compared, e.g., to a star-shaped pattern for which both locations would coincide. We recorded two-dimensional eye movements of subjects who were instructed to track the moving object.

Methods. Each presentation started with a horizontal left to right motion over 8° of the smallest chevron. The right end of this calibration track was the starting point for the instantly following compound motion back to the left end side where the target disappeared immediately. (No Rashbass-steps were applied.) Expansion was linear and reaches a factor of 21 at the end of each presentation. (Linear expansion corresponds to a decelerated motion of an approaching object in 3D space.) The chevron was an isoceles triangle without base-line and with a

right angle at the apex. It was vertically oriented with the apex at the top. Line width was 0.06° and the minimal length of each side was 0.27°. Due to pilot experiments we decided to chose a translatory speed of 13.3°/s for all experiments. All stimulus sequences were computer generated and stored by a real-time image memory system (Kürzinger 1986). Frame rate of the b&w video display was 100Hz. Background illumination was 34cd/m^2 and the target had a constant contrast of 33%. The frame of the monitor (width 17°), as well as items in the surroundings were clearly visible. Subjects were seated at a viewing distance of 1m from the display screen. Head movements were restricted by a forehead holder and a chin rest (W) or a biteboard (K). Viewing was free and binocular. Horizontal and vertical eye movements were recorded monocularly (left eye) by an infrared eye tracker (Bach 1983). Registration lasted for the duration of the compound motion (600ms). The digitized data were stored and are shown as 2D distributions of the relative frequency of occurrence of the eye positions during 80 (K) and 40 (W) trials. Contour intervals represent 20ppm.

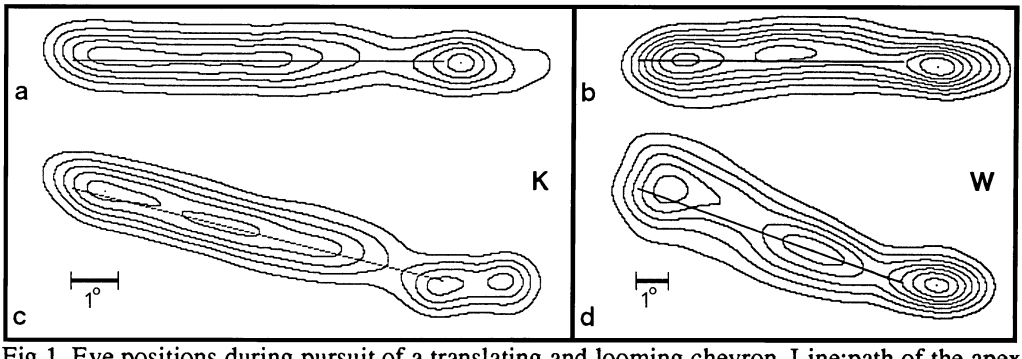

Fig.1. Eye positions during pursuit of a translating and looming chevron. Line:path of the apex

Results and discussion. Figure 1 shows typical results obtained from a naive subject "K" (Fig.1a,c) and from one of the authors "W" (Fig.1b,d). The plots on the top resulted when the apex of the chevron translated horizontally during expansion. When the location 64% below the apex translated horizontally we obtained the distributions shown at the bottom. These results clearly demonstrate that the human visual system pursues an expanding chevron target by fixating on or near its OPF. After an initial overshoot due to a delay of typically 100ms which follows the sudden reversal of direction from the forward calibration sweep to the backward compound motion, and the succeeding speed up that is accompanied by at least one foveating saccade (Carl 1987), the apex is reliably tracked for the remaining 300 to 400ms of compound motion.

Additional experiment. Another kind of compound motion, namely translation-coupled rotations, was considered for further testing the OPF hypothesis. A semicircular line was used as target pattern. Its diameter was 4° and, starting with its virtual baseline at the top, it translated 8° horizontally from the right to the left while rotating clockwise through 360°. This compound motion was preceded by a left to right calibration sweep of a small cross which was substituted at the end by the target pattern and which in turn stayed there for 200ms before backward

compound motion onset. Sixty trials were pooled and all other conditions were as described above.

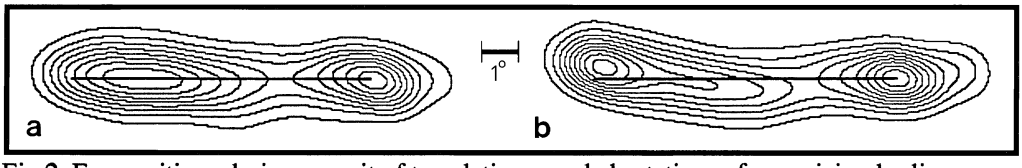

Fig.2. Eye positions during pursuit of translation-coupled rotations of a semicircular line.

Results and discussion. Figure 2 shows results that were obtained from subject "W" under two stimulus conditions: either the centre of the semicircle (Fig.2a), or a location 1.6° vertically below it (Fig.2b) translated horizontally during pattern rotation. The results indicate that fixation is again on or near the OPF which is the imagined centre of the semicircle and thus is no longer located on the pattern itself. If fixation were on the centroid, a trochoidal path of fixation would be expected in Fig.2a. This curve shows a maximal positive deviation from the horizontal line in the middle of the translatory path. This deviation is not present in our data. If, however, fixation is on the imagined centre of the semicircle, then a 180° phase-shifted trochoidal path of fixation is to expect in Fig.2b, i.e., the maximum of a negative deviation must be observed halfway between motion on- and offset, which is actually present in the plot. Due to the 200ms pause, there is no overshoot but again a delay etc. after motion onset (cf. Carl 1987).

Concluding remarks. If the human oculomotor system indeed minimizes non-translatory object motion, mechanisms for the estimation of motion parameters must be involved in this task. For expansions and rotations, radially and circularly organized arrays of motion detectors could serve for this purpose (Glünder 1989). These analyzer systems are selective to the type and centre of motion. We postulate the existence of sets of such non-translatory motion analyzers with their centres restricted to the foveal region. In order to minimize relative motion, the centre of one of the analyzers must coincide with an OPF of the moving object. The hereby defined optimal analyzer is selectively activated. Due mainly to translatory motion (retinal slip), activity will slowly change within the set of motion analyzers. Thus, we conjecture that the *position* of the centre of the optimal analyzer as well as *changes* of its position serve as command signals for the pursuit control loop and for position-correcting, i.e., foveating saccades.

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