O21-Effect of gaze direction on curvilinear heading discrimination

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While cornering, the drivers exhibit gaze fixation patterns in the vicinity of the tangent point (TP). The TP interest is mainly due to its angular position, linked to the road curvature, and, its minimal speed in the optical flow (OF). We assume that, because of its property, the TP is actually the best location in the dynamic optical array to perceive a change in the trajectory. In this study, we evaluated the ability of human observers to detect differences in their path from OF patterns, as a function of gaze direction in a simple virtual environment. The discrimination is minimal for a gaze directed toward a minimum of flow speed. A model based on Weber fraction of the foveal flow velocities correctly predicts the experimental thresholds.
Keywords: optic flow, heading, self-motion, gaze, visual motion perception

INTRODUCTION

Most approaches to the control of steering rely on the tangent point (TP) as a major source of information (Land & Lee, 1994; Authié & Mestre, 2011) The TP is the geometrical intersection between the inner edge of the road and the tangent to it, passing through the subject's position. It corresponds to a singular and salient point from in the subject visual field and its location reflects the road geometry and the self-motion direction. However, the particular status of the TP in the optical flow (OF), as a local minimum of flow speed, was often left aside. We therefore assume that the TP is actually the best location in the dynamic optical array to perceive a change in the trajectory. In this study, we evaluated the ability of human observers to detect variations in their path curvature from OF patterns, as a function of the gaze direction in a virtual environment. We simulated curvilinear self-motion across a ground plane. Using random-dot OF stimuli of brief duration and a forced-choice adaptive procedure, we determined curvature discrimination thresholds, as a function of simulated gaze direction.

METHOD

We used a two-alternative forced choice (2AFC) paradigm, in order to define the minimal difference of radius of curvature necessary to make an accurate judgment about his/her simulated trajectory. We projected OF displays which simulated a curvilinear movement over a random-dot ground plane. Each 2AFC trial consisted of two temporal intervals (500ms each), separated by a blank screen. In the first one, the dots movement simulated a curvilinear trajectory with a radius of curvature R. In the second interval the simulated trajectory has a different radius, larger or smaller. The observers had to decide which stimulus corresponded to the most curved trajectory (*i.e.* had the smaller radius of curvature). Each condition consisted in 70 trials. Although gaze direction was physically kept constant on the screen across all conditions (*i.e.* observer was asked to fixate a target located at the center of the screen), the gaze orientation of the observers in the virtual environment was manipulated between experimental sessions and kept constant during a given session. The gaze orientation in was changed by manipulating the camera orientation in the virtual scene (5 orientations: $-\theta$, 0, $+\theta$, $+2\theta$, $+3\theta$). The zero direction corresponds to a simulated gaze direction aligned with instantaneous heading. The $+\theta$ direction matches a local minimum of flow. We defined a perceptual model, based on foveal OF speed, to predict discrimination thresholds. We assumed that a trajectory discrimination task amounts to the discrimination of angular speeds (McKee, 1981), and that the discrimination performance is a function of the relative optical angular speed. This discrimination is considered to be well modeled by a Weber fraction law:

$$w=\frac{OF_{S1}-OF_{S2}}{OF_{S1}}\approx\frac{\mathrm{OF}_{S1}-OF_{S2}}{OF_{Sm}} \quad \textit{Equation [1]}$$

with OF_{S1} and OF_{S2} the OF speed at the gaze position for R1 and R2 radii, respectively; w a constant (between 0 and 1, depending on the subject discrimination performance); and OF_{Sm} the average speed of OF_{S1} and OF_{S2}.

RESULTS

Experimental thresholds. The curvature discrimination thresholds (expressed as the percentage of difference between radii of curvature that observers were able to discriminate) between the simulated trajectories in each condition are shown in Figure 1. A one-way repeated ANOVA revealed a large effect of the gaze direction [$F(4,44)=13.63$, $p<.01$, $\eta2p=.55$]. Newman-Keuls tests showed no difference between +2θ and 0 directions and between +2θ and −θ directions; but significant differences between all other orientations. The gaze orientation +θ corresponded to the minimal thresholds and the +3θ direction to the maximal thresholds.

Model thresholds. For our model (Figure 1), the discrimination thresholds between two complex stimuli (and two radii) corresponds to a comparison between two local OF vectors, through their relative speed. We chose a w value (i.e. the relative speed that observers are able to discriminate; equation [1]) which minimizes the root mean square error between the model and the average data. The best w parameter found was *w*=.147, which means that, on average, the relative difference between two OF speeds is perceived if greater or equal to 14.7%. The simulation fits well the data with a minimum threshold at θ and an asymmetry around this direction, with higher thresholds for +3θ than for −θ direction. A quantitative analysis revealed a good accordance between the data and the model ($R^2=.94$).

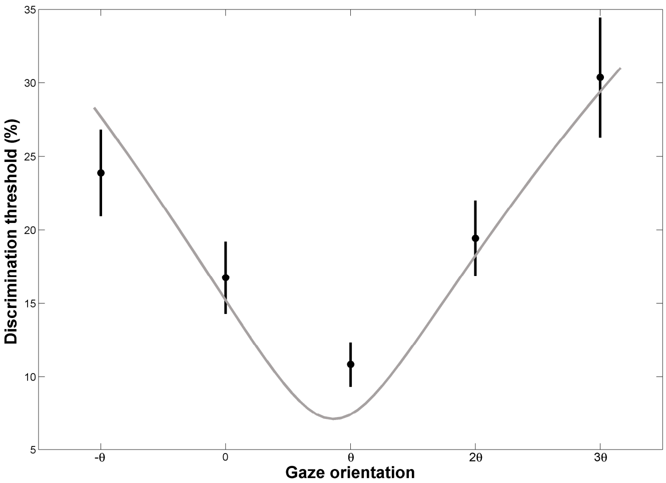

Figure 2: Thresholds from the model (gray) and the averaged data (black) as a function of the gaze orientation. Bars indicate between-subjects standard error.

DISCUSSION

In conclusion, the visual perception of the characteristics of self-motion is not equally precise across the visual field (at least in the horizontal direction). A given gaze direction of the moving observer corresponds to a single local flow velocity. This velocity affects the curvature discrimination thresholds which are minimal for a gaze directed toward a local minimum of flow speed. A model based on a Weber fraction of the foveal velocities (ΔV/V) predicts well the relationship between experimental thresholds and local flow velocity. We observe that a minimal speed direction corresponds to a maximal sensitivity of the visual system, as predicted by our model. Then, the spontaneous gazing strategies observed during driving (e.g. the TP fixation behavior) might correspond to an optimal selection of relevant and optimal information in the OF field. These findings are consistent with most of ecological situations; the minimal OF and the gaze direction often match the movement direction (for rectilinear trajectories; Gibson, 1950) or the future path (Wilkie & Wann, 2006), which correspond to areas of small flow speed, such as the focus of expansion or the TP.

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