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Head tilt during driving

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In order to distinguish between the use of visual and gravito-inertial force reference frames, the head tilt of drivers and passengers were measured as they went around corners at various speeds. The visual curvature of the corners were thus dissociated from the magnitude of the centripetal forces (0.30–0.77 g). Drivers' head tilts were highly correlated with the visually-available estimate of the curvature of the road ($r^2 = 0.86$) but not with the centripetal force ($r^2 < 0.1$). Passengers' head tilts were inversely correlated with the lateral forces ($r^2 = 0.3$–0.7) and seem to reflect a passive sway. The strong correlation of the tilt of drivers' heads with a visual aspect of the road ahead, supports the use of a predominantly visual reference frame for the driving task.

1. Introduction

Casual observation of drivers and passengers shows that they tilt their heads when cornering. Why do people do this? It seems to be a common belief that while going around corners, drivers tilt their heads in response to the centripetal forces generated. Yet little is known about this ubiquitous behaviour. Head tilt might, for example, form part of a strategy for resisting the tendency to be swung across the car during cornering; or it might be part of a physiological reflex that continuously aligns the body with a gravitationally-defined 'upright'. Previous studies (Rogé 1996) have investigated these issues with an imaginative use of simulators. In this paper real cars were used on real roads to test driving behaviour in the presence of centripetal forces.

A person in a car driving around a corner is exposed to two orthogonal, linear accelerations: gravity and centripetal acceleration. The combination of these two forces is equivalent and indistinguishable from a single acceleration and is called the gravito-inertial force (GIF). The direction of the GIF while cornering is tilted compared to the direction of gravity alone (figure 1A). The first hypothesis was therefore that drivers and passengers might align their heads with this tilted gravito-inertial force, thus indicating a dominance of a gravito-inertial reference frame and an attempt to keep the head aligned with this frame.

An alternative explanation has to do with vision. The view of the road through the windshield indicates the curvature of the road ahead (figure 1B). If riders in a vehicle were dominated by visual information corresponding to the layout of the road ahead, this might be reflected in their head orientation. The second hypothesis was therefore that drivers and passengers might align their heads with some visual aspect of the road.

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In order to discriminate between these two hypotheses the fact that the tilt of the GIF depends on the speed of cornering whereas the visual appearance of the road is not affected by how fast the vehicle is moving was exploited. Going round the same corners a number of times at different speeds varied the tilt of the GIF and the visual features of the road independently. Analysis then revealed with which variable the head tilt was best correlated.

2. Method

2.1. *Participants*

Twelve drivers with driving experience of between 4 and 8 years participated in this study. Some of the drivers also served as passengers. All subjects had 20/20 vision or corrected to 20/20 vision and no history of dizziness or other vestibular disorders. The subjects ranged in age from 22 to 26 years and in height from 157 to 185 cm with mean height being 167 cms. Three subjects were females and nine were males.

2.2. *Measuring lateral accelerations*

Lateral accelerations were produced by having subjects drive a normal, domestic van or car around a number of different corners of various radii at speeds of between 20

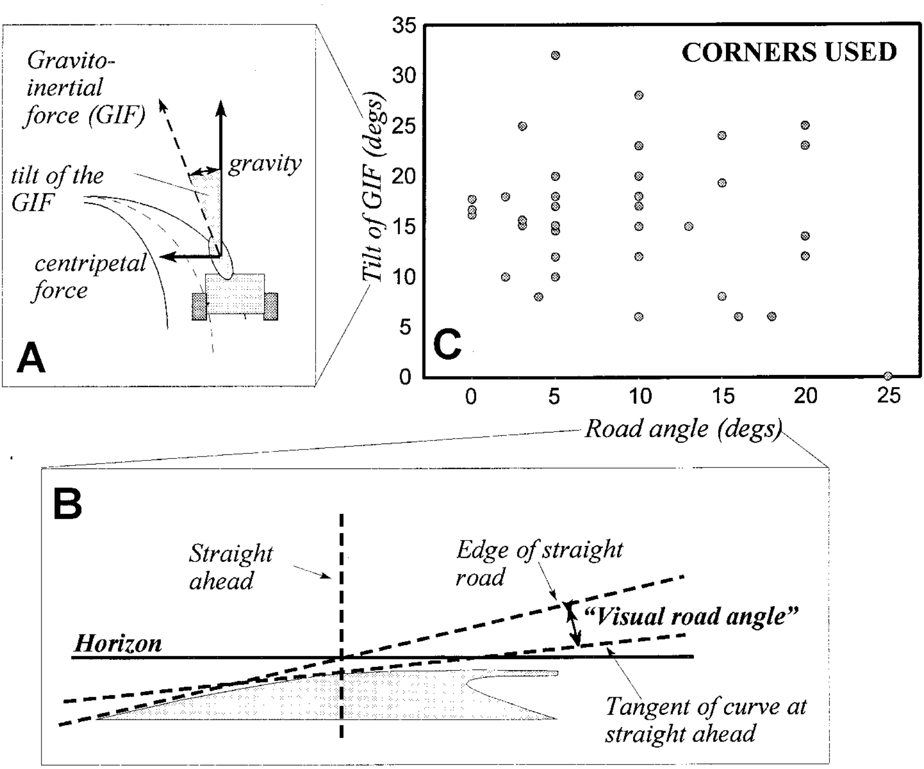

Figure 1. Going around a particular corner at a given speed is associated with a tilt of the gravito-inertial force (GIF, A) and a visual tilt (see text, B). By going round the same corners at a range of different speeds these variables were decorrelated (C). A given visual road angle was paired with a range of tilts of the GIF (corresponding to the different speeds used) as shown by the vertical columns of symbols in graph C.

and 80 km/h. The vehicle was equipped with a G-analyst, Vehicle Dynamics Monitor (model 500; Valentine Research Inc., Cincinnati, Ohio), which is a three-axis accelerometer that measures the lateral acceleration with a sampling interval of 0.1 s and an accuracy of 0.01 ***g***. The G-analyst stored the lateral acceleration profile digitally for later analysis. Its display screen, with a timer, was recorded on videotape that simultaneously recorded the subject's head orientation and a view of the road (see below). This enabled the analysis of the video and the G-analyst to be synchronized. Lateral accelerations were expressed as the equivalent tilt of the gravito-inertial force (figure 1A) by:

$$\text{tilt} = \tan^{-1}\ (\text{centripetal force}/\boldsymbol{g})$$

where '***g***' is the pull of gravity at 9.81 cm/s^2, and centripetal force is the lateral acceleration experienced by the vehicle and objects inside the vehicle during cornering.

2.3. *Measuring the visual tilt of the road*

The visual curvature of the road was assessed from the videotape of the view through the front windshield of the vehicle. Videotapes were played back on a freeze-frame system. A line was drawn on the video screen along the edges of the road when the road was straight. As the car went around a curve, a tangent was drawn along the far side of the road where it crossed the straight-ahead position (figure 1B). The angle that this tangent made with the edge of the straight road was taken as a measure of the visual curvature of the road. This produced an arbitrary but consistent measure of the tilt of the road from 0°(straight ahead) to about 35° when the tangent was horizontal.

2.4. *Measuring head tilt*

The head tilt of driver and passenger were measured from the video recorded by a camcorder mounted firmly in the vehicle 94 cm behind the subject. The video view also provided the view through the front windshield and the display of the G-analyst. In order to make measuring the orientation of their heads easier in subsequent freeze-frame analysis, drivers and passengers wore hats with several high-contrast vertical stripes. Rotation of the head without tilt produced no artefactual tilt of the lines on the hats. Tilts of the subjects' heads were measured relative to the orientation of the head before they went into the curve. Head tilt towards the centre of curvature of the corner is referred to as being 'into the corner' and tilts away from the centre as leaning 'out of the corner'. Tilts into the corner are assigned positive numbers and tilts out of the corner are assigned negative numbers (figure 2).

All the measures of tilt varied throughout a corner due to rapidly changing forces. Therefore, sections were selected where the three variables: head tilt, visual road tilt and GIF tilt, reached a plateau or steady state. The time relationship between the variables will be considered in a future paper.

3. Results

3.1. *Head tilts of drivers with their eyes open*

Drivers always tilted their heads into the curve, that is in towards the centre of rotation. Linear regression analysis showed that there was a strong correlation with the visual measure of road tilt (figure 2A; 0.82° of head tilt/degree of visual angle; $r^2 = 0.86$) but none with the gravito-inertial tilt (figure 2B; $r^2 = 0.01$). This is the central finding of this paper and it is remarkably clear.

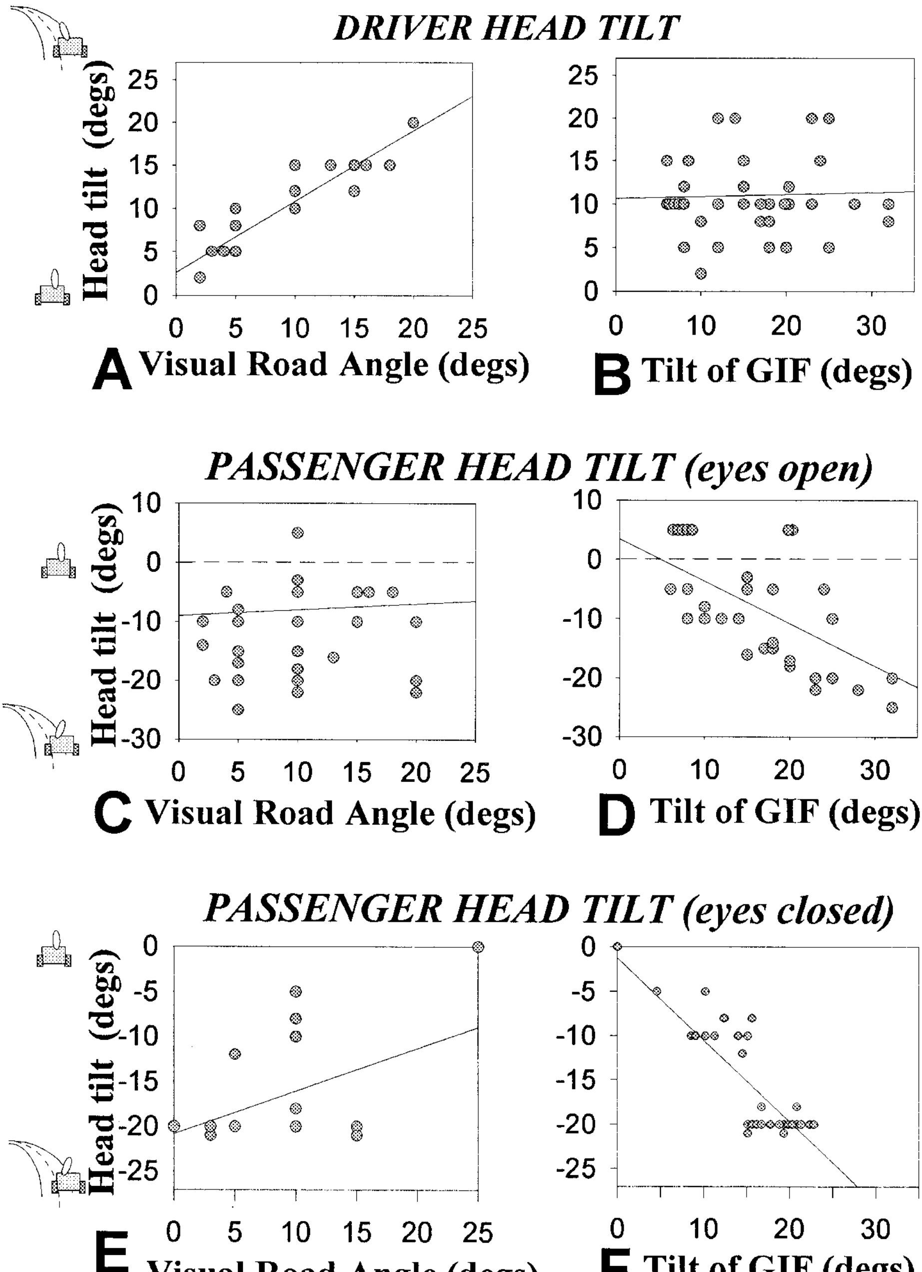

Figure 2. The head tilt of drivers and passengers plotted against the visual tilt of the road (A, C and E) and the tilt of the GIF (B, D and F). Each data point is plotted in both the visual tilt graphs and the GIF graphs. The solid lines are regression lines plotted through the data. Positive values indicate 'into the corner', whereas negative values indicate 'out of the corner'. See text and figure 1 for explanations of the axes.

3.2. *Head tilts of passengers with their eyes open*

Passengers with eyes open generally tilted their heads out of the corner, that is in the opposite direction to drivers. Their head tilts show a negative correlation (using linear regression analysis) with the tilt of the GIF (figure 2C; $-0.72°$ of head tilt/degree of tilt of GIF; $r^2 = 0.31$) and none with vision (figure 2D; $r^2 = 0.003$). There are some outliers to the regression. GIF tilts up to 20° were sometimes accompanied by head tilts of less than 5°. Occasionally a passenger's head tilted in the same direction as the driver's (into the curve, positive tilts in figures 2C and 2D).

3.3. *Head tilts of passengers with their eyes closed*

Head tilts of passengers with eyes closed were also measured. They tilted their heads out of the corner. Their head tilts show a negative correlation (linear regression analysis) with the tilt of the GIF (figure 2F; $-0.92°$ of head tilt/degree of tilt of GIF; $r^2 = 0.69$) and of course were not significantly correlated to the visual tilt of the road, which they could not see (figure 2E; $r^2 = 0.16$).

4. Discussion

The results clearly show a tremendous dominance of visual information over the orientation of the gravito-inertial forces in determining the orientation of a driver's head. The data show that the effect of drivers tilting their heads as they go around a corner is not to counteract the centripetal force or to line up the head with a misperceived direction of gravity, but rather to line up their heads with some visual feature of the road.

The pattern of *passenger* head tilt was not predicted by either hypothesis. Although passenger head tilt was correlated with the tilt of the GIF, it was *negatively* correlated. That is, there was no indication of passengers aligning their heads with the GIF, rather they tilted the other way. This was especially true when passengers had their eyes closed.

The movement of the passengers can probably be explained as a partially uncorrected sway due to the sideways forces. The centripetal force will tend to cause objects that are not fastened down to slide towards the side of the vehicle away from the corner. A driver tilting in the opposite way to this passive tilt therefore must be overcoming the passive sway and superimposing an active visually-derived tilt on this platform.

The results emphasize that driving studies must be done with both visual and gravitational cues occurring in their natural patterns to determine the real human utilization of these cues. Rogé's experiments in driving simulators (Rogé 1996) had suggested that GIF information might be significant and those who were dominated by it might drive better. The results reported here show that in real-life conditions, the tilt of a driver's head gives no indication that the orientation of the GIF is significant.

4.1. *Why do drivers tilt their heads?*

While it seems to make intuitive sense that drivers might want to line up their heads with an instantaneous estimate of gravity, this would in fact not be a good strategy while driving a car. It should be remembered that the tilt of gravito-inertial force when cornering is an *illusion* and does not correspond to the orientation of anything useful except the tilt of a pendulum hung from the roof of the car! When a driver goes round a corner, the lateral accelerations can be considerable. The drivers in this study experienced pulls of up to 0.77 ***g*** (figure 1C) going at modest speeds around normal suburban roads. Racing car drivers can easily generate centripetal forces in excess 4 ***g***, which would require a head tilt of over 70° ! The correct strategy is neither to allow the head to move passively out under the influence of the centripetal force nor actively to line the head up with the new gravito-inertial force but to line the head up in a way that allows the driver to make maximum use of visual information relevant to the control of the car.

A driver sitting down and holding onto a steering wheel is fairly stabilized against the tendency to tilt passively out of the corner like their passenger. There are other situations where it *is* important to line up the body with gravity in order not to fall over. Meeting the balance challenge of skiing, bob-sledding, motor-bike riding or just standing up requires positioning the centre of gravity of the body on a line parallel to the gravito-inertial force that goes through the support surface. Motorbike riders are particularly interesting from the point of view of this study as they simultaneously need to align their bodies with the gravito-inertial direction and to align their heads — if they use the same driving strategies as described here for car drivers — with the visual properties of the road ahead. Casual inspection of motorcyclists suggests that this might indeed be what they are doing. Future studies will investigate head tilt in motorcyclists using the same techniques as in the present paper.

4.2. *The use of vision by drivers*

What visual feature might be aligned with the head during head tilt? Figure 3 shows the projection of a road onto the flat surface of a vertical windshield. The road has horizontal lines painted across it at equal intervals. Lining up the head with a part of the road that the driver can anticipate arriving at shortly, requires a head tilt into the corner. How large a tilt is required depends how far down the road the driver is looking and the sharpness of the corner. Land and colleagues (Land and Lee 1994, Land and Furneaux 1995) found that drivers tend to look ahead at the tangent point of the road while cornering. Why align the head in the direction of this horizontal line? Drivers need to make left/right steering decisions based on their best estimate of the road conditions ahead. The correlation of the tilt of their head with the visual road angle indicates that they are working in a visual reference frame.

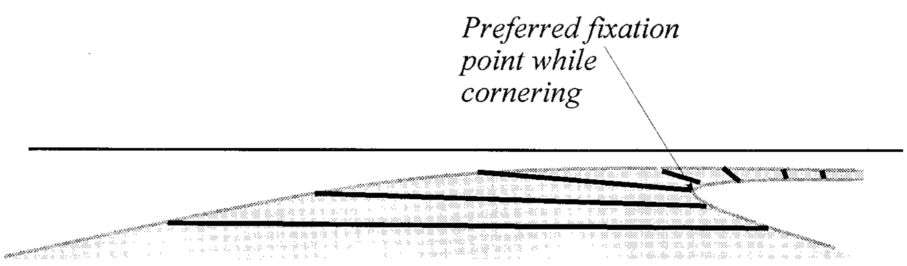

Figure 3. This diagram shows a view of a typical corner with horizontal lines painted across it. By tilting the head in a way related to the visual tilt of the corner, drivers can align their heads with the orientation of the oncoming road.

4.3. *Applications of the present results*

These results might form the basis for developing a guide for driver training. The results indicate what experienced drivers do when cornering and the information that they are probably using. Having established norms for head tilt during driving, driving instructors will be better equipped to spot unusual and inappropriate head strategies that might contribute to poor performance in novice drivers or drivers that have a history of accidents.

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