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The Effect of Field of View and Surface Texture on Driver Steering Performance

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Abstract. In the present study we investigated steering accuracy in terms of our ability to keep to the middle of a lane in a fixed-base driving simulator. In particular, we studied the dependence of steering accuracy on the visibility of different road sections, on the assumption that performance reflects the importance of different road sections in guiding steering. Other influences on steering accuracy - including the presence of textural cues, in the form of a textured road surface, and the horizontal field of view - were also investigated. We found that textural cues can improve accuracy in lateral lane control, presumably by providing strong optical flow, and that driving accuracy is little affected by increasing the horizontal field of view from 40° to a full field of 180°.

1 Introduction

One of the fundamental tasks in driving is the maintenance of lateral position on the road. Recently, the importance of different sections of the road in depth corresponding to the vertical height in the image projection was investigated by Land and Horwood (1995). By varying the position of the visible segments of the road, they found that even with restricted information, obtained through a single vertical aperture of 1°, driving could still be accurate, provided that the visible road section was optimally placed (at 5.5° below the horizon) and that the vehicle's velocity remained moderate. At higher velocities, as the visible segment was shifted away from the optimal position, lateral position accuracy decreased. From their work, Land and Horwood concluded that additional visual information about far regions of the road can help increase accuracy and reduce instability. This, together with the fact that at lower speeds such effects of aperture are not measurable, led Land and Horwood to conclude that two mechanisms are involved in driving.

The first, the so called 'far-road mechanism', is relevant at higher speeds where the curvature of the road must be anticipated to afford timely steering movements. The optimal information for this mechanism lies at 4° below the horizon. The second is the 'near-road mechanism', which provides additional information about the position-in-lane and is sufficient on its own for accurate road holding at lower speeds, for which the most information can be obtained at 7° below the horizon. These results are in accordance with a theoretical model (Donges, 1978), which suggests that the driving process can be described by open-loop activity (anticipation of the road's curvature), and closed-loop activity (for correction of the current path error).

The stimuli used by Land and Horwood consisted of a pair of white lines to demark the road boundary, and an artificial horizon drawn at 1° below the true horizon. One question which their work did not address was the influence of road texture. Such a texture would certainly provide a strong optical flow field which may well aid steering accuracy. Certainly, humans are well able to use optic flow to discern heading and therefore may well use it as a cue in normal driving (Lee & Lishman (1977); Warren & Hannon (1988); Warren, Mestre, Blackwell, & Morris (1991)).

Another question of interest to us in this paper is the influence of peripheral vision. In other work, peripheral vision was shown to affect speed estimation (Osaka, 1988), time-to-collision judgements (Groeger & Brown, 1988) and the fixation duration of eye movements (Osaka, 1991). A restricted visual field also influences driving speed and reaction times, although for other aspects of driving (e.g. road position), it seems to have little effect (Wood & Troutbeck, 1996). For this reason the current work also addresses the effect of an extended field of view on the accuracy of the lateral control.

The main objectives for this work were:

- To test whether, by simulating more realistic conditions, which incorporated a force-feed- back steering wheel, high image rendering and an increased update and frame-rate, comparable results to the findings of Land and Horwood (1995) would be obtained.
- To determine the influence of road surface texture on steering accuracy.
- To determine the effect of horizontal field of view on driving accuracy.

2 Methods

2.1 Apparatus

The driving simulation was carried out either in front of a computer monitor or in front of a projection screen. The monitor and projection screen differed in the following important respects (Table 1):

Properties	Computer monitor	Projection screen
horizontal FOV	40°	180°
vertical FOV	28°	55°
horiz. resolution	32 pixel/°	14 pixel/°
vert. resolution	36 pixel/°	14 pixel/°
contrast	++	+
reference frame	++	–

Table 1: Differences between computer monitor and projection screen.

2.2 Road Section

The course consisted of eight, different curves with intermediary straight sections, which were presented in random order, curving randomly either to the left or right. The radius of the curves varied between 114.6 m and 916.7 m, corresponding to an angular velocity of 8.45°/sec and 1.06°/sec respectively. The subjects drove with a constant velocity of 60.8 km/h (16.9 m/s) on a 3 m wide road. The road was defined either (a) by continuous white lines on a black background or (b) by two lines and additional road surface texture.

2.3 Visible Road Segments

The visible road was viewed through windows with a vertical height of 1°. The location of the windows was varied from 1° to 10° below the horizon, resulting in 10 different positions. As a further test, the 10 conditions were repeated when an additional road segment was visible, forming three conditions of segment combinations: (a) only a single segment was visible, (b) a second segment was positioned 1° below the horizon, or (c) the additional segment was visible 10° below the horizon. The conditions of the different segment combinations were presented in random order.

2.4 Subjects and Instruction

Six subjects participated in each of the two experiments. Their age varied between 18-36 years with a mean age of 23.25 years, and they were all licensed drivers. The subjects were informed about the general purpose of the experiment and instructed to drive "in the middle of the road" and "as smoothly as possible".

2.5 Measuring Performance

The measure of accuracy chosen to compare the experimental conditions in this study was the absolute lateral deviation from the centre of the road. Averaged over a span of approximately 31.5 s, a single mean represented approx. 975 data points. An instability index was also obtained by calculating the power spectrum density of the lateral deviation from

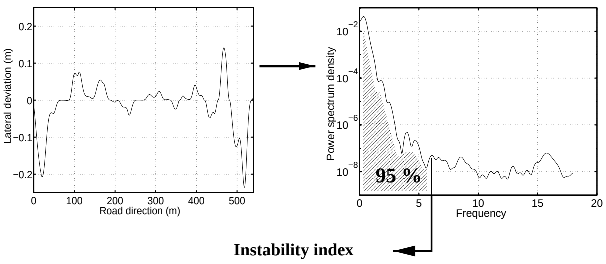

Figure 1: Computation of the instability index (95%-interval is not to scale).

the centre of the road and then establishing the frequency at which 95% of the integral of the power spectrum was attained (Fig. 1).

3 Results

3.1 Effect of the Vertical Position of the Visible Segment

The results presented in this section were achieved using a monitor projection with a 40° horizontal field of view. According to Land and Horwood's findings, one would expect to find an optimal position for a single vertical visible segment (at around 5°-6° below the horizon) for which the lateral deviation from the road's centerline is minimal. For segments closer to the horizon and nearer to the current position, the lateral deviation should increase. However, we were not able to reproduce a distinguishable optimum (Fig. 2). The lateral deviation did not differ statistically significantly over the range from 3° to 10° be low the horizon. The effect of the vertical position of a single segment was limited to the segments presented at a vertical height of 1° and 2° for which a statistically significant difference compared with the segment with the lowest deviation (7°) occurred ($p < 0.01$ and $p < 0.001$).

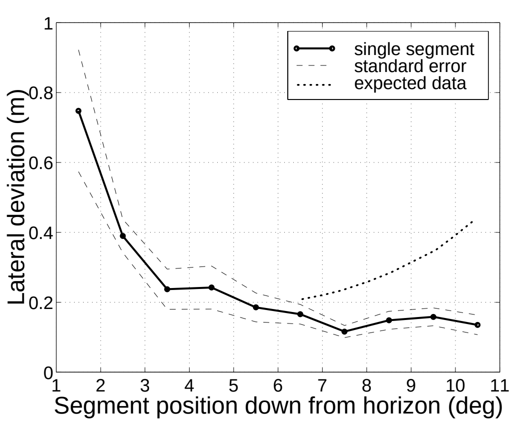

Figure 2: Obtained and expected lateral deviation from the middle of the road under a field of view of 40° (monitor). Data represents values for a single segment (n=6).

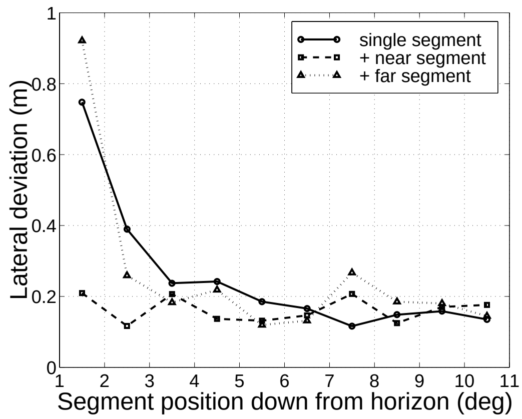

Figure 3: Effect of an additional segment either at 1° or 10° below the horizon (n=6).

By adding a further segment near the horizon (1°) there was no decrease in lateral deviation observable. Over the whole span of vertical locations, similar results were obtained to the case with a single segment (Fig. 3). In particular, an improvement in performance for very near segments on the road was expected, due to the potential anticipation of the course ahead. An additional near segment at 10° also had no effect upon the performance over a range of 3° to 10°.

The expected interaction between the vertical position and the second near segment existed only at 1° and 2° and differed significantly from the condition with only one segment or with a second far segment visible ($p < 0.05$ (2°), $p < 0.001$ (1°)).

The failure to improve performance with a second far segment is consistent with the analysis of the driving stability. Here, no reduction of the instability with a second far segment could be observed compared with a single segment (Fig. 4). According to these data, as the vertical position was lowered from 4° to 10° the instability increased. On the other

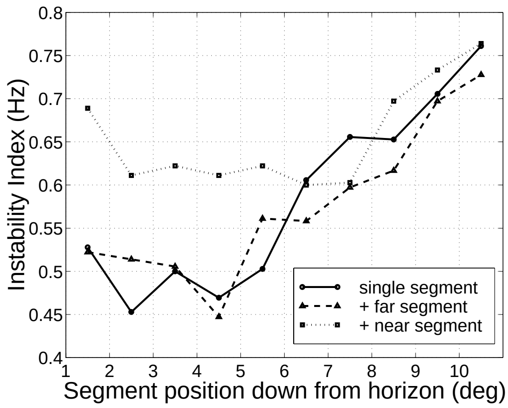

Figure 4: Effect of an additional segment in the vertical position of 1° or 10° upon the in stability (n=6).

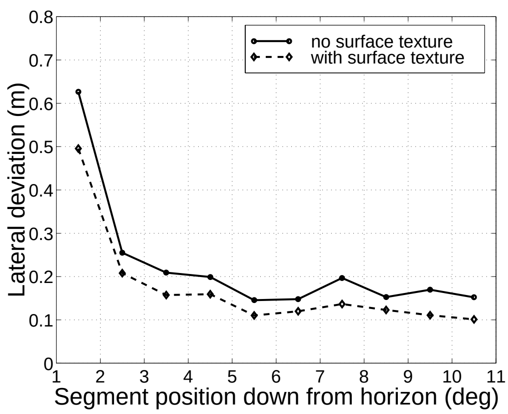

Figure 5: Comparison of lateral deviation while driving on a road with (a) only side boundaries or (b) with additional road surface texture (n=18).

hand the addition of a near segment greatly increased the instability when the first segment was positioned in far regions 1° to 4° below the horizon ($p < 0.01$).

3.2 Effect of Textural Cues

Apart from creating a more realistic impression of driving, we found that by adding a road surface texture on the monitor screen, driving accuracy increased (Fig. 5). Over all conditions a stable reduction of 5.3 cm occurred, compared with the conditions without texture ($p < 0.05$). However, as in the previous experiments, there was no interaction with the vertical position of the segment or with an additional second segment.

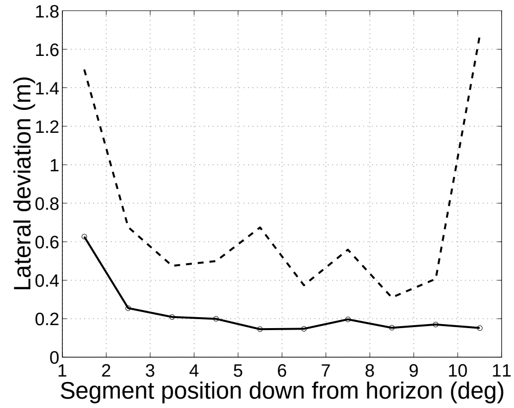

Figure 6: Comparison of the road without texture on monitor and projection screen (n=18).

3.3 Effect of the Projection Screen

The experimental design used in the monitor screen simulation was transferred to a large projection screen, and the performance was measured with 40° field of view. The data obtained here showed no effect of an additional far segment, as was the case with the monitor. Compared with the performance on the monitor an overall decrease occurred. Although the comparison of the mean lateral deviation failed to reach significance, the variance of the mean lateral deviation increased significantly on the projection screen ($F = 49.51$, $p < 0.0001$), indicating the worsened performance (Fig. 6).

Without road texture the overall performance decreased by 0.48 m compared with the monitor. Interestingly, the previous finding, that an additional surface texture reduces the lateral deviation, could not be replicated. No difference was found between the data obtained with and without surface texture. We suppose that this was due to the reduced resolution of the projection screen (Table 1), impeding the occurrence of a strong optical flow. Note that the lateral deviation at 10° reached a comparable size to that at 1°. This large deviation resulted from occasional catastrophic errors of some drivers.

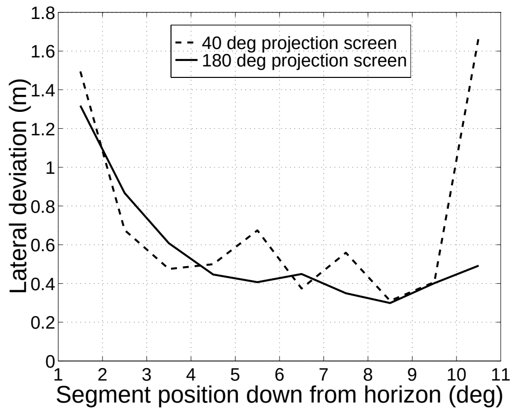

Figure 7: Comparison of the road without texture on projection screen with 40° and 180° field of view (n=18).

3.4 Effect of a 180° Horizontal Field of View

The conditions were repeated with 180° field of view on the projection screen. The analysis of the lateral deviation obtained with a 180° horizontal field of view indicated no statistically significant difference to the 40° condition on the projection screen. As one can see in Fig. 7, over the vertical position from 1° to 9° comparable results were obtained. However, with a visible segment at 10° no deterioration occurred with an extended field of view. This result is consistent with the idea, that a broader field of view can help prevent the catastrophic disorientation of the drivers, seen under the 40° field of view condition.

4 Discussion

Concerning the effect of the vertical position of the visible segment on the lateral deviation, the present study reveals that the subjects were able to perform commensurably over a wide range of segment positions, indicating a successful adaptation to the changing time-delay between the observed road course and heading to the current position. We failed to replicate the results of Land and Horwood (1995), who found an optimal segment for which the lateral deviation was minimal. We also found no significant improvement in driving accuracy in the presence of a far segment. An additional far segment influences performance, neither in the lateral deviation nor in the instability. Hence, we conclude that the drivers relied particularly on the nearest visible segment and did not take advantage of the enabled anticipation of the future course. At higher velocities one would expect anticipation to play a more important role, but at least for the rate of curvature studied here (1.06°/sec - 8.45°/sec) it appears that no such anticipation was made.

Concerning the influence of textural cues, it appears that the lateral deviation could be decreased, but only under conditions with high resolution and high contrast. In the case of the projection screen, lower resolution reduced the effectiveness of this cue. These findings are of importance for the future design of driving simulations and the technical properties of the projection system.

Concerning the effect of a 180° field of view, we found that a more than four-fold increase in the horizontal size did not affect lateral accuracy. These findings are consistent with other studies, where little effect of a restricted visual field on the road position was found (Wood & Troutbeck, 1996). The only major difference which we did find is that with a large field of view, both sides of the road remain visible even after a momentary inaccuracy in steering, allowing such small mistakes to be corrected. With a restricted field of view such mistakes sometimes lead to disorientation and the loss of the true line of the road.

As a final point, one of the important differences between a projection screen and a monitor is the reference frame (Tab. 1). The monitor provides a strong reference frame similar to a real car or to driving simulations with an integrated mock-up. The effect of the absence of a reference frame is not systematically investigated in this study, but it may well increase driving performance, and could be the main cause for the increase in the lateral deviation in the case of the projection screen.

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