Which parts of the road guide steering?

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A DRIVER steering a car on a twisting road has two distinct tasks: to match the road curvature, and to keep a proper distance from the lane edges. Both are achieved by turning the steering wheel, but it is not clear which part or parts of the road ahead supply the visual information needed, or how it is used. Current models of the behaviour of real drivers[1,2] or 'co-driver' simulators[3–5] vary greatly in their implementation of these tasks, but all agree that successful steering requires the driver to monitor the angular deviation of the road from the vehicle's present heading at some 'preview' distance ahead, typically about 1 s into the future. Eye movement recordings generally support this view[6–9]. Here we have used a simple road simulator, in which only certain parts of the road are displayed, to show that at moderate to high speeds accurate driving requires that both a distant and a near region of the road are visible. The former is used to estimate road curvature and the latter to provide position-in-lane feedback. At lower speeds only the near region is necessary. These results support a two-stage model[1] of driver behaviour.

We used a driving simulator based on program developed on an Archimedes A5000 RISC computer. This provided a perspective view of the moving edges (white on black, as in night driving) of a single-lane road, 3 m wide, with many bends, modelled on a real road used in a previous study of drivers' gaze direction[6]. There was no other scenery. The view extended for 63 m and was viewed from a height of 1.1 m. It was updated at 7 Hz, and was presented on a 60-cm wide screen at a distance of 80 cm, providing a road view with the same angular dimensions as the original. The display was driven by a steering wheel monitored by a 'mouse'. The integration constants converting wheel angle to car direction and car direction to lateral road position were chosen to give as realistic a performance as possible, and drivers found it easy to negotiate the road successfully. After an initial few drives, performance changed little. The measure of accuracy chosen to assess different experimental conditions was the reciprocal of the standard deviation (s.d.) of the car's position relative to the road's centre line, measured over the whole drive (68 s at 16.9 m s^{-1} (61 km h^{-1}; 38 m.p.h.)). This s.d. was typically 0.1–0.2 m.

The road was viewed either in its entirety, or with only one or more 1° high segments visible, these being positioned in 9 locations between 1° and 10° below the horizon. These segments moved exactly as they would in the full road. Three typical examples of driver performance are shown in Fig. 1. When only the distant part of the road was visible (*a*) the curvature was smoothly matched, but the position-in-lane was not well maintained. With only the near region (*c*) steering was difficult and jerky, as the short available response time forced the driver to change from a smooth to a 'bang-bang' feedback strategy. However, position in lane was quite well maintained compared with *a*. With middle-distance segments (*b*), both curvature and position were dealt with reasonably well, and this region gave the best driving performance. At the fast but not reckless speed of 16.9 m s^{-1}, there is an optimum position for the visible segment 5.5° down from the vanishing point, that is, 11.4 m or 0.68 s ahead (Fig. 2*b*, filled circles). However, the accuracy was 20% lower than with the whole road visible, and at higher speeds that percentage increased. At slower speeds (<12 m s^{-1}), accuracy with the optimum 1° segment was similar to or even better than the performance with the whole road visible; thus competent steering can occur with only a small region of the whole flow-field visible[10,11].

At higher speeds a better performance was achieved when two road segments were visible (Fig. 2*b*). The second road segment improved performance dramatically, depending on where it was positioned. With one visible region in the distant part of the road, a second region enhanced accuracy if it lay in the near region (open circles), and vice versa (open squares). However, merely doubling the amount of road edge in the near or far regions, or even near the single-segment optimum at 5.5°, had no effect. With both near and far segments visible the accuracy matched that with the whole road visible (dotted line). At higher speeds (19.7 m s^{-1}), this enhancement effect was even more dramatic, but at lower speeds (<12.5 m s^{-1}) the presence of an extra segment in the far part of the road had little effect on accuracy.

When a near segment is present (open circles) it is immediately clear to drivers that its effect is to provide an indication of position-in-lane, thereby preventing the kinds of error seen in Fig. 1*a*. Eye-movement recordings show that drivers rarely fixate this near region, but view it peripherally whilst tracking the distant part of the road (Fig. 2*a*). With a distant segment present (open squares) the enhancement is due to an improvement in stability. With a single segment the jerkiness of steering increases (Fig. 2*c*, filled circles) at near distances (as in Fig. 1*c*), but the presence of a distant segment (open squares) reduces that instability to the same level as when the whole road is visible.

These observations strongly support a double model of steering, originally proposed by Donges[1]. More distant parts of the road provide information about road curvature, perhaps through tangent-point tracking[5,6]. From Fig. 2*b* the optimum

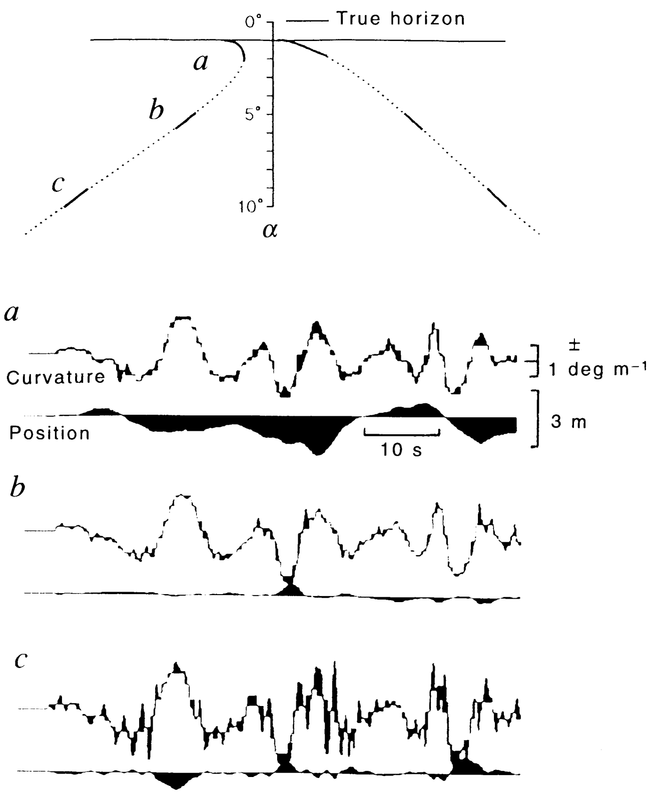

FIG. 1 Typical driver performance with only 1° segments of simulated road visible. The top panel shows locations of segments, the lower panels show corresponding performance. The upper trace in each record gives curvature of both road and vehicle track, with difference between them shown in black. The lower record gives vehicle position relative to centre line of road. In *a* and *b* curvature matching is good and almost smooth, but in *c* it is jerky, indicating instability. In *b*, and to a lesser extent *c*, position-in-lane is well maintained, but in *a* it is very poor. Subject M.L., speed 16.9 m s^{-1}. Road edges white on black background. Details of viewing conditions in text.

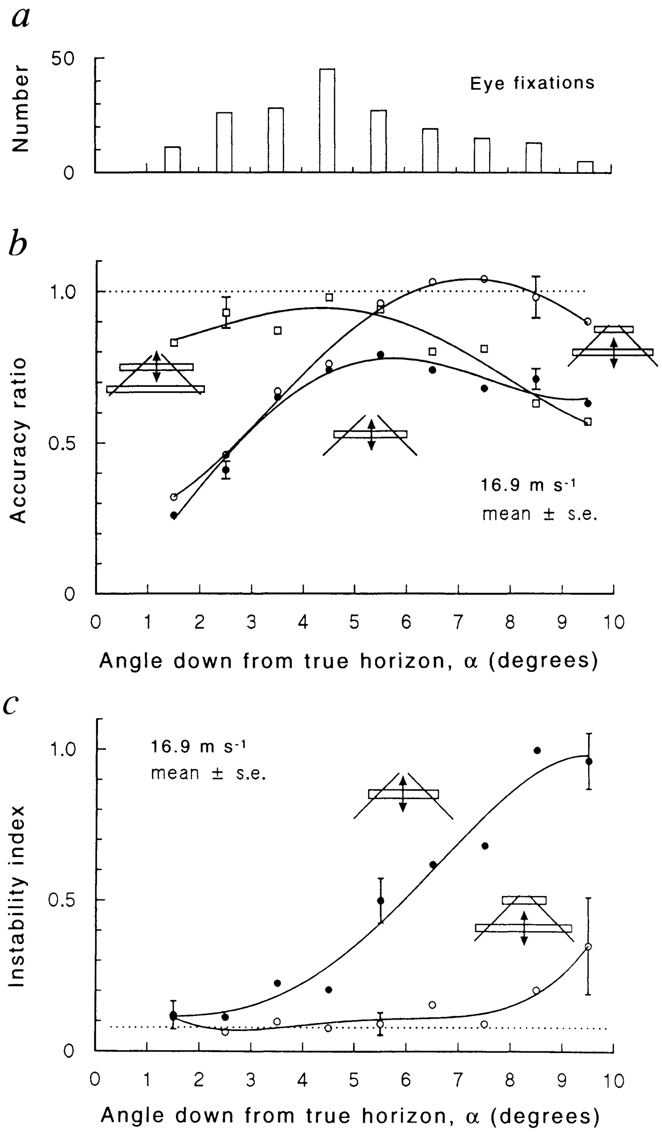

FIG. 2 Measures of driving performance with one and two 1° segments of road visible. In each part the results are combined from 3 drivers (M.L., a 53-year-old male; J.H., a 36-year-old female; and A.M., a 42-year-old male). Speed 16.9 m s^{-1} throughout. *a*, Histogram of gaze fixation positions on the road measured every second (methods as described previously[12]), when viewing the whole road. Abscissa as in *b* (α in Fig. 1). *b*, Accuracy of steering when only one or two 1° segments are visible. With only 1 segment visible (filled circles) there is an apparent optimum 5.5° below the true horizon. With an extra segment in the far part of the road 1–2° down (open circles) performance is greatly enhanced, but only if the other segment is in the near part. Similarly a segment in the near part 9–10° down enhances performance in the far part (open squares). In the latter case there is an optimum in the distant part of the road about 4° down, which corresponds to the fixation maximum in *a*. Accuracy is measured as the standard deviation of the distance of the vehicle's track from the centre line of the road, taken over the whole drive ($n \sim 500$). Accuracy ratio is s.d. with the whole road visible divided by the s.d. with one or two segments visible. Dotted line shows the performance with the whole road. Inserts indicate which visible segments are fixed, and which take the positions shown on the abscissa (arrowed). Differences between single and paired regions, at the points where the s.e.s are given, are highly significant ($P < 0.001$, *t*-test). Points represent means of 5 drives by 3 drivers. Curves are fitted 4th-order polynomials. *c*, Instability of steering with one region visible (filled circles), and the same region plus an additional region in the far part of the road (open circles). The effect of the far region is to reduce instability to the same level as when the full road is present (dotted line). The addition of a near visible region (not shown) does not reduce instability. The 'instability index' is the product of the number and amplitude of spike-like steering movements, of the kind visible in Fig. 1*c*, normalized to their maximum value. Other details are as in *b*.

for this mechanism at 16.9 m s^{-1} lies about 4° below the horizon (0.93 s or 15.7 m ahead). However, accurate position-in-lane information comes from the nearer part of the road, about 7° down (0.53 s or 9.0 m ahead). At moderate to high speeds, the near-road system is unstable on its own, but when road curvature has already been anticipated by the far-road mechanism, the near-road mechanism only needs to fine-tune the system, which can now be done smoothly. At slower speeds the near-road mechanism is adequate on its own, rather like driving in fog. □

Received 1 June; accepted 16 August 1995.

1. Donges, E. *Hum. Fact.* **29,** 691–707 (1978).
2. MacAdam, C. C. *IEEE Trans. Syst. Man Cyber.* v.SMC-11 no.6 (1981).
3. Dickmans, E. D. in *Active Vision* (eds Blake, A. & Yuille, A.) 303–335 (MIT Press, Cambridge, MA, 1992).
4. Okuno, A., Fujita, K. & Kutami, A. in *Vision-based Vehicle Guidance* (ed. Masaki, I.) 222–237 (Springer, New York, 1992).
5. Raviv, D. & Herman, M. in *Active Perception* (ed. Aloimonos, Y.) 191–226 (Elbaum, Hillsdale, NJ, 1993).
6. Land, M. F. & Lee, D. *Nature* **369,** 742–744 (1994).
7. Serafin, C. Univ. Michigan Transportation Res. Lab. Report UMTRI-93-29, 1–63 (1993).
8. Shinar, D., McDowell, E. D. & Rockwell, T. H. *Hum. Fact.* **19,** 63–71 (1977).
9. Jurgensohn, T., Neculau M. & Willumeit, H. P. in *Vision in Vehicles* Vol. 3 (ed. Gale, A. G.) 171–178 (North Holland, Amsterdam, 1991).
10. Warren, W. H. Jr, Mestre, D. R., Blackwell, A. W. & Marris, M. W. *J. exp. Psychol. hum. Percept. Perform.* **17,** 28–43 (1991).
11. Lee, D. N. & Lishman, J. R. *Scand. J. Psychol.* **18,** 224–230 (1977).
12. Land, M. F. *Proc. IEEE Syst. Man Cyber.* Conf, Le Touquet v3, 490–494 (1993).

ACKNOWLEDGEMENTS. We thank W. Warren for suggesting an experiment that led to Fig. 2*b*, and T. Collett and M. O'Shea for discussion. This work was supported by the BBSRC (U.K.).

Excitotoxin-induced neuronal degeneration and seizure are mediated by tissue plasminogen activator

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NEURONAL degeneration in the hippocampus, a region of the brain important for acquisition of memory in humans, occurs in various pathological conditions, including Alzheimer's disease, brain ischaemia and epilepsy. When neuronal activity is stimulated in the adult rat and mouse hippocampus, tissue plasminogen activator (tPA), a serine protease that converts inactive plasminogen to the active protease plasmin, is transcriptionally induced[1,2]. The activity of tPA in neural tissue is correlated with neurite outgrowth[3], regeneration[4] and migration[5], suggesting that it might be involved in neuronal plasticity. Here we show that tPA is produced primarily by microglia in the hippocampus. Using excitotoxins to induce neuronal cell loss, we demonstrate that tPA-deficient mice are resistant to neuronal degeneration. These mice are also less susceptible to pharmacologically induced seizures than wild-type mice. These findings identify a role for tPA in neuronal degeneration and seizure.

Although the expression of tPA in the hippocampus[6] and its induction by pharmacological and electrical stimulation are well documented[1,2], its role in the brain has not been established. As the four different cell types in the hippocampus—neurons, oligodendrocytes, astrocytes and microglia—perform distinct functions that each might involve proteolytic activity[7], defining the site(s) of synthesis of tPA is an important step in determining its function.