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Effect of driving experience on anticipatory look-ahead fixations in real curve driving

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ABSTRACT

Anticipatory skills are a potential factor for novice drivers' curve accidents. Behavioural data show that steering and speed regulation are affected by forward planning of the trajectory. When approaching a curve, the relevant visual information for online steering control and for planning is located at different eccentricities, creating a need to disengage the gaze from the guidance of steering to anticipatory look-ahead fixations over curves. With experience, peripheral vision can be increasingly used in the visual guidance of steering. This could leave experienced drivers more gaze time to invest on look-ahead fixations over curves, facilitating the trajectory planning.

Eighteen drivers (nine novices, nine experienced) drove an instrumented vehicle on a rural road four times in both directions. Their eye movements were analyzed in six curves. The trajectory of the car was modelled and divided to approach, entry and exit phases.

Experienced drivers spent less time on the road-ahead and more time on the look-ahead fixations over the curves. Look-ahead fixations were also more common in the approach than in the entry phase of the curve. The results suggest that with experience drivers allocate greater part of their visual attention to trajectory planning.

1. Introduction

Young drivers have a higher risk of accidents in curves (Clarke et al., 2006; Abdel-Aty and Radwan, 2000). For young males, curve accidents are often loss of control accidents which involve excessive speed (Clarke et al., 2006; Laapotti and Keskinen, 1998). While excessive speed is often chosen deliberately, another contributing factor for curve accidents could be novice drivers' poorer trajectory planning skills (choice of path and speed). In the current study, we study the effect of driving experience on look-ahead fixations over curves. Look-ahead fixations can be interpreted to serve trajectory planning by providing information on the future roadway and oncoming cars (Lehtonen et al., 2012, 2013).

1.1. Visual control of steering

In visually guided locomotion like driving, gaze is mostly towards the intended direction of locomotion, leading direction changes with a small preview time (e.g. Land and Lee, 1994; Imai et al., 2001; Bernardin et al., 2012; Vansteenkiste et al., 2013). In car driving, the visual preview in curves is typically approximately 2 s (Mars, 2008). In many steering models, this "looking where you are going" behaviour is interpreted as fixating on a steering point, e.g. the tangent point or some point on the future path (Salvucci and Gray, 2004; Wilkie et al., 2008; Boer, 1996; Land and Lee, 1994).

There are two main types of mechanisms proposed for the use of a steering point (for review, see Wann and Land, 2000; Steen et al., 2011; Lappi et al., 2013). The first type of mechanism proposes that the direction of the steering point or its change is used to adjust the steering (e.g. Land and Lee, 1994), as from the steering point it is possible to calculate the instantaneous curvature of the road. The second type of steering mechanism uses the retinal flow and active gaze to control the steering so that the driver will travel along a constantly curved path from the current location to the fixated steering point location (Wann and Swapp, 2000; Boer, 1996).

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Because fixations towards the road ahead with a small anticipatory lead time are thought to guide steering, we call these *guiding fixations*. With this naming, we intentionally relate them to the guiding fixations reported in many well-learned visually guided manipulation tasks. In these tasks, gaze is mostly directed to objects or locations relevant for guidance of the current action (e.g. Land et al., 1999; Pelz and Canosa, 2001; Hayhoe et al., 2003). This guidance of action is done typically in a just-in-time fashion (Ballard et al., 1995), which means that gaze is directed according to the immediate needs of the current task phase, leading motor action with a small time margin (<2 s).

There is empirical and modelling support for usage of multiple steering points at different preview distances. In two-level steering models (Donges, 1978, Land and Horwood, 1995; Salvucci and Gray, 2004; Frissen and Mars, 2013; for a critical view, see Cloete and Wallis, 2011) the steering mechanisms outlined earlier correspond to *the guidance level of steering*, which uses steering points in the *far zone*. In addition to the guidance level, there is *the stabilizing level of steering*, which utilizes steering points close to the car from the *near zone*. The stabilizing level of steering helps to maintain lane-position more accurately, and the guidance level is important for smoothness of steering (Land and Horwood, 1995; Salvucci and Gray, 2004). With experience, lane-keeping becomes possible with peripheral vision (Mourant and Rockwell, 1972; Summala, 1998; Summala et al., 1996) and thus most guiding fixations are directed towards the steering point in the far zone.

The steering models above are online control models, where current visual information is translated into the immediate steering response. However, online steering control is only part of the hierarchical control of the driving task (e.g. Michon, 1985; Summala, 1997). In the hierarchical control of actions, the higher levels set goals which are accomplished by a sequence of actions controlled by the lower levels (e.g. Cooper and Shallice, 2000; Grafton and Hamilton, 2007; Land, 2009).

1.2. Trajectory planning

In curve driving, *trajectory planning* can be thought as a control level superior to the guidance level of steering. Here, we used the term trajectory as a compound of path[1] and speed, because the two are inherently linked to each other. For example, cutting a corner allows higher speed. In trajectory planning, a driver utilizes visual information of the curve and of other road users to perceive an affordance for locomotion. The roadway and other road users place both static and dynamic constraints for locomotion (Gibson and Crooks, 1938; Fajen and Warren, 2003; Summala, 2007), and a trajectory plan can be thought as a solution which can satisfy these constraints. Of course, a trajectory plan is also affected by the performance of the vehicle and skills and motives of the driver.

As the situation unfolds, the trajectory plan can be updated–for example when an oncoming car emerges–if necessary and sufficient attentional capacity and time is available. In other words, trajectory planning can be thought also as a process for anticipatory maintenance of safety margins or a safety zone (Gibson and Crooks, 1938; Summala, 2007). For example, by choosing a trajectory with a low enough speed drivers can increase their time-to-line crossing (Godthelp et al., 1984).

One of the functions of a trajectory plan is anticipatory adjustment of speed before entering a curve (Hassan and Sarhan, 2012; Cruzado and Donnell, 2010; Charlton, 2007; Shinar et al., 1980). Another is anticipation of other road users, especially oncoming cars (Muttart et al., 2013; Lehtonen et al., 2012), which constrain the choice of path and speed.

As superior to the guidance and stabilization level of steering (Donges, 1978; Salvucci and Gray, 2004), trajectory planning is able to preprogram motor actions and execute them even in the absence of continuous visual feedback. Cavallo et al. (1988) demonstrated that drivers are able to time the steering wheel rotation correctly even when the visual field was occluded 2 s before entering a curve. Furthermore, experienced drivers (>100 000 km) were able to match size of the steering wheel rotation correctly under occlusion, while novices underestimated the required rotation. Without occlusion, there was no difference between learner drivers and experienced, because visual feedback was available for online control of steering to complete the trajectory plan.

Trajectory planning needs visual information from the roadway and other road users. Anticipatory eye movements towards the direction of the curve in driving have been often reported (Cohen and Studach, 1977; Shinar et al., 1977; Land and Horwood, 1996; Lehtonen et al., 2012, 2013; Mars and Navarro, 2012; Muttart et al., 2013; cf. Marigold and Patla, 2007 for trajectory planning in walking). However, the definition of an anticipatory eye movement towards a curve has varied, and is problematic, because often the same fixations can support both guidance and trajectory planning. While approaching a curve on a straight road, a fixation approximately straight ahead, towards the entry of the curve, can provide information for all three levels. In this case, the near zone is at relatively low eccentricity which makes it feasible to use peripheral vision for the stabilizing level (Summala, 1998; Summala et al., 1996), and a steering point in the far zone can be monitored. Also, the entry point of the curve is in the same direction, which makes it possible to anticipate the right moment of the curve entry. However, the rest of the curve which carries essential visual information from the horizontal and vertical curvature is not visible foveally when looking straight ahead.

1.3. Look-ahead fixations over curves

In order to acquire accurate foveal information from the rest of the curve, drivers need to make an eccentric fixation towards the road further up, disengaging the gaze from the visual guidance of online control of steering. These fixations have been called look-ahead fixations (Lehtonen et al., 2013; Mars and Navarro, 2012), relating these fixations to the look-ahead fixations reported in visually guided sequential manipulations task, where look-ahead fixations are often done towards the objects or locations relevant to a future task phase, but gaze is quickly returned back to the guidance of the current task phase (e.g. Pelz and Canosa, 2001; Mennie et al., 2007).

In curve driving, look-ahead fixations could help to construct and update the trajectory plan. In particular, look-ahead fixations are unlikely to be driven by the visual requirements of guidance level of steering. The guidance level models posit that the steering is adjusted relative to the steering point with a 1–2 s preview time so that a vehicle will travel along a constantly curved path, maintaining the lane position (e.g. Land and Lee, 1994) or reaching the steering point (Wann and Swapp, 2000) depending on the model. If the steering point is selected too far along the road with variable curvature, the required steering cannot be approximated with constant curvature. This is especially prominent when approaching a curve on a straight road where a steering response must not be initiated during the straight segment when fixating a point further ahead in the curve. Similarly, this also applies when fixating beyond the curve during steering within a curve.

Because guiding fixations towards the far zone may also carry anticipatory information for trajectory planning, e.g. when approaching an entry of the curve on a straight segment, it is not always

[1] For variation in choice of path in natural driving, see Spacek (2005).