Accident Analysis and Prevention 121 (2018) 268–278

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Gaze doesn't always lead steering

Esko Lehtonen[a,*], Otto Lappi[b], Noora Koskiahde[c], Tuomas Mansikka[c], Jarkko Hietamäki[c], Heikki Summala[c]

[a] Department of Mechanics and Maritime Sciences, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden
[b] Cognitive Science, University of Helsinki, FI-00014 Helsinki, Finland
[c] Traffic Research Unit, University of Helsinki, FI-00014 Helsinki, Finland

ARTICLE INFO

Keywords:
Intermittency
Distraction
Eye movements
Steering
Predictive processing

ABSTRACT

In car driving, gaze typically leads the steering when negotiating curves. The aim of the current study was to investigate whether drivers also use this *gaze-leads-steering strategy* when time-sharing between driving and a visual secondary task.

Fourteen participants drove an instrumented car along a motorway while performing a secondary task: looking at a specified visual target as long and as much as they felt it was safe to do so. They made six trips, and in each trip the target was at a different location relative to the road ahead. They were free to glance back at the road at any time. Gaze behaviour was measured with an eye tracker, and steering corrections were recorded from the vehicle's CAN bus. Both in-car '*Fixation*' targets and outside '*Pursuit*' targets were used.

Drivers often used a gaze-leads-steering strategy, glancing at the road ahead 200–600 ms before executing steering corrections. However, when the targets were less eccentric (requiring a smaller change in glance direction relative to the road ahead), the reverse strategy, in which glances to the road ahead followed steering corrections with 0–400 ms latency, was clearly present. The observed use of strategies can be interpreted in terms of predictive processing: The gaze-leads-steering strategy is driven by the need to update the visual information and is therefore modulated by the quality/quantity of peripheral information. Implications for steering models are discussed.

1. Introduction

Most of the time drivers' gaze is directed towards the road ahead. They look approximately two seconds ahead in curves; steering is closely coupled to gaze direction, with the gaze direction anticipating vehicle rotation with a lead time of approximately one second (Land, 1992; Land and Lee, 1994; Lappi et al., 2013; Lehtonen et al., 2014; Wilson et al., 2008). These gaze behaviours are known as *guiding fixations,* which are important for steering and make up the majority of fixations in normal driving (Lappi et al., 2013, 2017).

However, drivers do not keep their eyes on the road at all times. Often the close correlation between gaze and steering is deliberately broken, for example when performing anticipatory look-ahead fixations at a curve many seconds before any steering action is required (Lehtonen et al., 2013), scanning for potential hazards in intersections (Räsänen and Summala, 2000), or performing an eyes-off-road task while driving (Stutts et al., 2005). This time-sharing between the primary task of steering and other visual tasks—i.e. the *intermittency* of visual sampling—is a fundamental characteristic of natural driving behavior.

Eyes-off-road tasks have been extensively studied from the perspective of driver distraction. Their execution compromises lane-keeping and decreases driving speeds (Engström et al., 2005). Eyes-off-road glances increase the crash risk (Dingus et al., 2016) by delaying reactions in, for example, critical rear-end situations (Lamble et al., 1999)—where looking on or off the road often determines if a near-crash becomes a crash (Bärgman et al., 2015). Increasing driving automation may increase engagement in secondary tasks (Naujoks et al., 2016). Therefore, in the future it will be even more important to understand how drivers self-regulate their gaze behavior.

In this study, we investigated how on- and off-road glances are coordinated with steering corrections. The study had three objectives.

1) The first objective was to investigate if drivers use a *gaze-leads-steering* strategy, in which the gaze returns from off-road to the road ahead to glean guiding information for steering actions just before they are to be performed. This is a 'just-in-time' strategy; gaze is directed at the task-relevant regions at the last moment, to minimize reliance on short-term memory (Ballard et al., 1995; Land, 2009;

* Corresponding author.
E-mail address: esko.lehtonen@chalmers.se (E. Lehtonen).

https://doi.org/10.1016/j.aap.2018.09.026
Received 10 April 2018; Received in revised form 31 August 2018; Accepted 25 September 2018

Lappi, 2014). If drivers use this strategy, we should observe that gaze returns to the road ahead and a steering correction is made with a rather fixed latency (the visuomotor lag from processing the visual input). On the other hand, previous studies have shown that drivers can use peripheral vision to keep the car within the lane, even for tens of seconds, without looking back at the road (Bhise and Rockwell, 1971; Summala et al., 1996). This suggests that steering correction would not have to be temporally coupled to road-ahead glances at all; that is, drivers would not necessarily use the gaze-leads-steering strategy.

2) The second objective was to investigate whether the availability of peripheral visual information from the road ahead influences the use of the gaze-leads-steering strategy. The availability of peripheral visual information depends primarily on gaze *eccentricity,* the visual angle between the current gaze direction and the road ahead. When the road ahead is very eccentric to the line of sight, the peripheral visual information is lower in quality and/or quantity (Lamble et al., 1999; Summala et al., 1996; Warren and Kurtz, 1992). Therefore, to compensate, drivers have been found to foveate the road ahead more often during visual secondary tasks as the eccentricity between gazes at the task and at the road ahead increases (Summala et al., 1996).

In addition to eccentricity, asymmetry in the spatial resolution of human vision also influences the ability to use peripheral vision. Spatial resolution of human vision is more acute in the lower versus upper peripheral visual field, a phenomenon called 'vertical meridian asymmetry' (Talgar and Carrasco, 2002). Therefore, it may be that more peripheral visual information enters from the road when a target is at the level of the windscreen instead of down at the dashboard—because the road ahead is visible only in the upper visual field. Thus, targets that are equally eccentric in terms of the visual angle between the target and the road may still differ in the amount of visual information that is available peripherally, if one of the targets is lower down, at the dashboard level.

Consequently, we hypothesized that the gaze-leads-steering strategy would become more predominant as refreshing the visual information from the road ahead with a fixation became more important (due to increases in target eccentricity and/or vertical meridian asymmetry). It was also expected that the off-road glances would become shorter as the availability of peripheral vision decreased.

1) The third objective was to explore if there are any differences between targets inside and outside the car. Drivers tend to have longer glances to roadside advertisements than to in-car locations (Chan et al., 2010). It can be hypothesized that because a target outside the car is allocentrically stable (relative to the outside world, not to the car and driver) it might be used as input for controlling steering through optic flow, parallax, and/or depth perception; in contrast, since in-car targets are egocentrically stable (stable relative to the car and driver), they contribute no useful control information. Also, targets within the car are clearly very close to the driver, but targets out in the world are at distances more comparable to where gaze would normally focus on the road. Thus, looking at outside targets would be less likely to produce diplopia (double vision). For these reasons, it could be expected that off-road glances to targets in the outside world are 'easier' than in-car glances, enabling drivers to take longer off-road glances and even perform steering actions while looking off-road.

2. Methods

2.1. Task

In this study, the temporal coordination between visual sampling and steering control was studied using a self-paced peripheral viewing task. The intermittency in visual sampling was elicited by asking participants to look at either an inside or an outside target while they drove on a motorway with an instrumented car. A simple looking task was used, to keep the attentional and working memory requirements of the secondary task minimal

Participants were instructed to look at the designated target as much as possible, but always while prioritizing safe driving—including the maintenance of lane position and monitoring of other vehicles. They were also told to drive in the right lane of the motorway at a speed of 90 km/h (according to the speedometer), but to always keep a reasonable safety margin (a distance of two lamp posts) when there was another car in front of them. An accompanying researcher, who had access to the eye-tracking data in real time, monitored participants' compliance with all instructions.

In total, six different trials were performed. Five of them were '*Fixation*' trials, and the sixth was a '*Pursuit*' trial, which used a series of targets outside the vehicle (see Fig. 1 for target locations). Each Fixation target remained stable in egocentric coordinates in the vehicle frame of reference. In contrast, the outside targets remained stationary in the environment, thus drivers had to pursue them with their gaze.

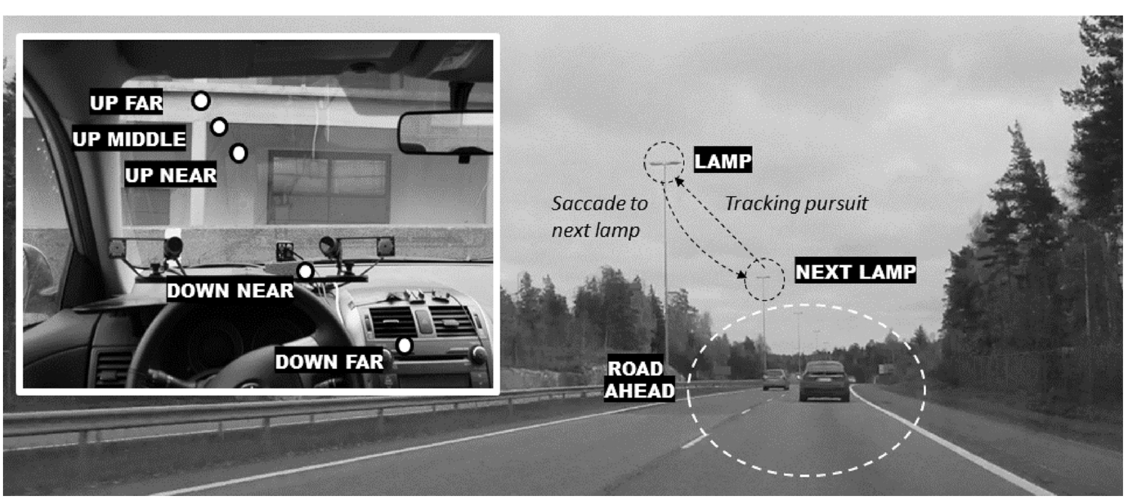

Fig. 1. Main picture: Schematic depiction of the Road Ahead region of interest, demonstrating how the driver is to track successive street lamps in the Pursuit trial. Inset: Positioning of the Fixation targets inside the car. 'Up' targets are on the windscreen while 'Down' targets are on the dashboard. Note that the Up-Near, Up-Middle, and Up-Far Fixation targets are located 9 cm, 16 cm, and 24 cm from the edge of the windscreen along an imaginary line; they are placed so that they would occupy the same part of the driver's visual field as the Pursuit targets.