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Tactical steering behaviour under irrevocable visual occlusion

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ABSTRACT

Objective: To investigate the extent of a driver's mental model with irrevocable visual occlusion and analysing the distance to crash.
Background: Drivers have a mental model of the immediate surroundings which allows them to predict their own as well as others' travel paths. To navigate safely through traffic, this mental model has to be updated frequently to remain valid. In between information sampling events, the mental model will become outdated over time, as the traffic system is dynamic.
Method: A simulator study with 22 participants was conducted to investigate the information decay in the mental model. This was implemented by extending visual occlusion until the driver collided with another vehicle or ran off the road, thus providing an estimate of how long it takes until the mental model becomes obsolete.
Results: An analysis of variance with the factors curve direction, curve radius and traffic showed that curve radius did not influence the distance to crash. Without traffic, drivers veered off the road sooner in right curves. Adding traffic eliminated this difference. Traffic ahead led to a shortened distance to crash. Compared to a tangential travel path from the current lateral position at the time of the occlusion, drivers crashed on average 2.6 times later than they would have, had they not had any mental model of the situation.
Conclusions: The drivers' mental representation of the future situation seems to include information on how to act, to alleviate deviations in yaw angle, including and considering the presence of other road users.

1. Introduction

An attentive driver should have a good-enough idea about the current situation and its future development. This inner representation has been formulated as a perceived "field of safe travel" (Gibson & Crooks, 1938), as a "mental model" of the situation (Boer, Hildreth, & Goodrich, 1998; Johnson-Laird, 1986) or as "situation awareness" (Endsley, 1995). As both the driver and other road users are moving, the mental model has to be updated to preserve the field of safe travel. Senders, Kristofferson, Levison, Dietrich, and Ward (1967) suggested that the mental model is maintained by an intermittent, rather than a continuous, intake of information. Between the intermittent sampling events, the mental model will gradually become obsolete.

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Sampling information from multiple targets, for example the forward view, the speedometer, and the mirrors, necessarily makes sampling from each individual target intermittent. In some situations, there may also be attentional capacity left, allowing the driver to sample additional information before the mental model is so outdated that it requires an immediate update. The visual occlusion technique was originally designed to gain insight about the visual demand of driving (Senders et al., 1967), and its different application methods are described by Lansdown, Burns, and Parkes (2004). By occluding the visual field of the driver, the occlusion time (see van der Horst, 2004 for a review) or occlusion distance (Kujala, Mäkelä, Kotilainen, & Tokkonen, 2016) can be used as a surrogate measure of when drivers feel their mental model needs to be updated with new information. This threshold is dependent on the present situation and individual factors (Kujala et al., 2016). The mental model was found to deteriorate faster in more complex situations, for example depending on road layout (Kujala et al., 2016; Senders et al., 1967; Tsimhoni, 2003), at higher speeds (Godthelp, Milgram, & Blaauw, 1984; Kujala et al., 2016; Senders et al., 1967), and depending on the manoeuvre and required interactions with other traffic (Kircher & Ahlstrom, 2017).

Several attempts to model steering behaviour in curves have been based on visual occlusion or optic flow (e. g. Cavallo, Brun-Dei, Laya, & Neboit, 1988; Godthelp, 1985, 1986; Godthelp et al., 1984; Hildreth, Beusmans, Boer, & Royden, 2000; Kountouriotis, Mole, Merat, & Wilkie, 2016). Godthelp (1986) found that performance did not decrease markedly with increasing curvature for occlusions of 1.5 s duration. Cavallo et al. (1988) specified that performance is affected differently, depending on where in the curve vision is occluded, where a greater degree of required anticipation led to decreased performance. Greater driving experience improved the ability to produce the correct yaw angle under occlusion. Kountouriotis et al. (2016) showed, that optic flow plays an important role in steering behaviour, and that added visual information can influence steering behaviour additionally (Kountouriotis, Wilkie, Gardner, & Merat, 2015). Thus, decreased performance under occlusion could be related to information decay in the driver's dynamic mental model, as no updated information can be acquired any longer, but it could also be due to the simple absence of optic flow as steering support.

The mentioned studies, and similar ones, typically use rather artificial roads with no other traffic and symmetrical road sides, creating a driving scenario that requires a driver response only on the operational level (Michon, 1985). They focus on one specific aspect of driving – steering in a curve. However, in real traffic, a driver normally has to combine the lane tracking task with interactions with other traffic, predicting and considering other road users' behaviour, and considering other relevant information, when determining the "field of safe travel". The present study uses a more natural-looking environment, and adds a tactical component, by including additional traffic.

In most occlusion studies, occlusion is intermittent. Both the onset and the duration can be determined either by the experimenter or the driver, rendering it more or less "voluntary". The driving speed can either be fixed by the experimenter or adapted by the participant, adding another component of self-regulation. Therefore, many set-ups investigating situational demands include a subjective component inherent to the driver, his or her comfort zone (Summala, 2007), which Kujala et al. (2016) have found to vary between drivers.

To find out whether the driver's mental model of the situation lasts for longer than the voluntary occlusion period, and to make the occlusion duration independent of the individual comfort zone, it has to be irrevocable, that is, it must last until the driver has run off the road or crashed. In such a setting, a fixed speed prevents the driver from braking to avoid a collision, and eliminates variations in speed as confounding variable. No optic flow is available any more, to aid in steering, such that the behaviour must rely entirely on the mental model available at the point of occlusion.

The time or distance to the crash will be compared to two scenarios, which represent a driver with no mental model of the current situation. In one scenario, the vehicle proceeds on a tangential path with respect to the road curvature, which incorporates the idea of going straight on from where one is, with respect to the road. In the other scenario, the vehicle continues with the same yaw angle as at the time of the occlusion, thus, including the external information that was available up to the time of occlusion.

Irrevocable occlusion has been used in relation to braking. Saffarian, de Winter, and Senders (2015) conducted a simulator study, in which the participants had to brake to a standstill under occlusion, targeting a mark on the road, which was visible prior to occlusion. An early occlusion onset, occurring 8 s, that is 215 m, before reaching the mark, led to a higher underestimation of the available stopping distance than later occlusion onsets. This indicates that it is either more difficult to estimate the distance correctly for larger gaps (see also Gilinsky, 1951), or that the longer period of time leads to a greater information decay along the way.

This simulator study focuses on whether and how the presence of other traffic can influence a driver's path of travel under occlusion in an otherwise similar environment. In the present set-up, the occlusion was fully determined by the experimenter, starting at a preselected location in a curve, and lasting until the participant drove off the road or collided with another vehicle. The following research questions were investigated:

1. For how long can the drivers travel until the mental model becomes so out-dated that they crash?

   We compare the distance from occlusion to crashing with the distance that would have been expected, if the driver had continued straight on at the time of occlusion without considering any previously visually sampled information, either on a tangential course, or with the current yaw angle. We use distance as performance indicator instead of time, as it is independent of travel speed (Godthelp et al., 1984; Kujala et al., 2016), even though the speed in the current study was kept constant. Our hypothesis is that drivers can stay on the road longer than if continuing on a tangential course, because they have a functional mental model of the upcoming scenario.