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A multinomial choice model approach for dynamic driver vision transitions

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A B S T R A C T

Exploring the continual process of drivers allocating their attention under varying conditions could be vital for preventing motor vehicle crashes. This study aims to model visual behaviors and to estimate the effects of various contributing factors on driver's vision transitions. A visual attention allocation framework, based on certain contributing attributes related to driving tasks and environmental conditions, has been developed. The associated logit type models for determining driver choices for focal points were successfully formulated and estimated by using naturalistic glance data from the 100-car event database. The results offer insights into driver visual behavior and patterns of visual attention allocation. The three focal points that drivers most frequently rely on and glance at are the forward, left and rear view mirror. The sample drivers were less likely to demonstrate troublesome transition patterns, particularly in mentally demanding situations. Additionally, instead of shifting vision directly between two non-forward focal points, the sample drivers frequently had an intermediate forward glance. Thus, seemingly unrelated paths could be grouped into explanatory patterns of driver attention allocation. Finally, in addition to the vision-transition patterns, the potential pitfalls of such patterns and possible countermeasures to improving safety are illustrated, focusing on situations when drivers are distracted, traveling at high speeds and approaching intersections.

1. Introduction

Perceiving information from the environment, 90% of which is visual (Ho and Spence, 2008), is the fundamental step of comprehending driving situations, making decisions and performing actions (Endsley, 1995). Drivers, to be aware of situations, must allocate visual attention resources to areas of interest. In addition, drivers experiencing problems in visual attention allocation will result in decision errors and actions under an insufficient understanding of the driving environment and thus possibly increased crash risk (De Waard et al., 2008, 2009; Marmeleira et al., 2009). In the United States, recognition errors, including inattention, distraction and inadequate surveillance, contributed to 41% of human-factor-related crashes (NHTSA, 2008). The US Department of Transportation's National Highway Traffic Safety Administration also estimated that there were at least 3000 deaths annually from crashes attributed to distraction, specifically due to the use of in-vehicle devices (NHTSA, 2012). Thus, exploring visual attention allocation, which is defined as conscious vision transitions, for drivers under varying conditions is vital for preventing crashes. A model capturing vision transition among various focal points is needed.

Previous studies have intensively analyzed driver visual attention allocation and extracted several factors related to attention demand (Underwood et al., 2002a,b, 2003; Martens and Fox, 2007; Levin et al., 2009; Borowsky et al., 2010; Konstantopoulos et al., 2010). Wickens et al. (2003, 2007); Wickens et al., (2003, 2007) proposed the concept of the SEEV model, summarizing factors into four constructs, salience, effort, expectancy, and value (Wickens et al., 2003, 2007; Horrey et al., 2006Werneke and Vollrath, 2012). Drivers pay more attention to the target that is more relevant to safety (value), or threats expected (expectancy) or salient. Meanwhile, drivers are more likely to shift vision to focal points closer to the current gazed point (effort). These studies have provided useful ways for driver visual behavior analyses; however, they show only the aggregated results and have not taken the dynamic attention-allocation behavior into consideration. Therefore, an enhanced understanding of information perception and situational awareness in naturalistic driving requires a refined model to capture vision transition among various focal points.

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To represent the process of drivers' visual attention allocation, previous studies have used the focal point glance probability (Wickens et al., 2003, 2007; Horrey et al., 2006Horrey et al., 2006; Wong and Huang, 2011) or the proportion of time spent on specific targets (Underwood et al., 2003; Levin et al., 2009; Borowsky et al., 2010; Konstantopoulos et al., 2010) to describe visual attention allocation. With these types of representation, the research results commonly showed that drivers spend most of their time looking forward. However, no detailed vision shifts among non-forward focal points are depicted. It would be difficult to find the sequential connection between two non-forward focal points, such as the path of shifting vision from the right to the front and finally to the left (Wong and Huang, 2013a). Thus, developing an effective method for representing the vision transition process is the first challenge in analyzing visual attention allocation.

In this study, the renewal cycle concept developed by (Wong and Huang, 2013a) is adopted to model the vision transition process. The next step is to identify the factors affecting vision transitions. The factors considered in the widely recognized SEEV model provide good references for this study. Lastly, an econometric model is needed to capture drivers' visual attention allocation behavior. In other words, the objective of this study is to model visual behaviors and estimate the effects of various contributing factors on drivers' vision transitions under limited data from realistic field settings

2. Vision transition process

Wong and Huang proposed the renewal cycle concept to represent visual attention allocation (Wong and Huang, 2013a,b). The forward glance, where drivers spend most of their time looking, is set as the reference point. A renewal cycle is defined as the process of glances starting from the reference point (forward), shifting to other focal point(s), and back to the reference point (forward) again. Treating the entire glance sequence of off-road focal points as a basic component avoids the creation of an analysis of visual attention allocation overly concentrated on forward glances; and it enables observations of the interaction between glances towards forward and non-forward focal points. In particular, renewal cycles containing various non-forward focal points can be identified and analyzed as needed.

The most frequently found renewal cycles, reflecting general visual behavior to prevent loss of awareness, involved drivers glancing from the front to only one non-forward focal point. Among them, certain renewal cycles can recur. Such repetitious behavior represents how drivers divide a long glance at a target into several shorter glances and repeatedly shift vision from the front to the intended focal point (Metz et al., 2011; Wong and Huang, 2013a). Moreover, instead of shifting vision along two non-forward focal points consecutively, drivers generally shift vision back to the front before shifting to another non-forward focal point. However, Wong and Huang (2013a) showed a substantial proportion of renewal cycles, approximately 10%, contained more than one non-forward focal point. Some of the multiple off-road glances were planned and may have no risks (Dukic et al., 2012). Despite the potential risk of losing awareness about leading traffic, drivers frequently shift vision directly between two non-forward focal points as needed under specific conditions, such as when approaching intersections. Still, a large portion of these renewal cycles containing more than one non-forward focal point were dangerous, particularly under complex road conditions and were likely the primary cause of crashes (Wong and Huang, 2013b).

To capture the vision transition paths between any two non-forward focal points, this study investigated the focal point choices after each non-forward glance. The conceptualized focal point choices follow a loop process in which drivers must choose a focal point at which to glance based on the current glanced point. With the concept of renewal cycles, three types of vision transitions can occur. In the developed loop process, Fig. 1 illustrates an example of vision transition after a non-forward glance, NF_a.

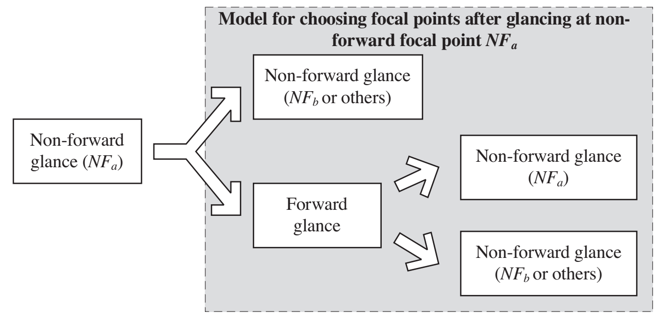

Fig. 1. Major types of vision transition.

The first type of vision transition is shifting from focal point NF_a directly to another non-forward focal point (NF_b or others). In this case, the current renewal cycle is incomplete because the driver has not shifted vision back to the front. For other types of vision transition, a driver who ends the current renewal cycle and begins a new one may choose to look at the non-forward focal point NF_a again. This second type of vision transition is referred to as the repeated renewal cycle. The third type of vision transition involves drivers shifting vision to another non-forward focal point (NF_b or others) after glancing at the non-forward focal point NF_a and the front sequentially. This type of vision transition requires drivers to determine a non-forward focal point at which to glance in the new renewal cycle, which forms a vision transition from one non-forward focal point to the forward side, and then to another non-forward focal point.

3. Model and specification

3.1. Model framework

Visual attention allocation is a continual process of choosing focal points and is described according to the three types of vision transition defined in Fig. 1. Intuitively, vision transition could be analyzed by a transition (duration) model or, alternatively, by a multinomial logit (MNL) model. The MNL is widely applied in various studies and considered a suitable tool for choice behavior; thus, it is adopted in this study. To represent the path connecting two non-forward focal points, the model consists of several sub-models; each represents the vision being shifted from a specific non-forward focal point. Fig. 2 shows the conceptual framework of an MNL sub-model representing vision transition from the specific non-forward focal pointNF_a.

Focal point choices involve two sequential steps, represented by the two MNLs shown in Fig. 2. In the first layer – modeling types of renewal cycle – vision shifts after a non-forward glance can be one of the following three types: shifting vision back to forward to begin a new renewal cycle, shifting vision back to forward to repeat the current renewal cycle, or continuing the current renewal cycle by shifting vision directly to another non-forward focal point. The results of the layer 1 model are used to calculate the probabilities of new renewal cycles, repeated renewal cycles, and multiple-glance renewal cycles.

Once the alternative of starting a new renewal cycle is chosen in the layer 1 model, another model for calculating the probability of choosing a specific non-forward focal point other than the point NF_a is required. Thus, this study formulated the second layer MNL model to derive the probability of a path connecting two renewal cycles. The results from the second layer model reveal the