Looks Are (Almost) Everything: Where Drivers Look to Get Information

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Objective: To describe the impact of Rockwell’s early eye movements research. Background: The advent of a new technology enabling measurements of eye movements in natural environments launched the seminal research of a Human Factors pioneer, Tom Rockwell, into how drivers process visual information. Method: In two seminal Human Factors articles—“Mapping Eye-Movement Pattern to the Visual Scene in Driving: An Exploratory Study” (Mourant & Rockwell, 1970) and “Strategies of Visual Search by Novice and Experienced Drivers” (Mourant & Rockwell, 1972)—Rockwell and his student, Ron Mourant, examined drivers’ eye movements in naturalistic driving environments. Results: The analyses of the visual fixations revealed systematic relationships between the sources of information the drivers needed to drive safely and the spatial distributions of their visual fixations. In addition, they showed that as drivers gain skill and experience, their pattern of fixations changes in a systematic manner. Conclusions: The research demonstrated that fixations and saccadic eye movements provide important insights into drivers’ visual search behavior, information needs, and information acquisition processes. Application: This research has been a cornerstone for a myriad of driving-related studies, by Rockwell and other researchers. Building on Rockwell’s pioneering work, these studies used eye-tracking systems to describe cognitive aspects of skill acquisition, and the effects of fatigue and other impairments on the process of attention and information gathering. A novel and potentially revolutionary application of this research is to use eye movement recordings for vehicle control and activation of in-vehicle safety systems.

Half a century ago, driver behavior research was in its infancy. Although the fatality rate on U.S. roads (per million vehicle miles) was more than five times as high as it is today, safety did not seem to be high on people’s—or researchers’—minds. A pioneer in that area was Tom Rockwell, who was intrigued by how drivers acquired the information they needed to drive and what specific information they selected from the visual field around them.

If the eyes are our windows to the mind, then observing eye behavior is a natural tool to use to understand how the mind acquires and processes visual information. The extensive research that has been conducted on eye movements in the past few decades clearly establishes that “eye movement data reflect moment-to-moment cognitive processes” (Rayner, 1998) and that eye movements are closely linked to attention: People tend to direct their gaze and fixations to the objects of their attention (Hoffman & Subramaniam, 1995). Consequently, a few researchers have made significant progress in the study of perceptual and cognitive processes by looking at visual scanning behavior. Perhaps the most comprehensive research in this area was conducted by Russian psychologist Alfred Yarbus and published in his classic book Eye Movements and Vision (1967). However, the early studies could be conducted only in very artificial laboratory settings with a subject who was essentially immobile observing a static image.

The technological breakthrough in applied eye movement research came with the development of portable eye cameras that could be installed in...
instrumented vehicles. Using an early model eye movement camera, Rockwell, Overby, and Mourant (1968) developed the first eye tracking system that monitored and recorded drivers' on-road visual scanning behavior. By today's standards, the system was extremely archaic. The fixations and visual scene were recorded with a very bulky 16-mm camera at a rate of 16 frames/s compared with current digital recordings at a rate of 100 Hz. The data reduction – transferring the images to fixations and saccadic movements – was a laborious manual task compared with today's instantaneous automated encoding. However, the nominal (not always achieved in the real world) accuracy of the system was as good then as it is today: 1/2 deg in the horizontal direction and 1 deg in the vertical direction. The system enabled us a first look at where and how long drivers look to obtain visual information.

The significance of eye movements research to traffic safety was underscored when two crash investigation studies – one in England (Sabey & Staughton, 1975) and one in the United States (Treat et al., 1977) – established that human factors were accountable for as much as 90% of crashes and that the predominant human factors were perceptual factors whereby the driver either misperceived the imminent hazard or perceived it too late. These findings made drivers’ eye movement research the “Holy Grail” for understanding critical issues related to the visual needs for safe driving and drivers’ strategies in meeting these needs.

In their first study, “Mapping Eye-Movement Pattern to the Visual Scene in Driving: An exploratory Study” (Mourant & Rockwell, 1970), Tom Rockwell and his graduate student Ron Mourant looked at the effects of route familiarity and driving conditions (open road vs. car following) on the visual scanning pattern of experienced drivers on urban expressways in normal traffic conditions. They examined the visual scanning behaviors when drivers drove on a short route three times: The first time, when they were unfamiliar with it, they were instructed to observe all signs. The second time they were instructed to observe only the signs relevant to their route. The third time – when they were presumably quite familiar with the route – they were instructed to complete the route without reading any of the signs. The drivers performed these three drives under two conditions: on the open road and when following another vehicle.

Their results – reproduced in many books on highway safety and driver behavior (e.g., Evans, 1991, 2004; Shinar, 2007; Shinar, McDowell, Rackoff, & Rockwell, 1978) – showed how the various task demands affected the drivers’ visual fixation patterns in a very systematic and predictable fashion. Initially, the drivers’ fixations are widely dispersed with a modal location above and to the right of the roadway, where most signs tend to be concentrated. As the drivers become more familiar with the route and attend to fewer signs, the fixations become more concentrated, and their modal position drifts close to the driving lane, far down the road, where drivers can obtain information with maximal lead time. As expected, in a car-following mode, the visual fixations tend to concentrate on the rear of the lead car. The study also revealed that the lane markers are rarely fixated (1% of all fixations in the open-road driving), suggesting that monitoring vehicle position within the lane is accomplished through peripheral vision – and therefore the cues, such as lane markings, should be conspicuous.

In their second study, “Strategies of Visual Search by Novice and Experienced Drivers,” Mourant and Rockwell (1972) compared the search pattern of newly licensed drivers who had “an almost complete lack of driving experience” with that of experienced drivers who had driven “at least 8,000 miles a year for the last five years.” Furthermore, the novice drivers’ eye fixations were recorded three times: “before they had any driving experience, when they were half-way through a driver education course, and just after they completed the driver education course.” This study extended the conclusions drawn from their first study on the visual fixations of drivers unfamiliar with the route to the visual fixation patterns of drivers unfamiliar with the driving task itself. For this study, the researchers already had a television eye movement recording system rather than the unwieldy 16-mm camera. The results showed that unlike the experienced drivers, beginning drivers were much more dependent on their foveal fixations for maintaining their car in the lane. Their fixations were distributed over a much smaller part of the visual scene, and a large proportion of the fixations were on the road directly in front of the car and on the lane markers. Also, the novice drivers – who were probably visually overloaded – fixated on their rear-view and side mirrors much less than experienced drivers did. Thus, this pattern
of eye movements revealed that novice drivers are much less confident about their ability to maintain their car in the lane and consequently tend to ignore many visual cues that are not directly related to basic vehicle control.

The two studies clearly established the link between drivers’ visual needs, their driving experience, and their search-and-scan pattern. Concurrent and later studies by Rockwell and his students further established the benefits of eye movement recording for assessing timesharing and workload (Kiger, Rockwell, & Tijerina, 1995; Mourant, Rockwell, & Rackoff, 1969; Rockwell, 1988), individual differences (Shinar et al., 1978), sign design and placement (Bhise & Rockwell, 1973), impairments from alcohol (Belt, 1969) and carbon monoxide (Ray & Rockwell, 1970; Rockwell & Weir, 1974), and the demands of various road geometries (Shinar, McDowell, & Rockwell, 1977). These studies demonstrated the utility of the new recording technology as a means of assessing the effects of various other variables on driving. They also helped advance theoretical modeling of driver information processing, provided a means of assessing limitations in driver information acquisition, and provided potential guidelines for driver licensing and roadway design.

A Web search (www.scholar.google.com) for citations of these two articles yielded 40 citations for the first article and 91 citations for the second article. Nearly all of the citations were in refereed journals. Most of the articles citing these two studies focused on driver behavior and highway safety, although a few were of a more theoretical nature, spanning the philosophical psychology of the relationship between gaze control and perceptual tuning (Kadar & Effken, 2005), oculomotor behavior as a reflection of attention and memory (Kramer & McCarley, 2003), applications of eye movements research to sports behavior (Moran, Byrne, & McGlade, 2002), and how users view Web pages (Grier, Kortum, & Miller, 2007).

Rockwell’s eye movement research has been cited especially in the context of more recent studies on young drivers’ skill acquisition. Mourant and Rockwell’s (1972) study provided impetus to many studies specifically focusing on young drivers. Young and novice drivers—which are typically the same group—are most involved in crashes relative to their exposure, especially fatal crashes involving high-risk behaviors such as speeding (Shinar, 2007). Young drivers are both less mature and less experienced than other drivers, and the relative contribution of these two factors is a key issue in any attempt to improve their driving safety. In a study titled “Young Novice Drivers: Careless or Clueless?” Mc Knight and McKnight (2003) demonstrated that it is the latter. Furthermore, their analysis of young drivers’ crashes showed that the principal deficiencies of the young drivers that contributed to their crashes were their inadequate visual scanning for potential obstacles (33.6%) and inattention to the driving task in general (23%). These conclusions, which were based on crashes, confirmed Mourant and Rockwell’s early direct observations that novice drivers are ineffective in their visual search and deficient in their information-gathering process. In fact, their original findings led Mourant and Rockwell to conclude that “the acquisition of good driving skill requires a great amount of visual perceptual training” and that “at the end of their driver education course, the novice drivers did not have search and scan patterns that were adequate for the detection of circumstances requiring emergency action” (p. 335).

Mourant and Rockwell’s early findings have been replicated by others using more sophisticated and automated equipment (Falkmer & Gregersen, 2005; Lee, Olsen, & Simons-Morton, 2006; Underwood, 2007), lending their early research more credibility. Their early findings and insights were instrumental to the eventual development of new and promising driver training programs such as training in visual search and target acquisition (Pollatsek, Fisher, & Pradhan, 2006), graduated driver licensing (Ferguson, 2003), training in hazard perception (Chapman, Underwood, & Roberts, 2002; Crundall, Chapman, Phelps, & Underwood, 2003; Pradhan et al., 2003, 2005), and “insight learning” (Gregersen, 1996).

In an article that synthesized many of his initial findings, Rockwell (1972) argued that eye movements can provide us with insights to the process of driver information acquisition. Recent theoretical formulations of driver behavior have in fact quantified some of these relationships by modeling the effects of novel in-vehicle systems on visual search and the implications of the changes in the ocular behavior for safety (Engström, Johansson, & Östlund, 2005; Reingold, Loschky, McConkie, & Stampe, 2003; Salvucci, 2006; Salvucci, Zuber, Beregoia, & Markley, 2005). This type of modeling can set the stage for what is
probably the most intriguing application of eye movements in driving: as triggers for actuating in-vehicle alerting and control systems. For example, Zhang, Smith, and Witt (2006) and Victor, Harbluk, and Engström (2005) showed that eye movement behavior (in combination with driving performance measures) can be used to detect visual driver distraction in real time, and Liang, Reyes, and Lee (2007); Victor et al. (2005); and Recarte and Nunes (2000, 2003) demonstrated that eye movements can serve the same purpose even for cognitive distractions. The ability to detect these changes in the visual search and scan pattern in real time now opens the door to their use as triggers for alerting devices.

One note of caution is appropriate in interpreting and using eye movement data. Visual fixations are not synonymous with attention. Although people tend to move their eyes to the targets of their attention, the converse is not true: The location of our fixations does not always reveal the target of our attention. The all-too-common phenomenon of “looked but did not see” that precedes many crashes (Stutts, Reinfurt, Staplin, & Rodgman, 2001; Treat et al., 1977) is a testament to that. The open eyes always fixate somewhere in space, but the mind is still free to roam and concentrate on nonvisual stimuli such as auditory inputs (as when talking on the cell phone) and deep thoughts. In fact, in such situations, there is a suppression of much of the saccadic eye movements, and the apparent concentration of the driver’s gaze on the road ahead is misleading, making target detection performance actually poorer (Victor et al., 2005).

REFERENCES


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