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# Driver's lane keeping ability with eyes off road: Insights from a naturalistic study

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ABSTRACT

Many studies have shown that driver inattention can influence lane-keeping ability. The majority of studies on lane keeping have been conducted in controlled on-road networks or in simulated environments. However, few studies have examined lane-keeping ability in naturalistic settings for the same purpose. In this current study, the relationship between driver inattention and lane keeping ability was examined using naturalistic data for 24 drivers. Driver inattention was placed into two categories based on whether drivers were looking forward toward the roadway (inattention with eyes-on-road) or not looking forward (inattention with eyes-off-road) while engaged in a secondary task. Repeated measures regression models were used to account for within-subject correlations. The results showed that, after accounting for driving speed and lane width, the eyes-off-road significantly increased the standard deviation of lane position (SDLP). The findings from this study are consistent with other studies that show that the amount of time drivers spend looking away from the road can impact drivers' ability to maintain their lane position. Additionally, this paper demonstrates how driver inattention can be examined with real world data while accounting for the roadway, environment, and driver behavior.



## 1. Introduction

### 1.1. Background

Driver inattention has been a major focus of driver safety research (Klauer et al., 2006; Ranney et al., 2000; Wang et al., 1996). Early studies have shown that driver inattention can contribute up to 25% of vehicular crashes per year (Ranney et al., 2000; Wang et al., 1996). In recent years however, naturalistic studies have made it possible to gain additional insights on driver behavior and have actually demonstrated that 78% of crashes and 65% of near crashes (or evasive maneuvers to avoid a crash) are driver inattention related (Klauer et al., 2006). This higher contribution may relate to the historically underreported associations of driver inattention in police reported crashes (Neyens and Boyle, 2007). Thus, examining objective measures (i.e., driver performance) in addition to crash data may provide greater insights in driver inattention. For example, drivers' lane keeping performance (or lateral control ability), which is usually measured by lateral accelerations, standard deviation of lane positions (SDLP), and steering control performances, can be considered since degraded lane keeping performance may lead to run-off-road crashes or collisions with other vehicles (Allen et al., 1996). Specifically, the increase in SDLP can dramatically increase the probability of lane departures that lead to a crash (Allen et al., 1996).

Driver distraction, which is a subset of driver inattention (Lee et al., 2009; Pettitt et al., 2005), has been extensively studied and shown to significantly degrade drivers' lane keeping performance (Anttila and Luoma, 2005; Horrey et al., 2008, 2009; Reed-Jouns et al., 2008). Visual related distractions occur when drivers need to divert their eyes away from the roadway such as when texting, and non-visual related distractions occur when drivers do not divert their eyes but are still distracted in other ways, such as cognitively when talking on a cell phone. Both distractions have been examined with respect to drivers' lane keeping performance. For example, technology-based in-vehicle visual distractions, such as tuning the radio, using the CD player and iPod, and viewing a video on a DVD have been shown to increase the SDLP and lateral accelerations on curves (Chisholm et al., 2008; Funkhouser and Chrysler, 2007; Hatfield and Chamberlain, 2005; Salvucci et al., 2007; Wikman et al., 1998). Texting can also increase the number of lane departure events (Hosking et al., 2005), and dialing numbers on a cell phone can negatively impact driver's steering control (Brookhuis et al., 1991).

Non-technology based distractions, such as eating, have been shown to decrease drivers' lane keeping ability as well (Jenness et al., 2002). However, the effects of other activities on lane keeping, such as reaching for objects, grooming, reading, and writing

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have not been as fully explored. Bendak and Al-Saleh (2010) have suggested that distractions located outside the vehicle (e.g., billboards and other road furniture), can also decrease lane keeping ability.

The findings for non-visual related distractions are not as consistent in terms of lane keeping performance. Most studies have shown that merely listening to in-vehicle entertainment systems (i.e., iPod, DVD player, radio and CD player) has no effect on lane keeping ability (Hatfield and Chamberlain, 2005; Salvucci et al., 2007). Similarly, in the Liang and Lee (2010) study, cognitive and verbal secondary tasks were found to increase the steering error but have no negative effect on SDLP. However, there were test track studies that did reveal the negative impact of cognitive tasks on SDLP (Horrey et al., 2008, 2009).

Lane keeping performance can be used to assess the broader implications of driver inattention but has not been as thoroughly investigated. Naturalistic data provide a means for capturing the impact of inattention. In the 100-car naturalistic study by Klauer et al. (2006), driver inattention was observed to include a broader scope of driver behaviors that included distraction as well as non-specific eye glances (i.e., driver glances away from the roadway at no discernable object or person) and drowsiness. Using this definition of driver inattention, Klauer et al. (2006) found that regardless of glance location, eye glances that were more than 2 s away from the roadway due to inattention significantly increased the likelihood of having a crash or near crash by almost 2-fold. Specific to lane keeping, Liang and Lee (2010) have suggested that, regardless of the distraction type (i.e. visual or non-visual), longer eyes-off-road time is associated with larger SDLP. Additionally, Zwahlen et al. (1988) have suggested that unsafe SDLP values can be observed after 2–4 s of in-vehicle glances. These findings are consistent with Wickens (2002) multiple resource theory, which suggests that multiple tasks that compete for the same resources degrade the performance of one or more tasks. Since visual perception is the primary resource for maintaining lane position, driver inattention that also requires visual perception is expected to impact lane keeping performance (Liang and Lee, 2010). Therefore, understanding the influence of drivers' visual behavior on lane keeping performance is essential in studying driver inattention and improving driver safety.

### 1.2. Project objectives

This study used naturalistic driving data to examine the relationship between driver inattention (eyes-off-road and eyes-on-road) and lane keeping ability. Eyes-off-road was defined in this study as the moments when the driver glanced away from the forward roadway due to any non-driving related reasons. For example, eyes-off-road could include looking at a passenger, reaching for an object inside the vehicle, using an in-vehicle system, eating, texting, looking down in the vehicle toward an unknown distracter (i.e., the distracter cannot be identified by the researcher), or eyes closed due to sleepiness. Inattentive eyes-on-road was defined as the moments when the driver's attention was diverted from driving but the driver was still looking forward toward the roadway. This might include conversing with passengers, grooming, singing, smoking, or talking on cell phone. Additionally, attentive driving was defined as the moment when neither eyes-off-road nor eyes-on-road inattention was observed.

Compared to controlled studies, the value of naturalistic studies is the potential insights gained on driver initiated distractions in complex circumstances and the adaptive behaviors that can manifest while distracted (Dingus et al., 2006; Horrey and Lesch, 2009). Therefore, naturalistic data can be useful to identify a more accurate relationship between driver inattention and lane keeping ability. In this study, naturalistic data were used to examine the hypothesis that eyes-off-road can negatively impact driver's lane keeping ability when compared with inattention with eyes-on-road and attentive driving. A subsequent hypothesis relates to long glances off road and their relationship to larger SDLP when compared to short glances off road and attentive driving.

## 2. Method

### 2.1. Data source

The naturalistic driving data used in this study were a subset of data reduced from the University of Michigan Transportation Institute (UMTRI) Road Departure Crash Warning System (RDCW) Field Operational Test study. The RDCW system was designed to provide real time warnings to the driver when a drift to lane edge was detected. A curve-speed warning system was also incorporated to alert drivers when the speed while approaching or negotiating a curve was too high.

The original UMTRI study included 78 drivers from Michigan (39 males and 39 females, from 20 to 70 years old (mean = 45.0 years, sd = 16.6 years)). They were asked to drive as they normally would in an instrumented vehicle that was equipped with the RDCW system for four weeks (1 baseline week without feedback from the system and 3 feedback weeks). Driver activities were collected for both urban and rural areas in Michigan. The authors requested and received the first week of baseline data in the rural area to evaluate the relationship between inattention and lane keeping. Consequently, drivers did not receive the alerts triggered from the RDCW system and thus, their lane keeping performance as examined in this study was not influenced by the system. The dataset contained vehicle kinematic and roadway data, as well as driver face and forward view images for a total driving distance of approximately 4000 miles across the 78 drivers (LeBlanc et al., 2006).

The driver face images received from UMTRI were recorded at 10 Hz for two types of driving clips. One type was 5-s clips that were recorded every 5 min during the trip; these were collected for the original UMTRI protocol to study driver behaviors. The other type was 8-s clips that were recorded when a road departure or curve warning event was noted and alerts would have been triggered had the RDCW been active (4 s before and 4 s after the trigger). For the current analysis, only these two types of driving clips were used. Other clips in the original UMTRI study, recorded at 0.5 Hz, did not provide enough details to discern the driver's face. The 5- and 8-s clips were not distinguished from each other in the current study, since the RDCW system was not considered and thus did not impact the current study purpose.

### 2.2. Data reduction

Driver inattention with eyes-off-road and on-road were identified using the driver face images, and matched and merged into the vehicle kinematic data based on time stamps. Driving clips were removed from the data when drivers' eye locations were difficult to determine due to sunglasses or glare. Off-road glances that were considered driving-related (i.e., checking mirrors and instrument panels) were also excluded to avoid potential confounding.

Due to the variation in the roadway conditions in the naturalistic study, the entire 5- or 8-s driving clip was not always feasible for analysis. For example, the vehicle might start to enter a curve at the last 2 s during an 8-s clip. In order to keep a relative large sample size for analysis, a 3-s segment that met all data reduction criteria was extracted from each clip. The 3-s segments were first extracted based on driver inattention information. If any driver inattention was observed in a 5- or 8-s driving clip, the 3-s segment was extracted starting from the moment that the inattention was first observed. The extracted segment was then called inattentive