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DRIVER ATTENTION DURING LANE CHANGES: A STUDY OF GAZE TIMES FOR CUTTING IN AND EXITING VEHICLES

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Abstract. *It is crucial to maintain an adequate following distance between vehicles to help prevent road accidents. However, many drivers drive at insufficient following distances. A main reason for this behavior is the belief that leaving more distance between vehicles will invite interruptions from vehicles cutting in from the next lane, which will increase travel time. Previous research has indicated that the impact of interrupting vehicles is generally overestimated by drivers. To investigate this in detail, this study used a driving simulator to examine drivers' gaze times with respect to vehicles cutting in and exiting from a neighboring lane. It was found that gaze time for vehicles changing lanes was longer when they were interrupting the lane than when they were exiting it. This suggests that differences in collision risk in lane changes affect how drivers pay attention to the vehicle in front.*

Keywords: Gaze objects, Driver gaze behavior, Risk perception, Driving simulator, Lane change

1. **Introduction.** It is crucial to maintain an adequate distance between vehicles to prevent driving accidents. However, many drivers maintain insufficient following distances [1,2]. One reason for this is drivers' intention to avoid automobiles cutting in from neighboring lanes. Drivers believe that if they maintain a large following distance, vehicles from adjacent lanes will cut in, leading to longer travel times.

However, a roadside demonstration experiment conducted by Kumagai et al. [3] found that maintaining a sufficient following distance produces little difference in travel time. This is because vehicles from adjacent lanes cut in frequently when maintaining a larger following distance, but those vehicles eventually cut out into other lanes, such that the number of vehicles cutting in and the number of those exiting are roughly the same. However, Kumagai et al. [4] found that cut-in behavior produces a stronger impression on drivers than cut-out behavior. This may be related to the way that drivers allocate visual attention during lane changes. Recent advancements in gaze measurement technologies have enabled detailed investigations of driver behavior and risk perception in driving tasks. Eye-tracking systems, providing real-time data on gaze direction and fixation duration, are in widespread use in assessing driver attention allocation. For example, Wu et al. [5] developed an attention-enhanced model to predict lane-changing intention based on driver gaze behavior, demonstrating the critical role that gaze plays in understanding decision-making. Similarly, Sonom-Ochir et al. [6] developed a dual-camera system to detect visual distractions, analyzing the driver's gaze direction and moving objects in the driving environment. Their study emphasizes the importance of monitoring gaze allocation in assessing driver attention and decision-making processes, especially during critical tasks like lane changes.

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However, despite these advances, little research has directly compared gaze behavior during lane-cut-in and lane-exit maneuvers. These comparisons are crucial for understanding how differences in perceived collision risk can influence driver attention. Building on these advances, this study examines the gaze times that are allocated to vehicles performing cut-in and cut-out maneuvers, thereby offering novel insights into the relationship between risk perception and attention allocation. To explain the phenomenon observed by Kumagai et al., whereby cut-in behavior tends to leave a stronger impression than lane exit, this study proposes the hypothesis that drivers allocate attention differently between cut-in and cut-out behaviors, which influences their memory. While following, drivers must direct their attention toward the obstacle posing the highest collision risk. Where a cut-in occurs from an adjacent lane, drivers tend to spend more time focusing on the vehicle cutting in because it presents the highest collision risk. In addition, when the vehicle in front exits into the adjacent lane, collision risk is only high until the vehicles overlap in lane change. Beyond this point, the risk diminishes significantly, and the driver's attention naturally shifts to the new vehicle ahead of them in their lane, reducing the need to focus on the exiting vehicle. This difference in attention paid to cut-in and cut-out behaviors likely accounts for the stronger impression that cut-ins leave on drivers. This difference will be particularly pronounced when the possibility of emergency braking by the leading vehicle arises.

This study investigates the characteristics of drivers' attention and tests the proposed hypothesis by creating scenarios in which a vehicle cuts in between the driver's vehicle and a lead vehicle. In these scenarios, both the cut-in and the cut-out behaviors are of equal duration, and the vehicles maintain a short following distance. While the original aim of this study is to evaluate the objects that drivers pay attention to, the direct measurement of attention is difficult, so gazing time is useful as a proxy. In general, attention and gaze direction do not always align perfectly. However, in the following, attention is directed primarily toward objects that pose a high collision risk, and the gaze naturally follows it. Drivers tend to fixate intuitively on objects presenting a high collision risk, making the direction of paying attention and direction of the gaze almost synonymous. Therefore, in this study, gazing time is used as an index to evaluate drivers' attention, allowing for an indirect assessment of attention allocation.

2. Experiment.

2.1. Objective. This study examines how drivers allocate their attention to cut-in and cut-out behavior. Specifically, we compare drivers' gazing times when a cut-in vehicle enters the lane in front of the driver and when it exits the lane to evaluate drivers' attentional responses to these behaviors.

2.2. Method.

2.2.1. *Participants.* A total of 10 participants (age range: 21-51 years; mean age: 25 years) took part in this experiment. Of these, eight participants held a regular driver's license, one had completed driving school but had not obtained a license and one had no driving experience. Recruitment broadly targeted adult individuals, resulting in this variation in driving experience and license status. All participants were informed in advance of the purpose and details of the experiment, and informed consent was obtained before participation.

2.2.2. *Experimental apparatus.* In this study, a driving simulator (DS) was used that incorporated a VR headset (Pico4 Enterprise) to present the driving environment and measure the driver's gaze. The VR headset allowed for the real-time presentation of visual scenes responding to the driver's head movements, providing participants with a sensation similar to that of real-life driving. The driving scene in the DS was developed using

Unity, enabling flexible adjustments to the traffic environment and vehicle behavior with reference to experimental conditions.

A three-lane straight road was used in the DS, where the participant's vehicle (own vehicle) and a vehicle in front (the lead vehicle) drove in the middle lane. A third vehicle (the cut-in vehicle) performed lane cut-in and cut-out maneuvers by entering from the adjacent lane, driving for a set period in the lane, and then cutting out to exit. The driving controls utilized a Logitech G27 steering wheel and pedal system to provide a driving realistic experience.

The eye-tracking feature of the Pico4 Enterprise allowed precise and real-time recording of the driver's gaze in both gazing time and gaze direction.

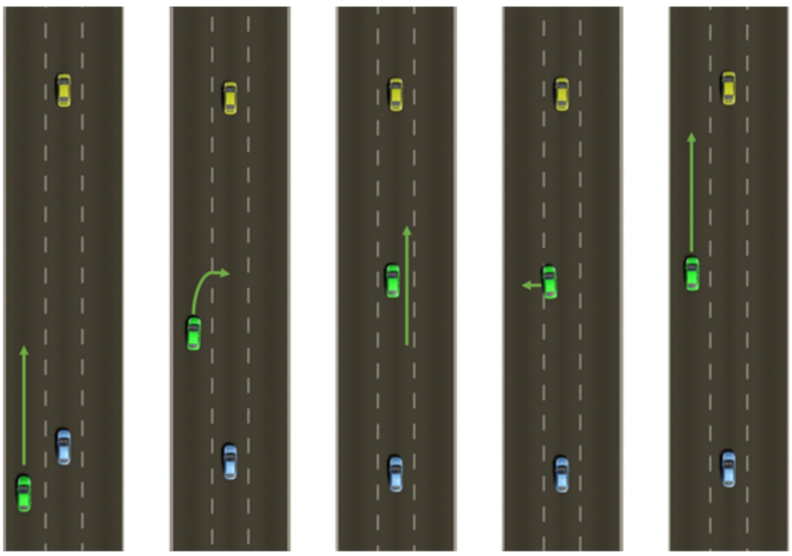
2.2.3. *Procedure.*

Pre-experiment Preparation. Informed consent was obtained from all participants before the experiment began and after the nature, purpose, and potential risks of the experiment were explained. The participants were then provided with a detailed explanation of the driving maneuvers that would be possible during the experiment. They were given time to familiarize themselves with the VR headset, steering wheel, and pedal system. Following this, the pupil distance for each participant was automatically measured, and the VR headset's display was adjusted accordingly. This was done to ensure that the visual display properly aligned with the participant's eyes, enhancing immersion and comfort. The eye-tracking system was then calibrated to ensure accurate gaze data collection for each participant.

Practice Session. Before the practice drive, the participants were notified that both the cut-in vehicle and the lead vehicle could brake abruptly. They were advised to brake as necessary and were reminded to keep the vehicle they were monitoring as close to the center of their field of vision as possible when observing other vehicles.

Participants were given the opportunity to experience all of the driving events (lane change and abrupt braking) that could occur in the main experiment. This session was undertaken to ensure that participants could understand the variable behavior of the other vehicles and would become aware that various events, including abrupt braking, could occur, as in real-world driving scenarios.

Main Experiment Session. The cut-in and cut-out behaviors of the cut-in vehicle were presented based on the scenario depicted in Figure 1. The yellow vehicle represents



(a) Appearance (b) Cut-in (c) Following (d) Cut-out (e) Disappearance

FIGURE 1. Scenario of cut-in and cut-out behavior

the lead vehicle, which always drives ahead of the participant's vehicle. The blue vehicle, or own vehicle, is operated by the participant, and it follows the lead vehicle in the middle lane. The green vehicle is the cut-in vehicle, performing both the cut-in and cut-out maneuvers. The green arrows illustrate the relative movement trajectories of the cut-in vehicle relative to the own vehicle.

Initially, the cut-in vehicle appears from either the left or the right lane behind the own vehicle, passes it, and proceeds to begin a cut-in maneuver (Figure 1(a)). Once it reaches this position (Figure 1(b)), the cut-in vehicle takes approximately 10 seconds to change lanes, flashing its turn signal, and it merges in front of the own vehicle. After completing a cut-in maneuver, the cut-in vehicle positions itself between the lead vehicle and the own vehicle in the middle lane, following the lead vehicle for a certain period (Figure 1(c)). It then performs a cut-out maneuver, taking another 10 seconds to change lanes, again while flashing its turn signals and moving to either the left or the right lane (Figure 1(d)). After exiting, the cut-in vehicle accelerates, overtakes the lead vehicle, and eventually disappears from the participant's view (Figure 1(e)).

Each lane change (cut-in and cut-out) constitutes one trial. The participants underwent a total of 10 trials during the experiment. An abrupt braking event by the cut-in vehicle was introduced in the fifth and sixth trials to increase participant awareness and to simulate a realistic driving scenario.

The following conditions were applied to all trials:

- The distance between the own vehicle and the cut-in vehicle was maintained at a constant value from the moment the cut-in behavior was completed to the moment the cut-out behavior began.
- The durations of the cut-in and cut-out were standardized to 10 seconds.
- The direction of the cut-in vehicle's entry and exit (whether from the left or right lane) was randomly determined for both the cut-in and cut-out maneuvers.

2.2.4. *Data collection and analysis.* The specific object in the virtual environment that participants were gazing at (such as the lead vehicle or the cut-in vehicle) was recorded at a frequency of 50 Hz, along with the speed and position of each vehicle. Using these data, the participants' gazing behavior and the movements of each vehicle were analyzed separately for cut-in and cut-out events.

The data from the fifth and sixth trials, in which abrupt braking events occurred, were excluded from the analysis because abrupt braking itself can be expected to cause fluctuations in gazing time.

Statistical analysis was performed using a paired t-test to compare mean gazing times in cut-in and cut-out phases. The effect size (Cohen's d) was calculated to assess the magnitude of the observed difference. The threshold for statistical significance was set to $p < 0.05$. All analyses were conducted using Python's scipy.stats library (version 1.11.3) to ensure accuracy and reproducibility.

2.3. **Results.** Table 1 presents the mean gazing times for each participant during the cut-in and cut-out phases, as well as the difference between these phases. The overall mean gazing time during the cut-in phase was 4.95 seconds ($SD = 1.17$), and the mean gazing time during the cut-out phase was 2.76 seconds ($SD = 1.11$). On average, the participants spent 2.19 seconds longer gazing during the cut-in phase than during the cut-out phase.

A paired t-test was conducted to compare mean gazing times between the two phases. The test confirmed a statistically significant difference, $t(9) = 13.19$, $p < 0.001$, indicating that participants gazed significantly longer during the cut-in phase. The effect size (Cohen's $d = 4.17$) suggests a very large difference, which emphasizes the substantial impact of the cut-in maneuver on attention allocation.

Table 1. Mean gazing times during cut-in and cut-out events and the differences in gazing times for each participant

Participant	Mean gazing time [s]		Difference in gazing time [s]
	Cut-in	Cut-out	
A	4.77	2.89	1.88
B	7.84	5.22	2.62
C	5.28	3.77	1.51
D	5.72	3.74	1.98
E	4.78	2.67	2.11
F	4.05	1.74	2.31
G	5.14	1.82	3.32
H	3.17	1.57	1.60
I	4.43	2.25	2.18
J	4.33	1.96	2.37
Mean	4.95	2.76	2.19

2.4. **Discussion.** The results of the paired t-test showed a statistically significant difference in gazing times between the cut-in and cut-out phases, with participants spending more time gazing at vehicles during cut-ins. The large effect size (Cohen's $d = 4.17$) highlights the substantial difference in attention allocation between these maneuvers. These findings suggest that drivers' attention allocation is influenced by the type of lane change, with cut-ins eliciting greater visual attention.

2.4.1. *Factors contributing to prolonged gazing time.* Differences in physical risk perception between cut-in and cut-out behaviors could have influenced the gazing time. In this experiment, the distance between the cut-in vehicle and the own vehicle was set as the same for both cut-in and cut-out phases. However, during the cut-in phase, the cut-in vehicle enters the driver's lane, blocking the driver's path. In this case, the driver must pay more attention to the cut-in vehicle because it poses an increasing risk of collision. Conversely, during the cut-out phase, collision risk gradually decreases as the cut-in vehicle moves away from the driver's lane.

Furthermore, during the cut-in phase, the driver's available avoidance options (e.g., steering maneuvers) become increasingly limited over time. By contrast, during the cut-out phase, the space available for evasive actions widens, providing the driver more room to maneuver. As a result, of these physical factors, the risk of collision increases during the cut-in phase, enabling the driver to allocate more attention to the cut-in vehicle. This is the likely reason for the extended gazing times during cut-ins. These findings echo those of Lappi et al. [7], who found that drivers prioritize their gaze toward objects that pose immediate risks, such as vehicles encroaching into their path. This prioritization likely explains the extended gaze times that are observed during cut-ins.

2.4.2. *Psychological factors and risk perceptions.* Drivers' psychological perception of risk could also have influenced differences in gazing time. When a vehicle cuts into the lane, drivers face unpredictable situations that require them to be prepared for unforeseen events. Here, the driver must accurately predict when and how the cut-in vehicle will merge in front of their own vehicle, leading to a heightened sense of caution. Uncertainty concerning the cut-in vehicle's movements and the anxiety caused by its sudden actions increase psychological stress during the cut-in. This heightened psychological vigilance likely contributes to the longer gazing time during cut-ins.

Kosuri and Budhkar [8] demonstrated that heightened risk perception in complex driving scenarios, such as navigating curves, influences drivers' behavioral responses, including their speed adjustments, as a strategy of mitigating perceived threats. Likewise, Sayed et al. [9] emphasized that psychological stress and risk perception play a substantial role in shaping drivers' attention allocation and decision-making in hazardous situations. Although these studies do not specifically measure gaze behavior, their findings suggest that psychological stressors affect broader attentional strategies, which likely extend to visual attention patterns in lane changes. This theoretical framework provides a basis for understanding the prolonged gazing times that were observed during cut-ins, where heightened psychological vigilance prompts drivers to closely monitor the cut-in vehicle as a potential threat.

By contrast, as the cut-in vehicle exits, the driver's perception of risk decreases, which creates a sense of safety as the vehicle leaves their lane. Once the vehicle has cut-out, the drivers feel that the immediate danger has passed, which reduces their psychological burden. This reduction in perceived risk is expected to result in less attention being allocated to the cut-out phase, producing a shorter gazing time.

3. **Conclusion.** In this study, we hypothesized that drivers would allocate additional attention to cut-in vehicles than to cut-out vehicles, as a result of the increased physical risk and psychological alertness associated with cut-ins. The results supported this hypothesis, as drivers' gazing time for cut-in vehicles was significantly longer than for cut-out vehicles. This suggests that drivers tend to pay more attention to cut-in vehicles, which is likely due to heightened risk perception and limited avoidance options in cut-ins.

Limitations and Future Directions. The distance between vehicles was kept the same for both cut-in and cut-out maneuvers. However, in real-world driving, cut-in vehicles often enter the lane at a distance shorter than the driver's preferred following distance. Conversely, during cut-outs, vehicles typically leave this preferred distance and then quickly increase the gap. As a result, of these differences, the simulation settings used in this study may not fully capture the dynamics of real-world driving conditions.

Additionally, this study included participants with differing levels of driving experience, including two non-licensed participants. While this diversity offers the opportunity to observe potential differences in gaze behavior, the limited sample size restricts the generalizability of the findings. This study focused on differences in gaze behavior during cut-ins and cut-out maneuvers, rather than on the effects of driving experience. Future research should aim to recruit a larger and more diverse sample, with stratified groups based on license status and driving experience, to better isolate and evaluate these factors.

Future work should also use more realistic driving environments by simulating scenarios in which cut-in vehicles enter the lane at distances that are shorter than the driver's optimal following distance, and where cut-out vehicles exit while maintaining an ideal gap. Such simulations would allow for a more precise evaluation of driver behavior in more varied and realistic conditions.

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