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Investigating Lane Change Behaviors and Difficulties for Senior Drivers Using the SHRP 2 Naturalistic Database

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EXECUTIVE SUMMARY

Older drivers have been shown to be 1.5 times more likely to be involved in a lane change crash compared with middle-aged drivers (Di Stefano & Macdonald, 2003), with many drivers failing to make over-the-shoulder (OTS) glances. While a number of different blind spot warning systems and intervention systems exist, a more thorough understanding of in situ lane change behaviors and difficulties for older drivers may be beneficial to inform future lane-change support system implementations and the development or improvement of related training modules.

This effort examined lane-change behavior and glance locations for three age groups, younger (18–29), middle-aged (30–49), and older drivers (70–94), using data from the Second Strategic Highway Research Program (SHRP 2) Naturalistic Driving Study (NDS). Descriptive outcomes were reported for several glance characteristics, including glance duration and percentage of time, as well as entropy as a measure of glance dispersion. Various behaviors, including turn signal use, glance errors, and environmental characteristics, were analyzed.

While other studies have examined real-world lane changes in naturalistic settings (Fitch et al., 2009; Lee, Olsen, & Wierwille, 2004), this effort is the first known study using real-world naturalistic data to examine lane change behaviors across different age groups.

COMMON FINDINGS

For both uninterrupted and interrupted lane changes, results showed that many drivers, regardless of age, failed to make OTS and side mirror glances prior to *initiating* the lane change maneuver. When taken across several glance metrics, the trend emerged that few drivers allocated a glance to the OTS location prior to or during lane change maneuvers. Most drivers relied on side mirror and rearview mirror checks for lane change safety—especially the rearview mirror for right-hand lane changes. Also, many drivers failed to check the side mirror prior to initiating the lane change maneuver.

In addition to glance behaviors, results showed that many drivers failed to activate the turn signal prior to lane change initiation. Approximately 60% of older drivers activated the signal at any point during the lane change maneuver.

The vast majority of both uninterrupted and interrupted lane changes occurred within moderate levels of traffic density. Apparently, when density was light, there was little need for lane changes and when density was heavy, there was little opportunity. The results revealed a normal-like distribution slightly skewed toward higher levels of traffic density, with moderate levels of traffic density accounting for the greatest proportion of lane changes and low-density and high-density traffic representing the tails of the curve.

PART A – UNINTERRUPTED LANE CHANGES

Part A focused on uninterrupted lane changes - those in which the maneuver was judged to be intentional and was one where the participant vehicle moved completely from one lane to another without any sort of interrupting behavior on the part of the participant. When a conflict did occur with relation to the lane change maneuver, it was most frequently associated with either a lead vehicle in or a lead vehicle incurring into the destination lane. When evaluating

potential sources of conflict for a lane change maneuver, the threats commonly thought of involve vehicles to the sides and rear of the vehicle, especially those concealed by blind spots. The more attention one allocates to the side and rearview mirrors, the less attention is available for the scene in front (i.e., where our data revealed to be the greatest source of conflict for uninterrupted lane changes).

PART B – INTERRUPTED LANE CHANGES

Part B focused on interrupted lane changes – those which the maneuver was judged to be intentional and where the participant performed an evasive maneuver such as steering wheel corrections or braking to safely complete or cancel the maneuver. Results for interrupted lane changes showed that when a conflict did occur with relation to the lane change maneuver, it was most frequently associated with *two* sources of conflict: lead vehicle in or incurring into the destination lane or a trailing vehicle in or incurring into the destination lane. Left lane changes also showed a moderate level of conflict with adjacent vehicles in or incurring into the destination lane.

Nearly one-third of interrupted lane change maneuvers involved an event where the participant proceeded with a lane change with improper spacing and cut off a trailing vehicle in the destination lane. As driver age increases, the percentage of events where the driver cut off another vehicle increases: while younger drivers cut off another vehicle 19% of the time, middle-aged drivers did so 27% of the time and older drivers 28% of the time.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS AND SYMBOLS

AOI	area of interest
CAN	Controller Area Network
DAS	data acquisition system
DMV	Department of Motor Vehicles
FOV	field of view
GPS	Global Positioning System
IRB	Institutional Review Board
NDS	naturalistic driving study
OEM	original equipment manufacturer
OTS	over the shoulder
SCE	safety-critical event
SHRP 2	Second Strategic Highway Research Program

PREFACE

This effort focused on identifying and quantifying various aspects of lane change events and behaviors recorded during the Second Strategic Highway Research Program (SHRP 2) Naturalistic Driving Study across young, middle-aged, and older driver age groups. The goal of this exploratory work was to look for interesting and meaningful trends in the data that would allow for generation of specific hypotheses in future targeted research efforts. As such, one should use caution when interpreting the results presented herein, as they are strictly descriptive in nature and no tests for statistical significance have been conducted.

Results and discussion in this work are divided into two parts: Part A focuses on uninterrupted lane changes; Part B on interrupted events. An uninterrupted lane change was one in which the participant completed the lane change without any disruption to the flow of the lane change. An interrupted lane change was one where the lane change was delayed, altered, or utterly discontinued via a notable steering or braking input in response to a perceived threat.

For both parts, only the most salient findings are presented in the body of the report; other analyses are included in appendices.

CHAPTER 1. BACKGROUND

The population of older drivers continues to rise. As of 2015, there were almost 40 million licensed older drivers—up 49% from 1999 (Federal Highway Administration, 2015). In 2012, 5,560 older drivers were killed and 214,000 injured in crashes, accounting for 16.6% of all traffic fatalities (up from 15.6% in 2003) and an increase of 16% in injuries from 2011 (National Highway Traffic Safety Administration, 2012).

Studies have shown that older drivers struggle with lane change maneuvers and experience increased crash risk during these maneuvers relative to other age groups (Chandraratna & Stamatiadis, 2003; McGwin & Brown, 1999). Lane changes can pose a significant potential hazard for an older driver as the maneuver requires one to interrupt the current flow of traffic, move one's head through a full range of motion, and quickly gather several sources of information about the safety and timeliness of the lane change. This maneuver requires the driver to scan for visual hazards, not only ahead and to the side, but also over the shoulder (OTS), to check for clearance. Such glances require a large range of motion, which can often be limited in the older population (Eby, Trombley, Molnar, & Shope, 1998; Morgan & King, 1995; Yee, 1985). In addition to scanning for objects in hard-to-see locations, the driver must sift through all the information and make a quick decision to proceed with the lane change in a safe manner. Such decisions may take longer and require more effort in the older population where cognitive-motor declines may be common (Eby et al., 1998; Morgan & King, 1995; Stelmach & Nahom, 1992).

Figure 1 illustrates just how complex even a relatively simple lane change situation can be. It shows just some of the data that must be integrated carefully and quickly by the driver of the red subject vehicle—at least implicitly—before a lane change can be safely attempted. Also note that each metric represented in the diagram is dynamic in real life, continuously varying according to the momentary speed and acceleration of each vehicle in the scenario relative to the subject vehicle.

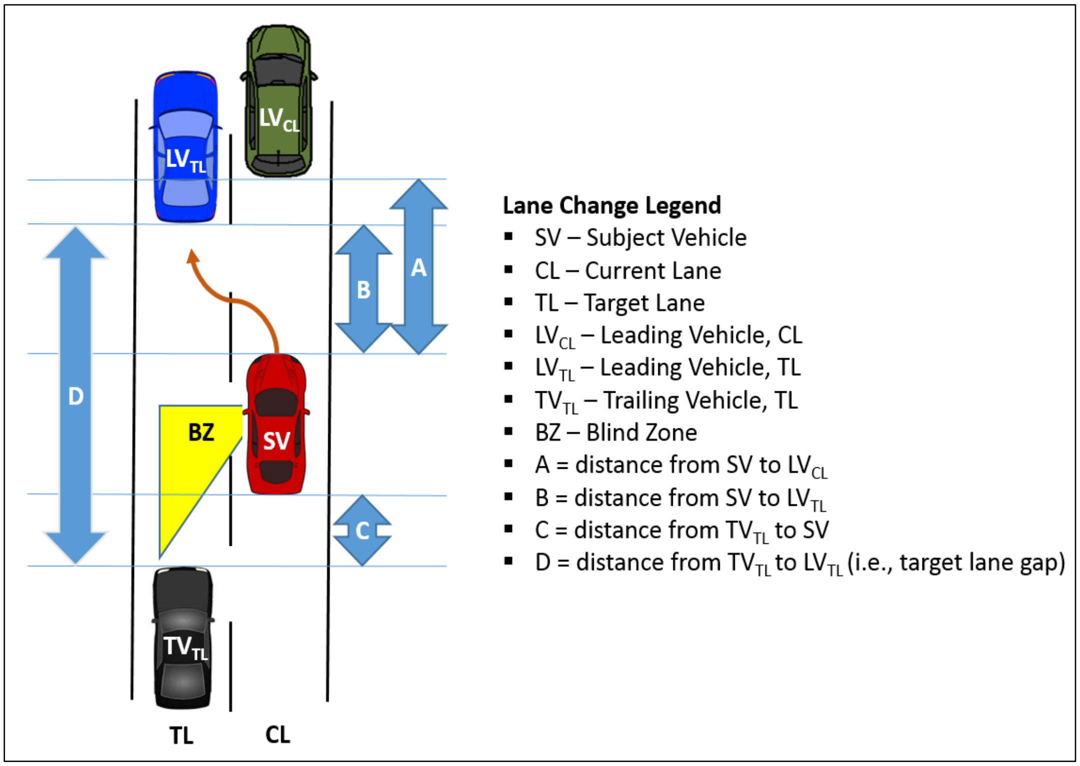


Figure 1. Diagram. Simple lane change factors.

DRIVING ABILITY SELF-RATING

While older drivers have generally been driving for many years, they may tend to perceive their driving abilities as greater than those of their peers, which suggests that many may in fact be overconfident in their driving abilities. Sixty-five percentage of older drivers rated themselves as performing better on a driving test than others, while nearly 53% who considered themselves “a lot better” had unsafe driving performance in an accompanying simulator drive (Freund, Colgrove, Burke, & McLoed, 2005). Similarly, Marottoli and Richardson (1998) evaluated 125 drivers aged 77 and older on a series of self-perception questions; a subset also performed an on-road drive. Not one driver rated themselves as being “worse than other drivers”: the majority (43.5%) rated themselves as “a little bit better” and 24.2% as “much better than.” Of the 50 drivers with an adverse driving event, 34 (68%) rated themselves as being “better” or “much better” drivers among those without a history of adverse events. Much like Freund et al., there were no statistically significant relationship between those who rated themselves highly and their driving performance. Older drivers’ overestimation of their driving performance as shown above, may also be present in lane changes, potentially indicating a lack of insight as to how difficult and risky the maneuver actually is, especially for anyone with diminished functional capabilities.

CRASH RISK

Crash data from Kentucky during the years 1995–1999 demonstrated that older drivers were 1.5 times more likely to be involved in a lane change crash compared to drivers in other age groups. Of all high-speed lane change crashes in the study, 82% were sideswipe crashes. Di Stefano and

Macdonald (2003) found in one study that during licensing renewals, when older driver's errors were tallied, 62% of drivers failed to make OTS glances and 26% failed to check their mirrors. McGwin and Brown (1999) showed that 4.6% of crashes for older drivers involved "improper lane changes." However, when Zhang, Fraser, Lindsay, Clarke, and Mao (1998) evaluated Canadian crash data from 1984–1993, they failed to find a statistically significant crash risk odds ratio for older drivers during lane changes. Their lack of findings could be methodological; while "improperly changing lanes" was not found to be significant, "make a U-turn, or merging" was noted as significant. Merging behaviors could easily be added to the lane changing category and may have elevated the odds ratio to statistically significant levels.

McKnight and McKnight (1999) examined a sample of 407 older drivers (aged 62+) during an on-road drive. The prevalence of errors indicative of skill deficiencies (e.g., attentional, sensory, perceptual, etc.) noted during the drive were positively correlated with previously reported instances of unsafe driving as reported by the police. The authors noted that the correlation was significant, but small ($r = 0.1$ to 0.2). Results showed that police-reported instances of unsafe driving positively correlated with the following errors made during the on-road drive: lane change signal usage, lane change speed (too fast or too slow), and lane change gap acceptance. Older drivers who failed to complete a lane change within a safe envelope of time were more likely to have unsafe driving records. The same holds true for those who failed to signal their intent to change lanes as well as those who incorrectly assessed available space when merging.

In 1998, Staplin, Gish, Decina, Lococo, and McKnight evaluated 82 older drivers referred to the California Department of Motor Vehicles (DMV) for testing on a series of assessments and two on-road drives: one standard route and one familiar route around their home area. A trained DMV in-vehicle assessor collected data on errors committed. Results showed that older drivers "failed to check traffic when changing lanes or merging" 69% of the time on the standard route and 57% of the time on their home route. Other notable lane change errors included progression into others' right of way when changing lanes. This occurred 8% of the time for the standard route and 23% of the time for their home route. Similarly, there was a general failure to use turn signals (65% of the time for a standard route, 20% of the time for their home route).

GLANCE DISTRIBUTION

Failure to demonstrate a complete and robust glance distribution, especially toward the intended lane of travel, can lead to trouble. Lavalliere, Laurendeau, Simoneau, and Teasedal (2011) examined age-related deficits in the frequency of glances to relevant glance areas during lane changes. Participants drove in a simulated environment where lane changes were "forced" by the presence of slower-moving vehicles or static objects in the roadway. The frequency of OTS glances prior to or during the lane change was lower for seniors compared to their younger counterparts. Only 41% of seniors' lane changes included an OTS glance compared to 86% for younger drivers. Additionally, older drivers showed a failure to include an OTS glance 68% of the time prior to initiating a lane change. In a previous study, the complexity of the lane-changing maneuver was shown not to significantly change the frequency of glances to specific areas of interest (Lavalliere, Ngan, Tremblay, Laurendeau, Scialfa, Simoneau & Teasedal, 2007). Similar findings have been reported during real-world drives as well. Lavalliere, Reimer, et al. (2011) showed that during left-hand lane changes on a predetermined highway route, older drivers failed to provide an OTS glance 76.1% of the time. It is worth noting that in Lavalliere, Laurendeau, Simoneau, and Teasdale (2011), no participants reported any difficulty turning their head or back and none reported any pain that may have interfered with the movements. No such information was presented in their other research.

CHAPTER 2. OBJECTIVE

The objective of the current study was to compare senior drivers' lane change-related behaviors to those of younger drivers using naturalistic data collected during real-world driving.

CHAPTER 3. METHODS

DATA COLLECTION

The current effort utilized data collected during the Second Strategic Highway Research Program (SHRP 2) Naturalistic Data Study (NDS). Driving data were collected from 3,645 participants, aged 16–98, from 2010 to 2013. Participants lived near one of six sites: Buffalo, NY; Tampa, FL; Seattle, WA; Durham, NC; Bloomington, IN; and State College, PA. The installed data acquisition system (DAS) hardware provided four camera views (forward, rear, face, and hands). The DAS also incorporated several sensors, including a gyroscope, accelerometers, radar, Global Positioning System (GPS), and collected various vehicle Controller Area Network (CAN) variables (Figure 2). The final DAS installation was unobtrusive and allowed data collection without interference to the driving task. Data were collected continuously while driving, up to two years for some participants, resulting in a total of over 30 million miles of data comprising over two petabytes of storage.

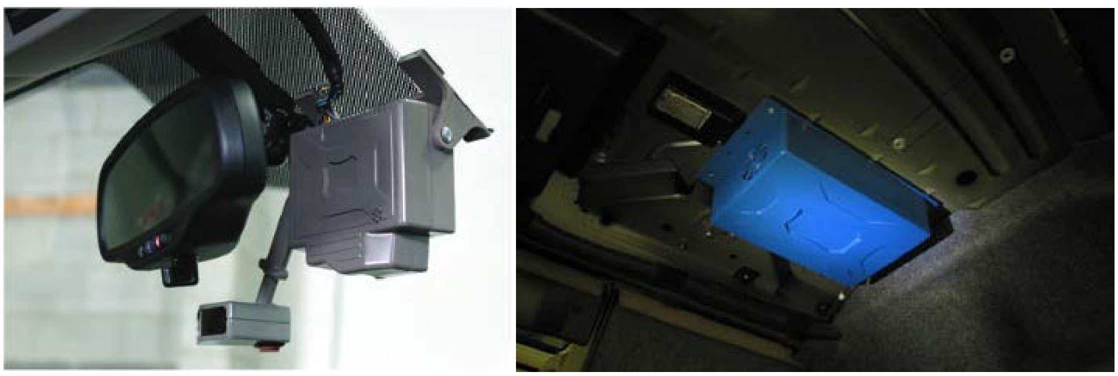


Figure 2. Photos. SHRP 2 DAS installation: head unit behind rearview mirror (left); main unit onto the roof of the vehicle's trunk (right).

Uninterrupted Lane Changes

A sample of 595 uninterrupted lane changes was compiled from 443 unique participants by examining baseline samples and safety-critical events (SCEs) reduced for the SHRP 2 study. Included lane changes were not subject to certain speed or location requirements; however, merge behaviors and potential lane changes within parking lots were excluded. Each included lane change was judged to be intentional and was one where the subject vehicle moved completely from one lane to another without any sort of interrupting behavior on the part of the participant. A lane change event with an SCE was only included if the completed lane change was unaffected by the presence of the SCE. For the uninterrupted lane changes identified, the breakdown of age and gender is presented in Table 1. It is worth noting that ~73% of uninterrupted lane changes are baseline events, whereas ~24% are near-crashes and ~3% are crashes.

Table 1. Age and gender distribution of the uninterrupted lane change events data set.

Age	Male	Female	Unavailable
Young (16–19)	96	102	4
Middle (30–49)	113	100	11
Older (70–94)	97	62	10

Interrupted Lane Changes

A data set of interrupted lane changes was created. Interrupted lane changes are those in which the participant driver initiated a lane change maneuver, but then felt the need to perform an evasive maneuver such as steering wheel corrections or braking to safely complete or abort the maneuver. During the SHRP 2 SCE reduction, a number of events occurred where an intentional lane change was recorded as a pre-incident maneuver. A subset of those SCEs included 104 interrupted lane change events for 88 unique participants. The distribution of age and gender is shown for the interrupted lane change data set in Table 2. Interrupted lane change events were nearly all near-crashes (~93%); baselines (~4%) and crashes (~3%) made up the remainder.

Table 2. Age and gender distribution of the interrupted lane change events data set.

Age	Male	Female	Unavailable
Young (16–19)	14	14	1
Middle (30–49)	25	23	0
Older (70–94)	21	5	1

In many of the analyses presented below, the main factor shown is the lane change phase. Phase is defined and illustrated in Figure 3 below.

Phase 1: Five seconds prior to initiation of the lane change	**Phase 2:** From the point of initiation to first contact with the *first* lane line (if multiple lanes are crossed)	**Phase 3:** From contact with the lane line to completion

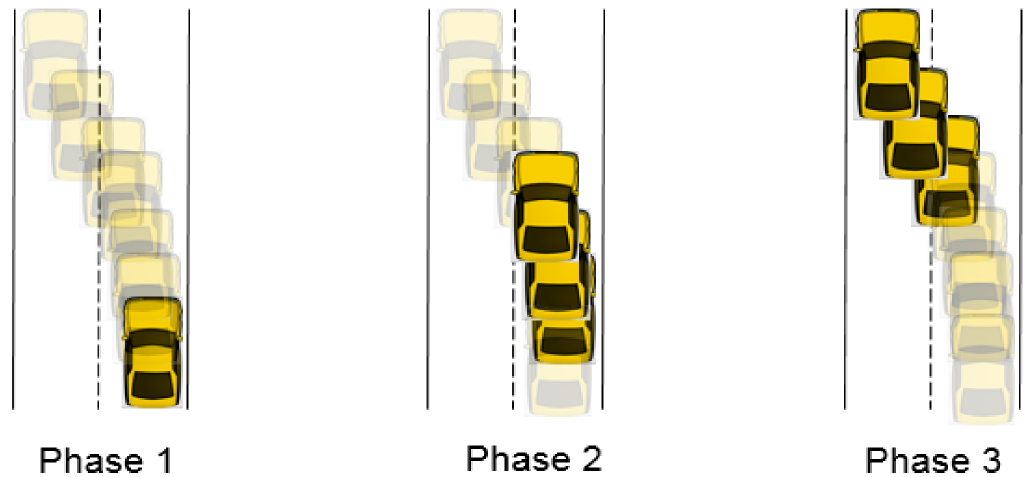


Figure 3. Diagram. Representation of lane change phases.

DATA REDUCTION

All events included in both data sets were subject to a series of questions by trained analysts. All staff who viewed the data were Institutional Review Board (IRB)-trained individuals familiar with the process. Two separate protocols were developed. The Overall Lane Change Event data reduction included approximately 45 questions about each specific lane change event, including such factors as turn signal usage, lane change direction, and surrounding vehicles. See Appendix A for these data reduction protocols. All events were again reviewed for accuracy by a designated quality assurance manager (who did not participate in the original event reduction). The resulting data set is an event-by-event description of the lane change maneuvers that can be compared across a number of factors.

The second data reduction protocol comprised a frame-by-frame Glance Location data reduction (at a 15 Hz frame rate) starting 5 seconds prior to the lane change initiation and continuing until the end of the lane change event (see Appendix B). Glance reduction was interpreted such that for a glance fixation to be recorded at a specific location, the eyes had to be fixated at that location for a minimum of 1 frame (0.066 seconds); when the driver's eyes moved from one location to another, the frames between glance fixations were recorded as transitions. An example glance reduction is presented in Figure 4. The resulting data set is a frame-by-frame record of glance locations for each lane change event. Table 3 below shows the independent and dependent measures in this study.

Table 3. Independent and dependent variables used in this effort.

Independent Variables	Dependent Variables
Lane Change Type (Uninterrupted or Interrupted)	Glance – Percentage of Time
Age Group (Young, Middle, Older)	Glance – Percentage of Glances
Lane Change Direction (Left or Right)	Glance Duration
Lane Change Phase (Phase 1, 2, or 3)	Glance Counts
	Glance Probability
	Entropy
	Errors – Over The Shoulder Check
	Errors – Side Mirror Check
	Errors – Turn Signal Failure
	Errors – Cut-Off other Driver
	Traffic Flow
	Number of Passengers
	Day of Week
	Time of Day
	Conflict Type
	Crash Severity (Crash or Near-Crash)
	Aggressive Driving
	Sporty Driving
	Secondary Task Engagement
	Turn Signal Use

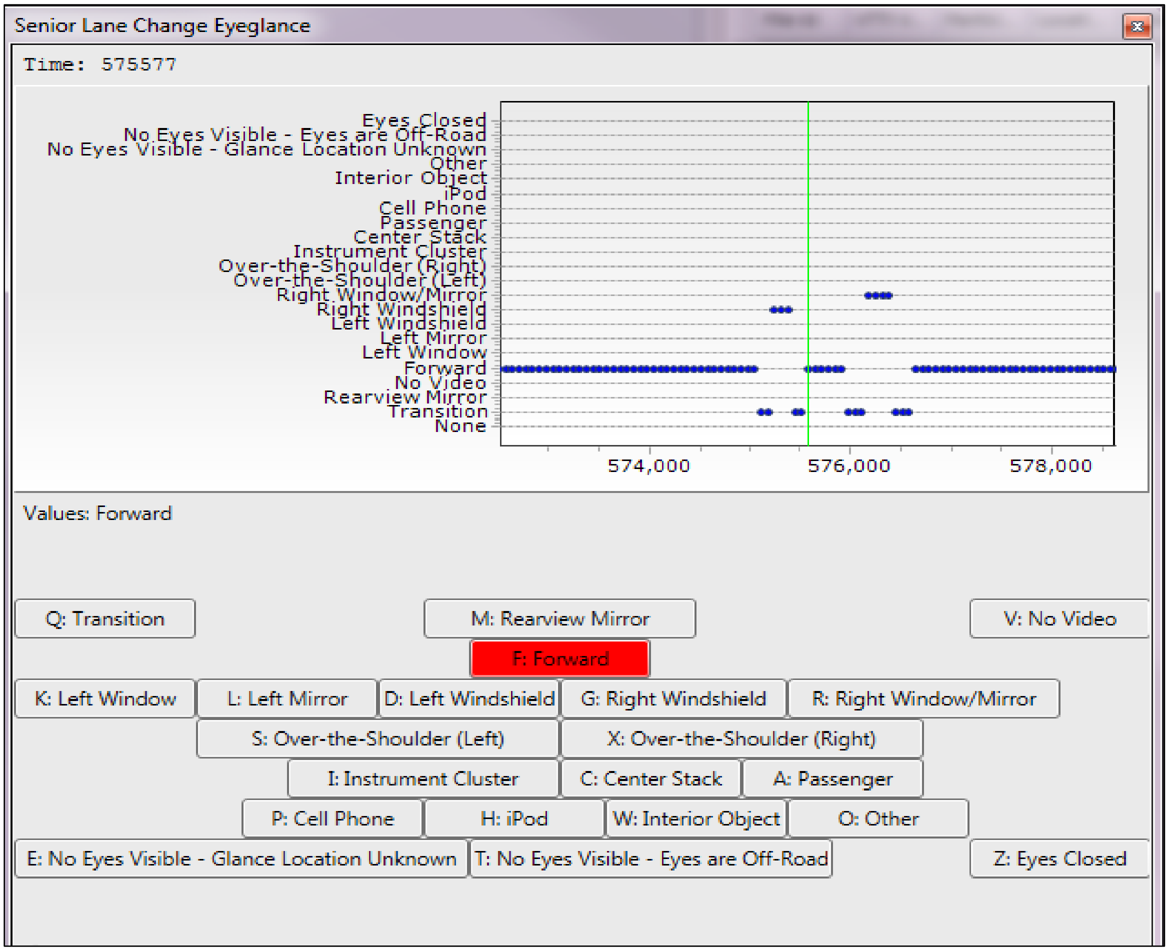


Figure 4. Screen capture. Example glance reduction.

GLANCE ANALYSIS METHODS

For each of the glance analyses presented below, a different approach was required. For each analysis, specific *areas of interest* (AOIs) were deemed the most important glance locations for the driver to check prior to and during lane change maneuvers. These were defined for left lane changes as forward, left mirror, left window, OTS left, and rearview mirror; and forward, right window/mirror, OTS right, and rearview mirror for right lane changes (see Figure 5).

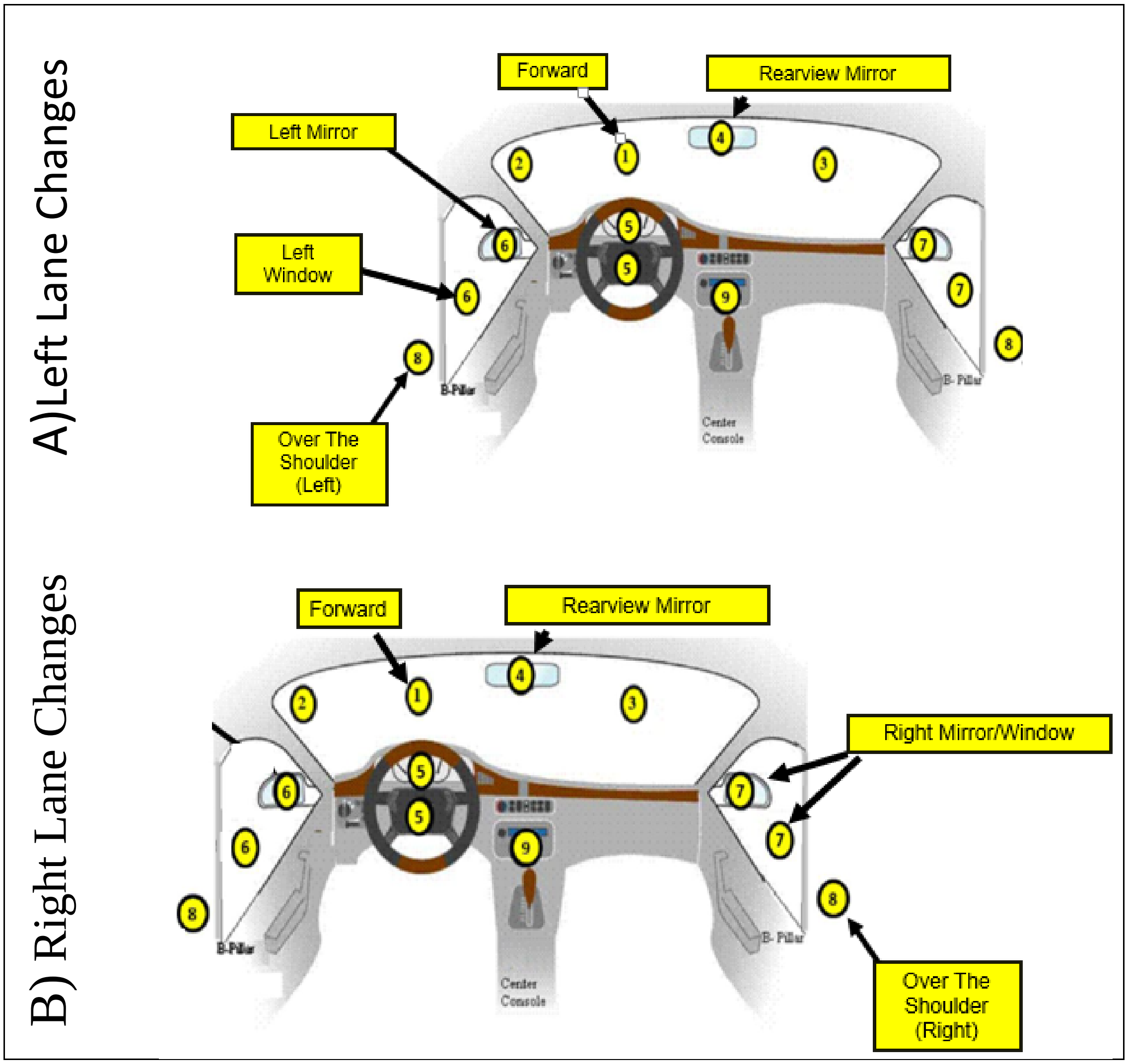


Figure 5. Diagram. AOIs for glance locations for left lane changes (A, labeled above) and right lane changes (B, labeled below).

Percentage of Time

The percentage of time analyses were calculated by totaling the allocated glance durations to a given AOI for each individual participant and phase of the lane change. The results were averaged across participants and divided by the total time spent glancing during each phase for all possible glance locations. All lane change events were included in these analyses.

Percentage of Glances

The percentage of time analyses were calculated in the same fashion as the percentage of time analyses described above with the exception that they were based on the number of glances. By totaling the number of glances to specific AOIs and dividing by the total number of glances present within that particular phase, a percentage was created. All lane change events were included in these analyses.

Glance Duration

Analyses for glance duration were limited only to events where a single lane was crossed; that is, if more than one lane was crossed during the maneuver, that lane change event was not included in these analyses. Doing so only eliminated about 5% of the data for both uninterrupted and interrupted data sets. The duration for glances to a particular area of interest was averaged across glances (if multiple glances to a given AOI were present) and drivers for a single duration value at each specific phase of the lane change. The choice to reduce the number of events to a single lane entered was to keep results comparable to one another; that is, glance durations for a single lane change might be quite different than durations for crossing two or three lanes at a time. Analyses focused only on instances where a driver made a glance. Instances where a driver did not glance to the specific areas of interest were not counted as zero but rather ignored, as they would artificially lower the average duration. For example, if we had three drivers but only two of them made a glance to the left mirror, we would average the duration of those two glances and not include a zero duration for the one driver who failed to direct a glance in that direction. As glance reduction was interpreted at 15 Hz, all results are shown to the first decimal point.

Glance Probability

To calculate glance probabilities—the probability for glances to a specific AOI—the number of glances for a specific location was divided by the total number of glances for that particular phase. Probabilities were calculated separately for each participant and each phase and then collapsed across participants. Note that not all probabilities in the graphs will add up to 1. This is due to a number of additional glance locations that are not represented on these graphs and were not judged to be of interest for this analysis (center console, instrument cluster, any secondary tasks, passenger, etc.). All lane change events were included in the analyses.

Glance Count

The glance count analysis (presented in Appendix C) was calculated in the same way as glance duration, and was also limited to a single lane entered to keep results comparable to one another as the number of glances directed when crossing multiple lanes would likely be higher than crossing into a single lane. In the same vein as the glance duration analyses, the removal of events where drivers crossed multiple lanes only eliminated about 5% of the data across both uninterrupted and interrupted data sets. The average number of glances was calculated by participant and lane change phase and then collapsed into age groups. Similar to the glance duration analyses explained above, if a participant did not glance to a specific area of interest, that value was not counted as a zero (again artificially lowering the average glance count), but rather ignored. That is, the average glance counts are only based on directed glances.

Entropy

Entropy, or degree of glance dispersion, was calculated for each phase of the lane change and for each participant individually, then the level of glance dispersion across participants was averaged for each phase. All lane change events were included in the entropy analyses. The formula used to calculate the entropy is presented in Equation 1:

$$Entropy_{bits} = -\sum_{i=1}^{n}(p_i \log p_i) \quad (1)$$

where n = the total number of possible predefined glance locations and p_i = the probability of a single glance landing on the i^{th} predefined glance location. Note that for any $p_i = 0$, we define $p_i \log p_i = 0$.

All results presented below are descriptive as this effort represents an initial exploration of the topic area. The results presented here can serve to guide future studies and their specific hypotheses.

CHAPTER 4. PART A – UNINTERRUPTED LANE CHANGE RESULTS

Due to the expansive nature of this project, only the most pertinent results are discussed. For complete analyses, please see Appendix C. In addition to the results and figures presented below, the information has also been distilled into tables, which are presented in Appendix D.

Glance Characteristics

Percentage of Time

One of the several glance behaviors quantified in this research effort was the percentage of time glancing at specific AOIs. Figure 6 below shows the percentage of time glancing to all AOIs for left lane changes during each of the three phases. Results showed that while the percentage of time glancing to the forward roadway decreased from Phase 1 to Phase 2, it decreased the most for middle-aged drivers (from 75% to 61%, 14 percentage points). Younger and older drivers showed a decrease of 7 and 6 percentage points, respectively. The results also showed that, in general, drivers during Phase 2 showed a greater percentage of time glancing to AOIs relative to Phase 1.

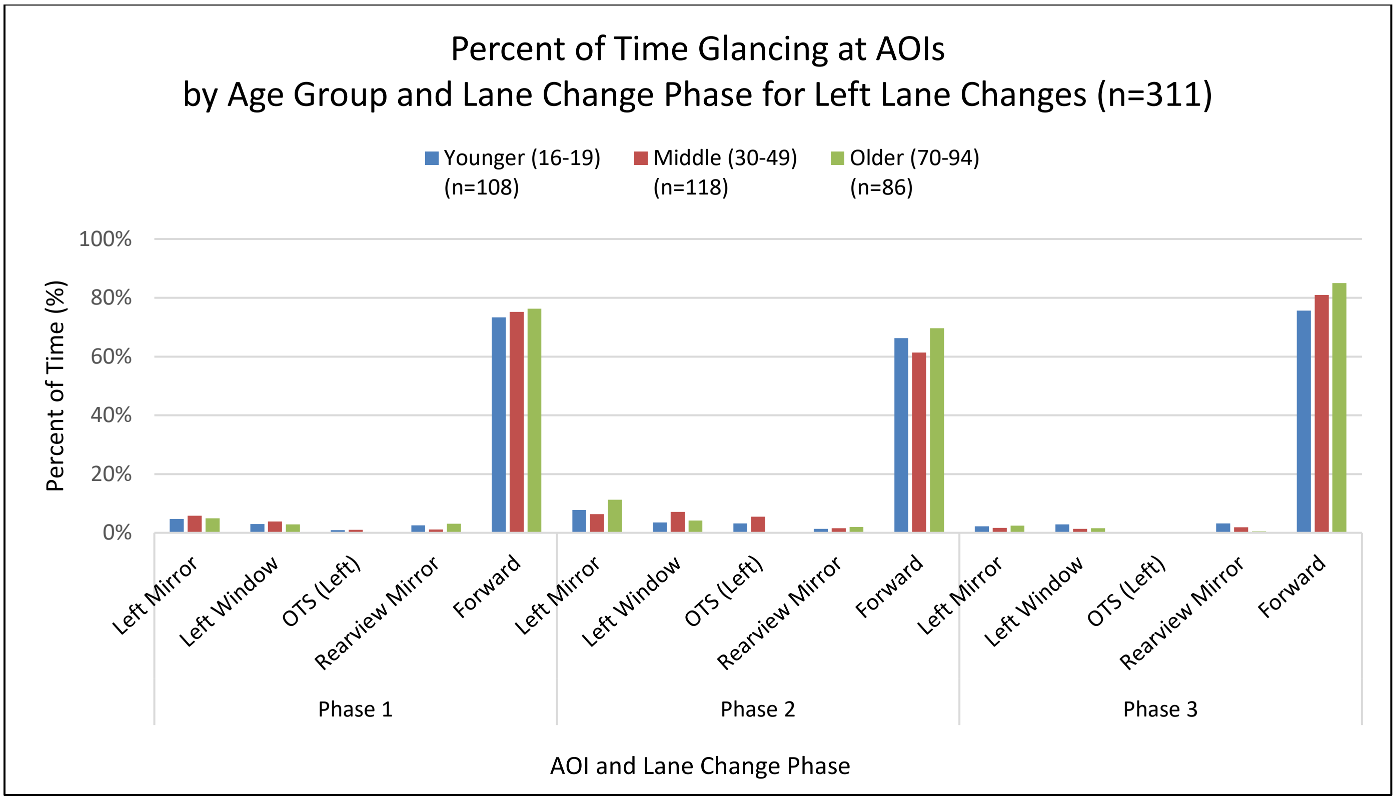


Figure 6. Chart. Percentage of time glancing at AOIs by age group and lane change phase.

The percentage of time participants glanced at AOIs during Phase 2 of the uninterrupted lane change events was also evaluated. Participants showed a greater percentage of time glancing at left lane change AOIs for left lane changes than right lane change AOIs for right lane changes. Younger drivers showed an increased percentage of time glancing to the left mirror, from 5% to

8%, while older drivers more than doubled their percentage of time from 5% to 11%. During Phase 2 of the lane change maneuver, younger drivers showed an increased percentage of time for OTS glances, from 1% to 3%, and middle-aged drivers from 1% to 5%. Older drivers did not show any glance time to OTS glances. Middle-age drivers also showed less glance time overall to the forward roadway (61%) than their younger (66%) and older (70%) counterparts. See Figure 7 for the distribution of glance percentages for Phase 2 by age group.

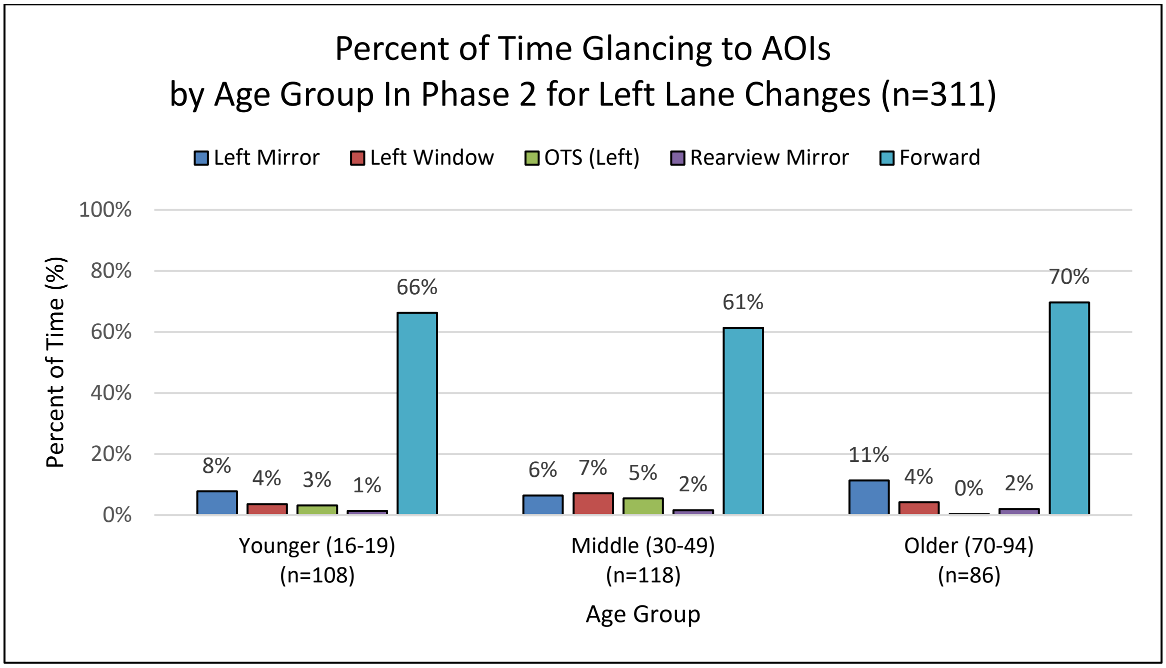


Figure 7. Chart. Percentage of time glancing at AOIs by age group for Phase 2 of uninterrupted left lane changes.

Figure 8 shows the percentage of time glancing to AOIs by age group and lane change phase for right lane changes. From Phase 1 to Phase 2, an increase in the percentage of time glancing to AOIs can be seen. Larger increases, in general, were seen for middle-aged drivers to the right window/mirror and right OTS glance locations, as well as a doubling of time glancing to the right window/mirror location for older drivers when moving from Phase 1 to Phase 2.

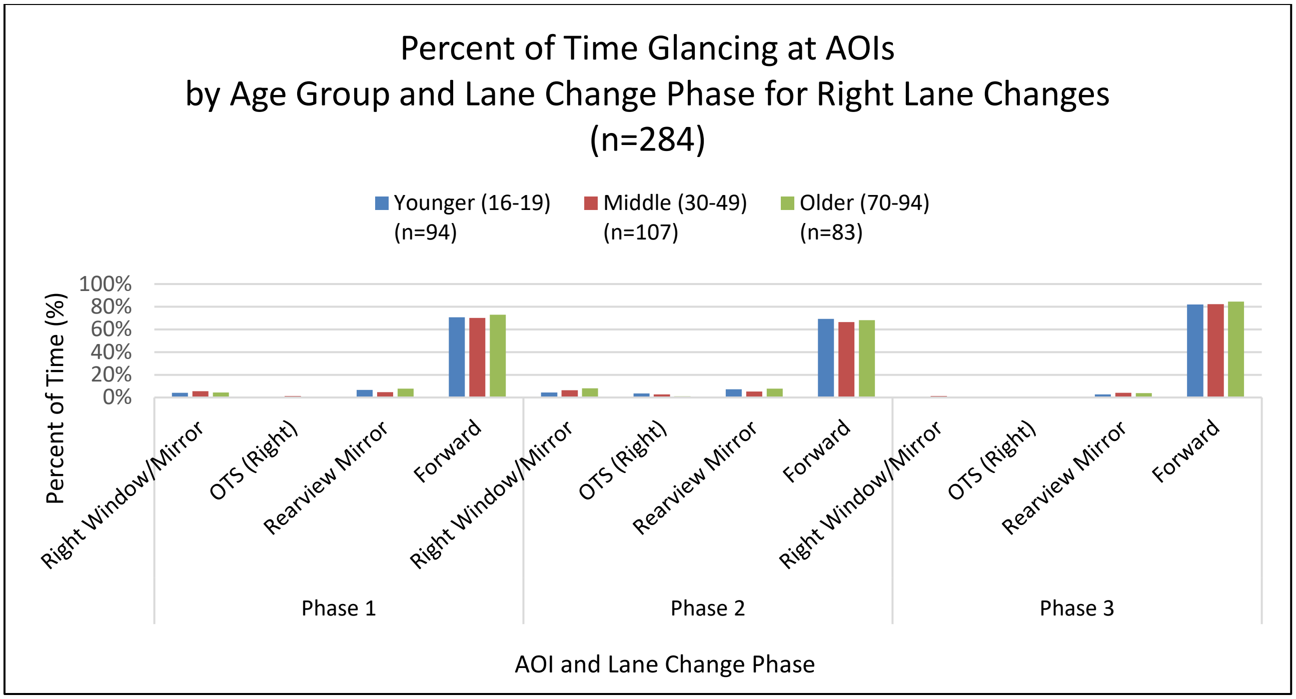


Figure 8. Chart. Percentage of time glancing at AOIs by age group and lane change phase for uninterrupted right lane changes.

Figure 9 shows the percentage of time glancing to specific AOIs for right lane changes during Phase 1 of the maneuver. Younger drivers and older drivers showed a greater percentage of glance time to the rearview mirror than the middle-aged group (7% and 8% vs. 5%). The percentage of time to other AOIs for Phase 1 of right lane changes was very similar across age groups and AOIs.

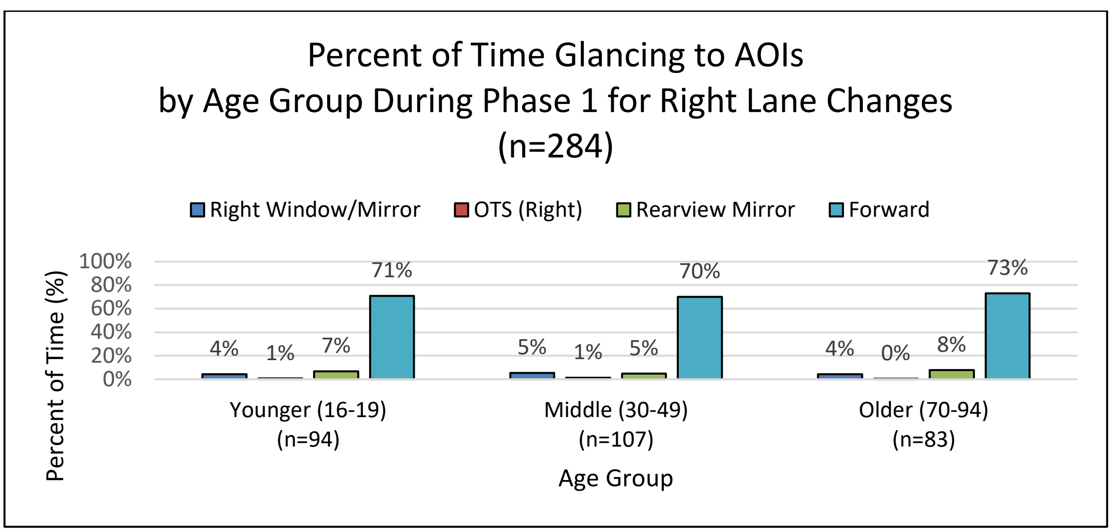


Figure 9. Chart. Percentage of time glancing at AOIs by age group for Phase 1 of uninterrupted right lane changes.

During Phase 2 of right lane change events, an increase can be seen in time glancing to the right window/mirror for middle-aged and older drivers versus younger drivers (6% and 8% vs. 4%). Of greater interest to note is that while the percentage of time glancing to the rearview mirror stayed similar to Phase 1, an increase of percentage of time for OTS right glances can be seen. For both younger and middle-aged groups, the percentage of time allocated to the OTS glance location increased dramatically for Phase 2, but not for older drivers. Figure 10 below shows the distribution of time by age group and AOI.

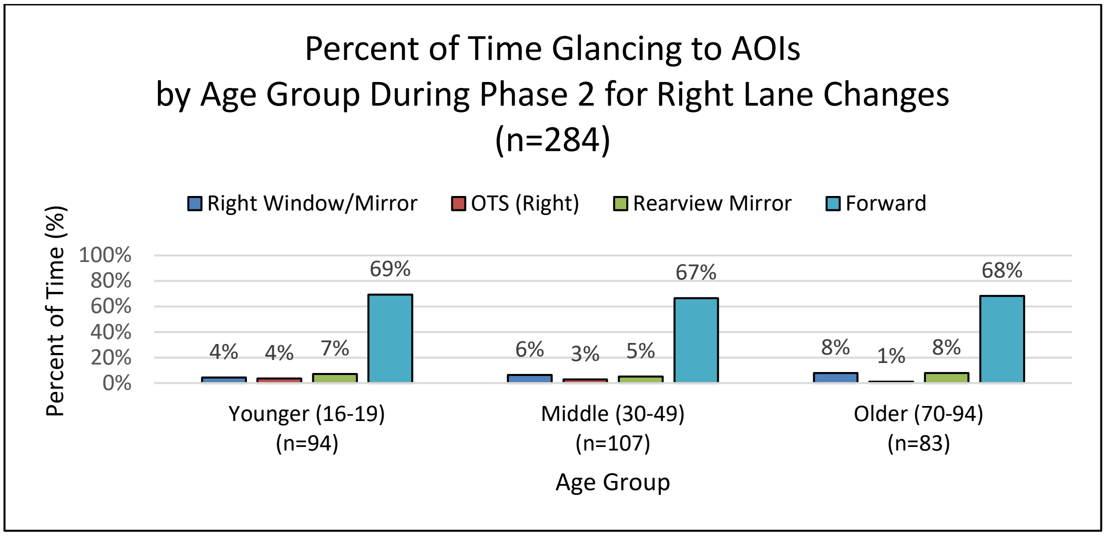


Figure 10. Chart. Percentage of time glancing at AOIs by age group for Phase 2 of uninterrupted right lane changes.

Percentage of Glances

When comparing the percentage of glances to specific AOIs for left lane changes, the left OTS glance location stands out for younger and middle-aged drivers as a change from Phase 1 to Phase 2. When moving from Phase 1 to Phase 2, younger drivers showed an increase from 1% to 5% of glances for glances to the left OTS location, and middle-aged drivers showed an increase from 2% to 6%. Older drivers, however, increased their percentage of glances from 0% to 1%. However, older drivers showed a decrease in reliance on the rearview mirror when moving from Phase 1 to Phase 2 (see Figure 11).

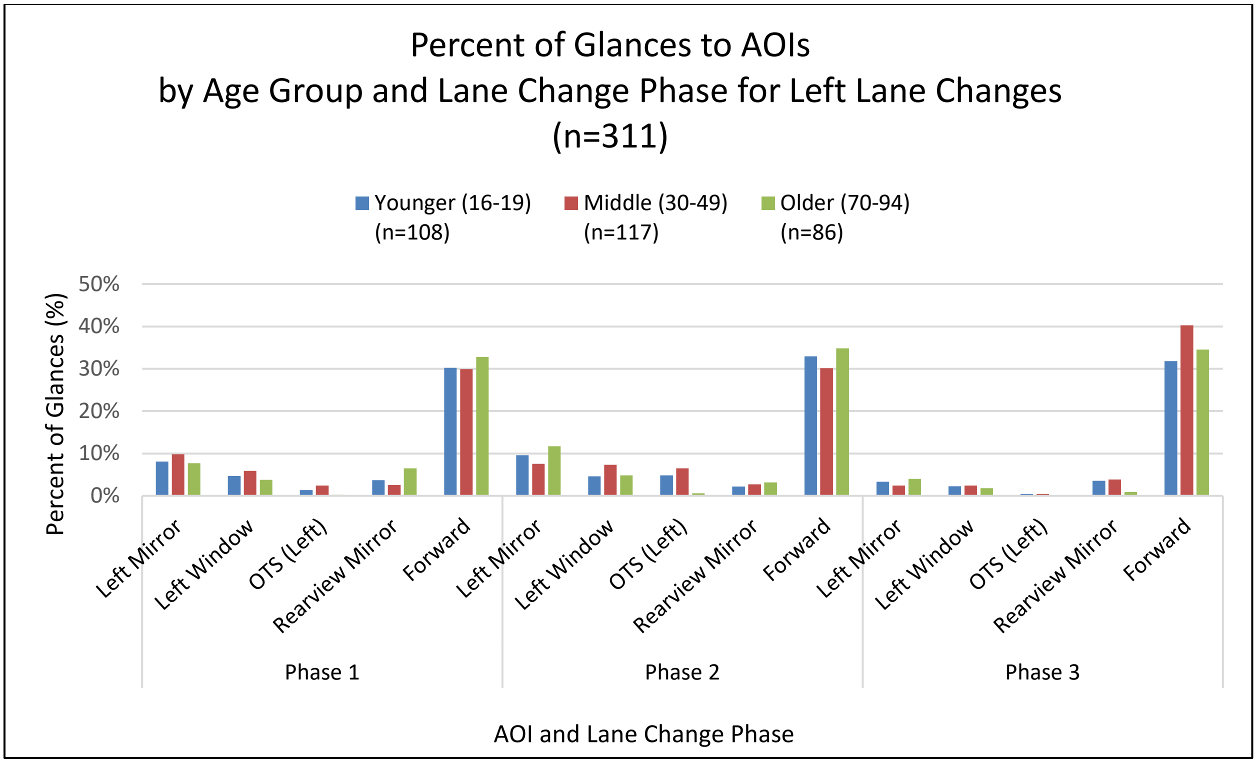


Figure 11. Chart. Percentage of glances to AOIs by age group and lane change phase.

During Phase 1 of uninterrupted left lane changes, the percentage of glances to each of the AOIs was quite similar across age groups (see Figure 12). All three age groups showed an increased percentage of glances to the left mirror (8%, 10%, and 8% for younger, middle-aged, and older drivers) compared to the other three AOIs. Older drivers showed a slightly elevated percentage of glances to the forward roadway (33%) when compared to younger (30%) and middle-aged drivers (30%).

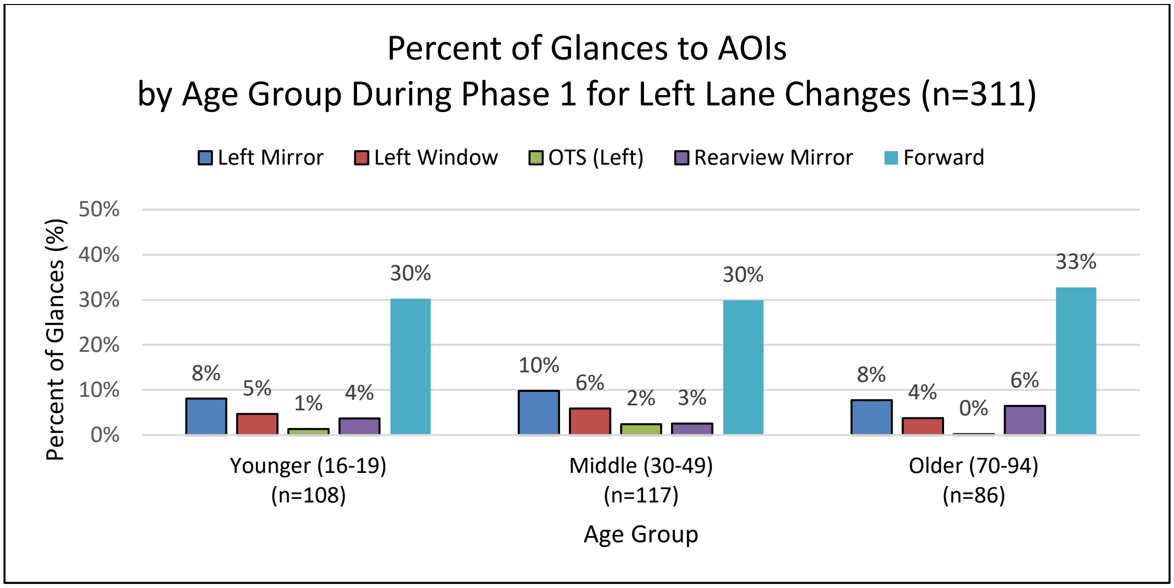


Figure 12. Chart. Percentage of glances to AOIs by age group for Phase 1 of uninterrupted left lane changes.

The percentage of glances to the various AOIs during Phase 2 of uninterrupted left lane changes again showed a similar distribution for all three age groups for the left mirror, left window, and rearview mirror, but revealed a difference for the OTS glances (see Figure 13). While younger drivers and middle-aged drivers performed 5% and 6% of their glances to the OTS location, older drivers only performed 1% of their glances to that location. Older drivers continued to show an elevated percentage of glances to the forward roadway (35%) during Phase 2, particularly when compared against middle-aged drivers (30%).

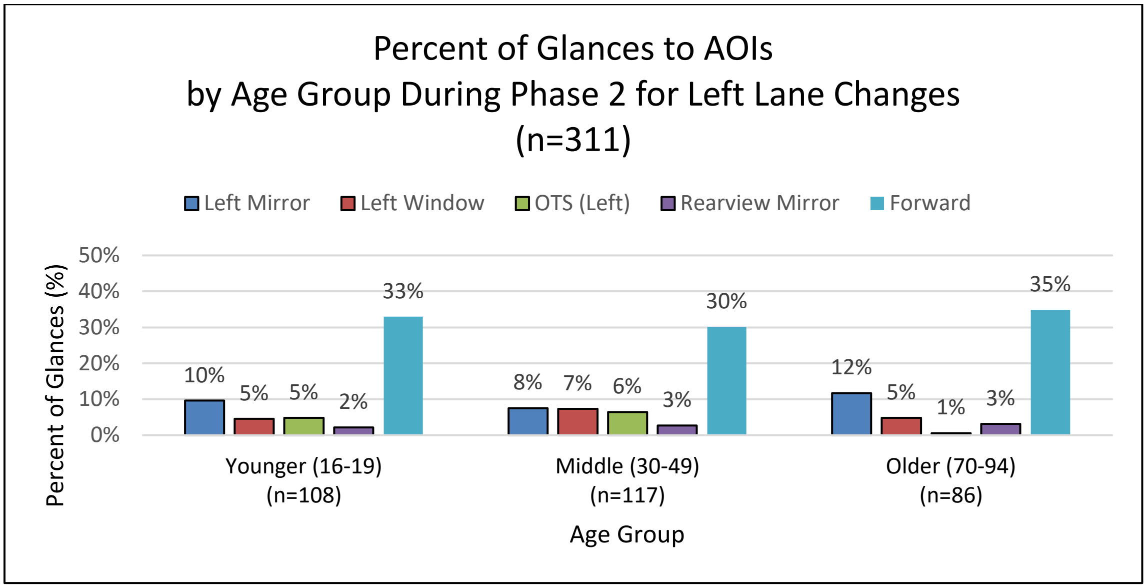


Figure 13. Chart. Percentage of glances to AOIs by age group for Phase 2 of uninterrupted left lane changes.

When investigating the percentage of glances for right lane changes, we can see an increase of glances to the right window/mirror location for older drivers (6% to 10%), whereas younger and middle-aged drivers both showed no increase (stable at 7% for both age groups). Other increases in percentage of glances can be seen for the right OTS location: younger drivers showed an increase from 2% to 5% of glances, while middle-aged drivers showed an increase from 2% to 4%. Older drivers, however, remained stable with only 1% of glances to the right OTS location for both Phase 1 and Phase 2. Figure 14 below shows the percentage of glances to given AOIs across the three lane change phases.

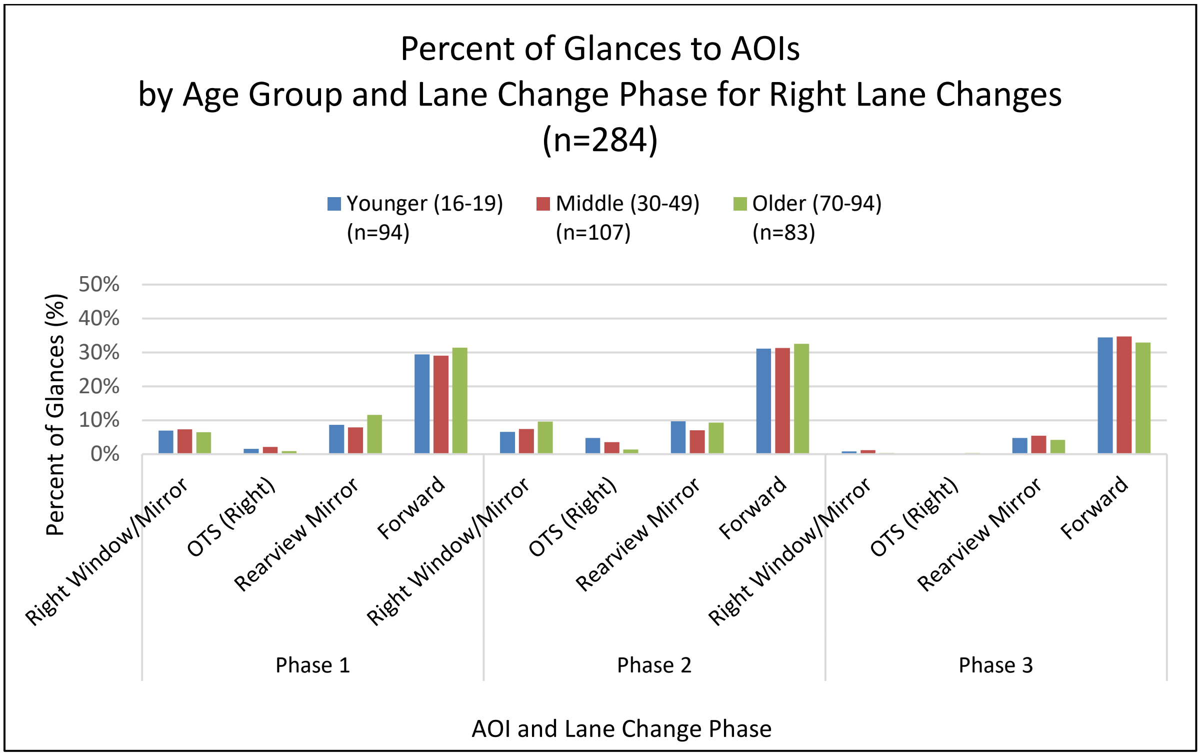


Figure 14. Chart. Percentage of glances to AOIs by age group and lane change phase for uninterrupted right lane changes.

The percentage of glances in Phase 1 for right lane changes showed a higher reliance on the rearview mirror for older drivers (12%) compared to younger (9%) and middle-aged drivers (8%). Figure 15 shows the distribution of glances by age group.

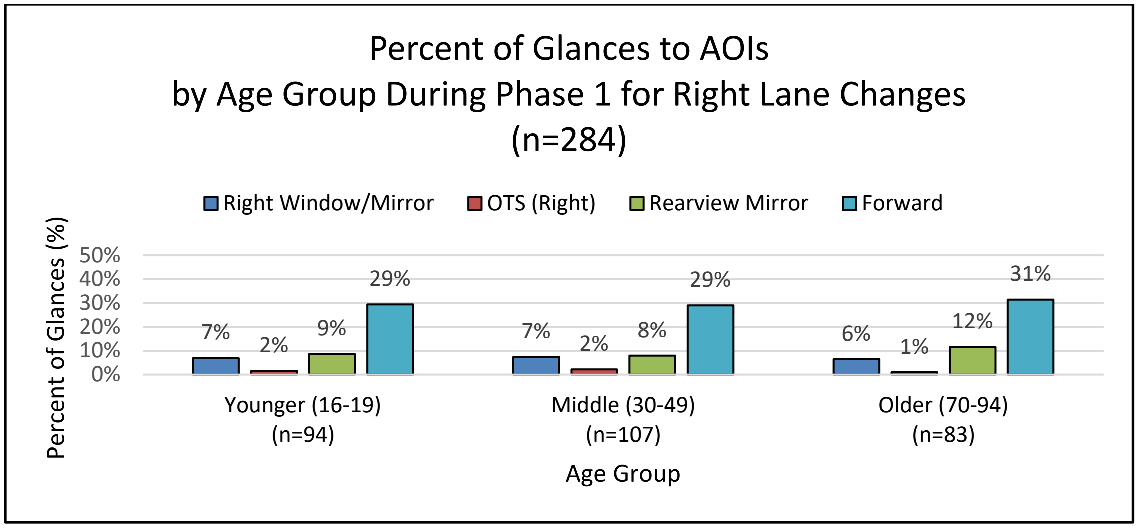


Figure 15. Chart. Percentage of glances to AOIs by age group for Phase 1 of uninterrupted right lane changes.

During Phase 2, results showed that older drivers performed more of their glances to the right window/mirror than younger and middle-aged drivers (10% vs. 7% and 7%; see Figure 16). Of particular note is the difference in percentage of glances to the OTS location. While younger drivers performed 5% of their glances to the OTS location and middle-aged drivers performed 4%, older drivers only executed 1% of their glances to the OTS location.

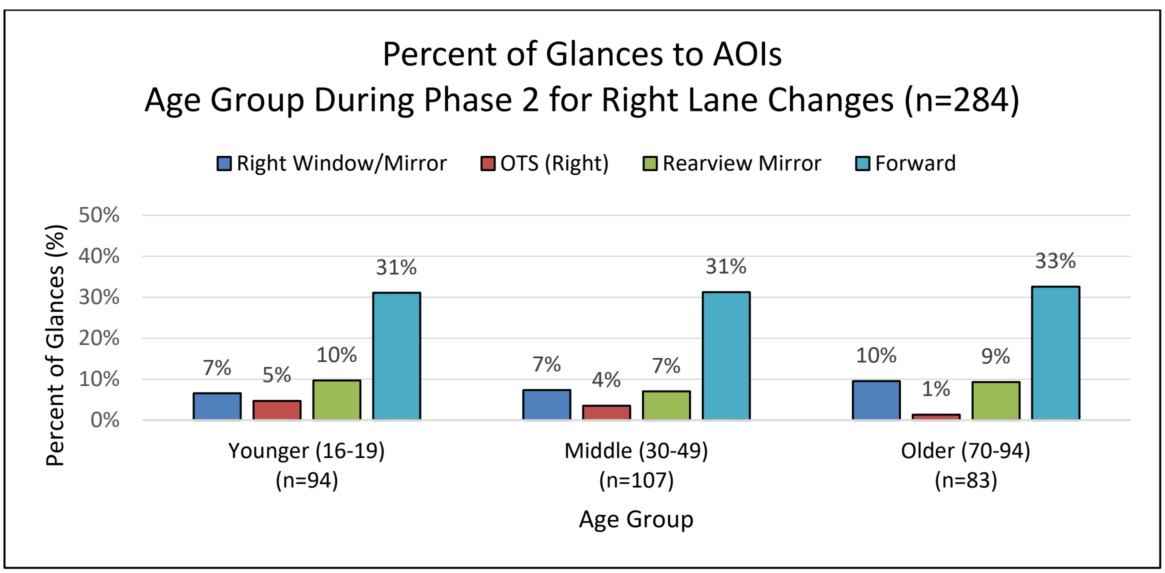


Figure 16. Chart. Percentage of glances to AOIs by age group for Phase 2 of uninterrupted right lane changes.

Glance Duration

In addition to the percentage of time allocated to glance locations and percentage of glances, the glance duration at each AOI was calculated. Glance duration provides another piece of the puzzle regarding glance behaviors: two glances to the same location can have very different durations.

The average glance duration to various AOIs was calculated for left lane changes and is shown in Figure 17 below. The most obvious difference seen is the major reduction in glance durations made to the forward roadway when moving from Phase 1 to Phase 2 for all age groups (from about 3.7 seconds to 1.5 seconds). On average, glance durations during Phase 2 were shorter than those in Phase 1 across all locations and age groups.

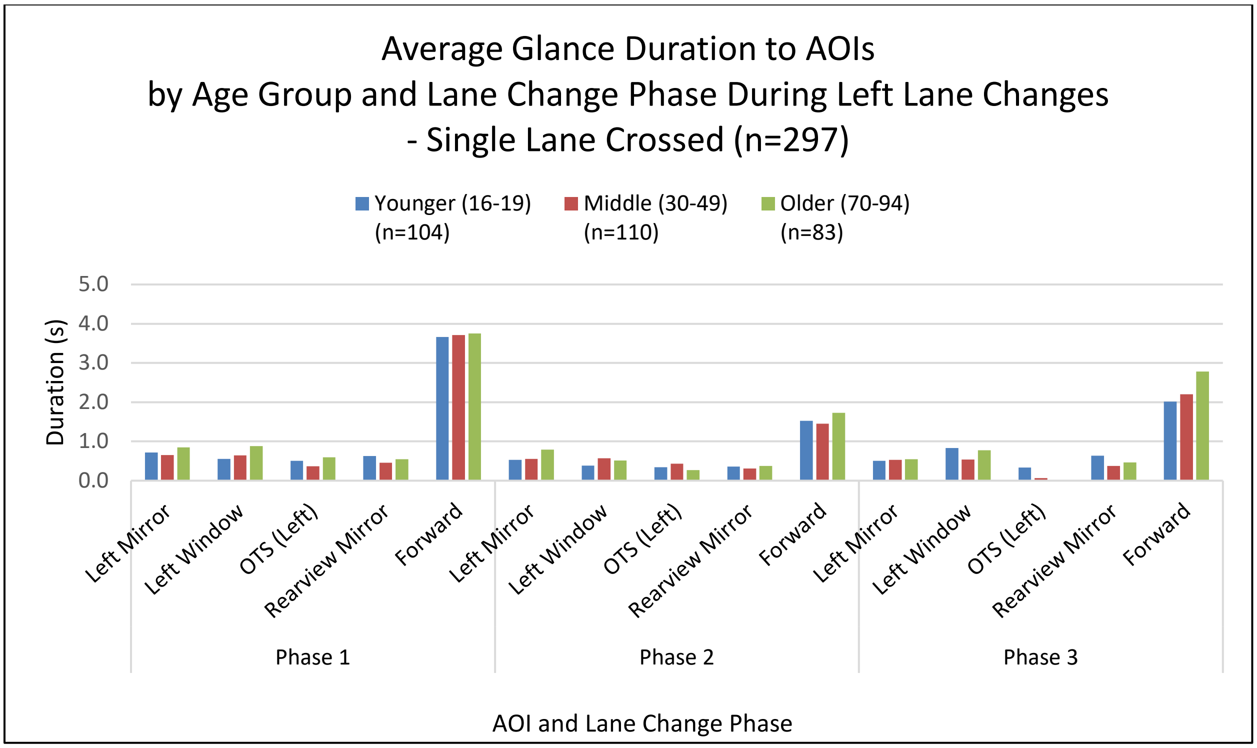


Figure 17. Chart. Average glance duration to AOIs by age group and lane change phase.

The distribution of glance durations to AOIs during Phase 2 left lane changes is shown in Figure 18. Older drivers showed an average glance duration to the left mirror of 0.8 seconds compared to 0.5 seconds for younger and 0.6 seconds for middle-aged drivers. Older drivers had longer glance durations on average (1.7 seconds) to the forward location than younger (1.5 seconds) and middle-aged (1.5 seconds) drivers. Other glance durations were similar across age groups.

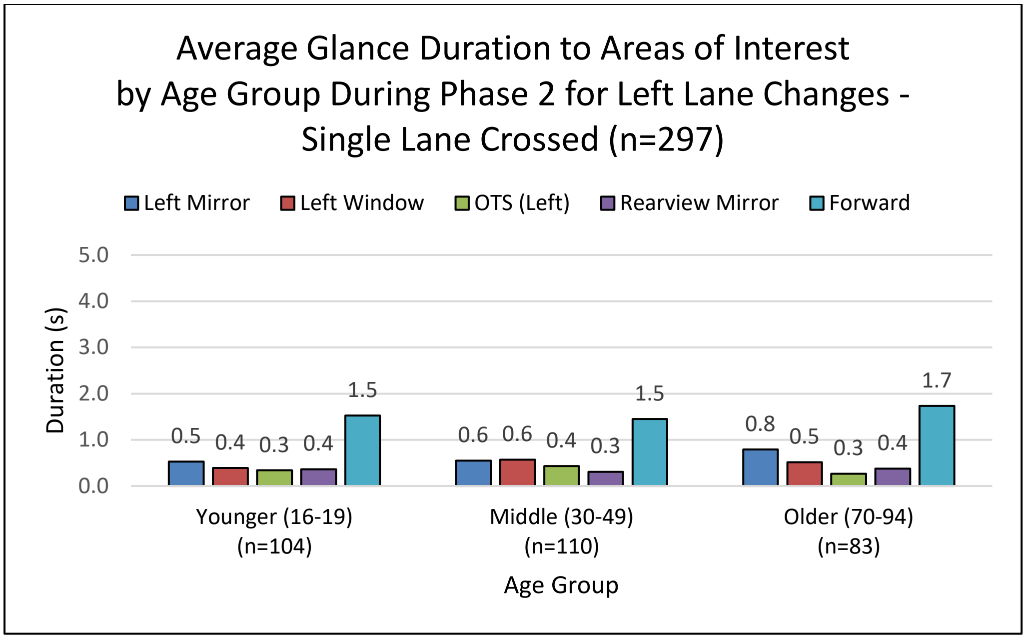


Figure 18. Chart. Average glance duration to AOIs for Phase 2 of uninterrupted left lane changes.

The average glance duration for right lane changes across phases is shown in Figure 19 below. Similarly to the left lane changes above, the glance durations for the forward location are markedly higher for Phase 1 than Phase 2. Across all age groups, the duration dropped from about 3.6 seconds to 2.1 seconds, with one exception: older drivers did not show as much of a decrease (from 3.6 seconds to 2.5 seconds). Overall, glance durations were shorter for the right window/mirror location for younger and middle-aged drivers, but not for older drivers. In fact, older drivers did not show any decreased glance duration to any locations other than forward. No decrease in glance durations to the right OTS glance location was seen from Phase 1 to Phase 2.

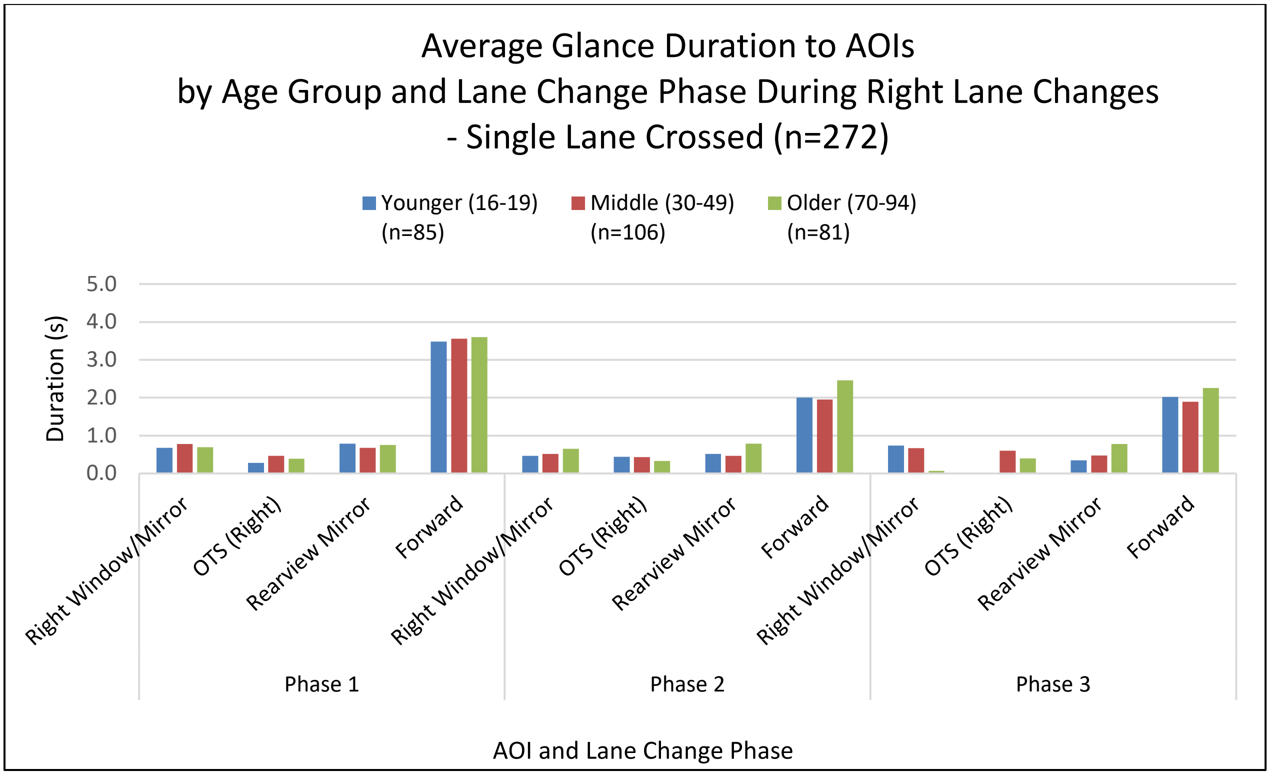


Figure 19. Chart. Average glance duration to AOIs by age group and lane change phase for uninterrupted right lane changes.

The distribution of glance durations for Phase 2 right lane changes is shown in Figure 20. Overall, glance durations to the three AOIs for right lane changes did not change much by age group. Older drivers' glance durations to the right window/mirror were higher (0.7 seconds vs. 0.5 seconds) compared to younger and middle-aged drivers. Glance durations to the rearview mirror were also higher for older drivers (0.8 seconds) compared to younger and middle-aged drivers (both 0.5 seconds).

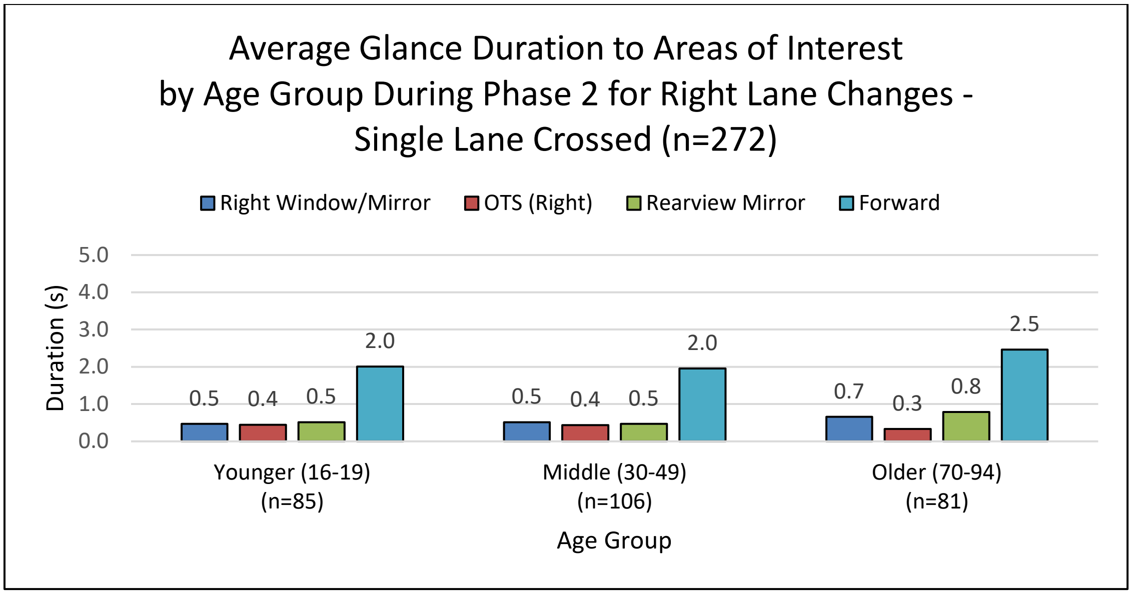


Figure 20. Chart. Average glance duration to AOIs for Phase 2 of uninterrupted right lane changes.

Probability

Glance Probability

The average glance probability to AOIs for left lane changes is presented in Figure 21 below. As would be expected, the greatest probability is shown for the forward location. Following that, middle-aged drivers showed a higher probability for glances to the left mirror (0.14) compared with the other age groups (0.09 for younger and 0.10 for older drivers). Older drivers showed the highest probability (other than forward) for the rearview mirror (0.09) when compared with younger (0.05) and middle-aged drivers (0.03).

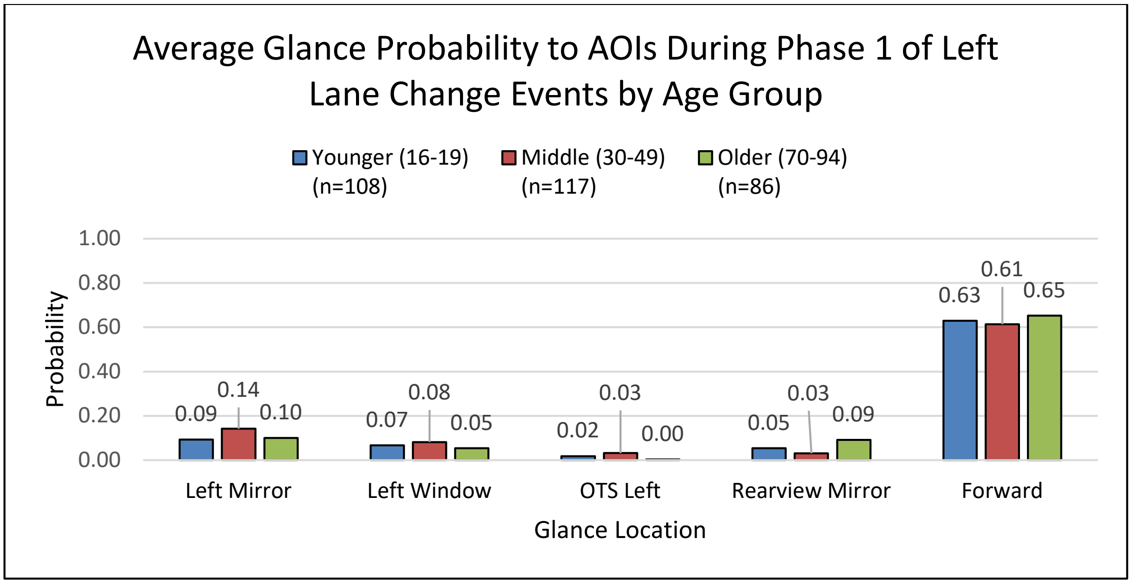


Figure 21. Chart. Average glance probability during Phase 1 of uninterrupted left lane changes.

Average glance probabilities during Phase 2 are presented in Figure 22 below. In addition to the forward location showing the highest level of probability, the left mirror location was the highest of the remaining AOIs, with probabilities ranging from 0.10 to 0.14. Middle-aged drivers were the most likely to glance to the left window (0.10) when compared with younger (0.06) and older drivers (0.07). Older drivers also showed a very small probability of glancing to the OTS location (0.01), far lower than younger (0.07) and middle-aged drivers (0.08).

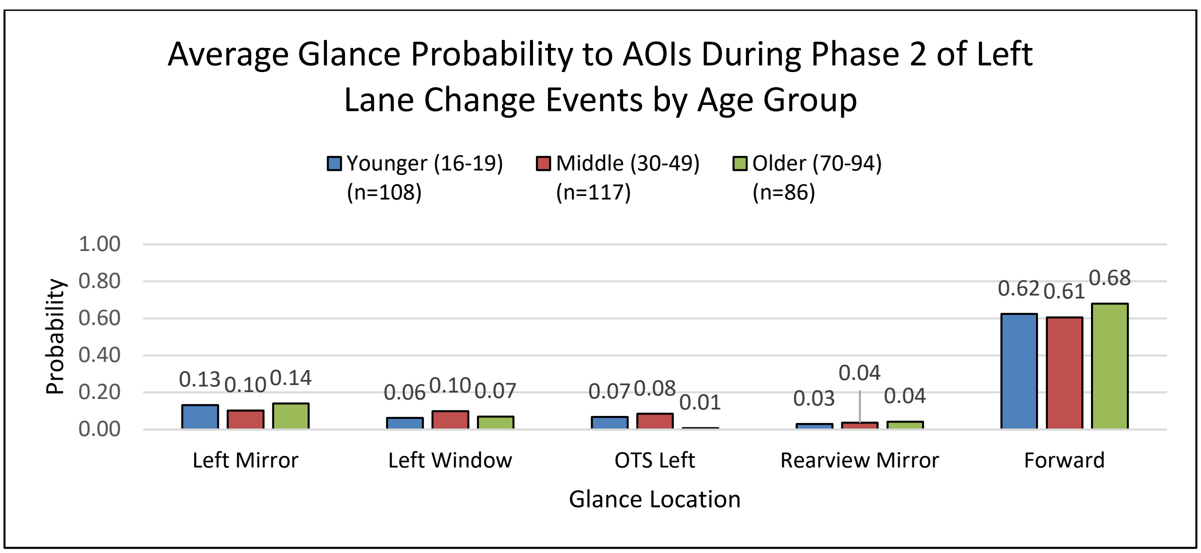


Figure 22. Chart. Average glance probability during Phase 2 of uninterrupted left lane changes.

Average glance probabilities for Phase 2 of right lane changes are presented in Figure 23 below. The probabilities showed that right window/mirror and rearview mirror locations yielded the highest probabilities of the AOIs. Older drivers showed the greatest glance probability to the right window/mirror of the age groups (0.13) versus 0.09 for younger and 0.11 for middle-aged drivers. The distributions of glance probabilities for the rearview mirror were nearly identical across the three age groups (a range of only 0.01). Of note is also the OTS location. Older drivers showed the lowest probability of the three groups (0.02 versus 0.06 for both the younger and middle-aged drivers).

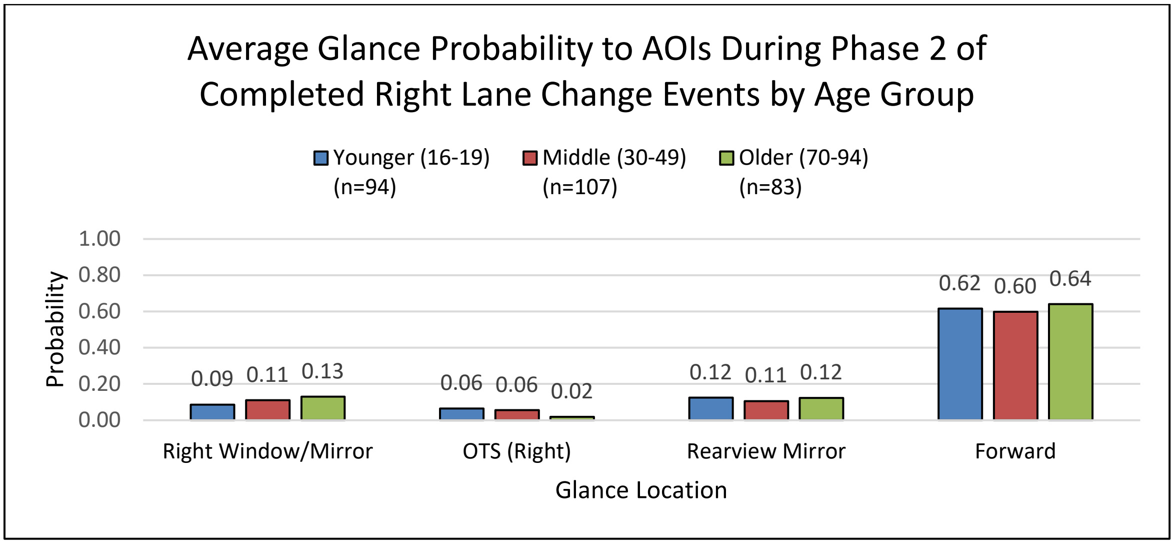


Figure 23. Chart. Average glance probability during Phase 2 of uninterrupted right lane changes.

Entropy

Glance entropy describes the degree of dispersion in a participant's glances as the participant completes the lane change maneuver. The overall level of entropy, or glance dispersion, is shown by age group and lane change phase collapsed by lane change direction (see Figure 24). The glance dispersion results showed a lower level of dispersion for older drivers in each of the three phases. Additionally, younger drivers had an increased level of dispersion relative to middle-aged drivers for Phase 1 and Phase 3; however, the trend was reversed in Phase 2. During Phase 2, middle-aged drivers had the greatest glance dispersion of the age groups.

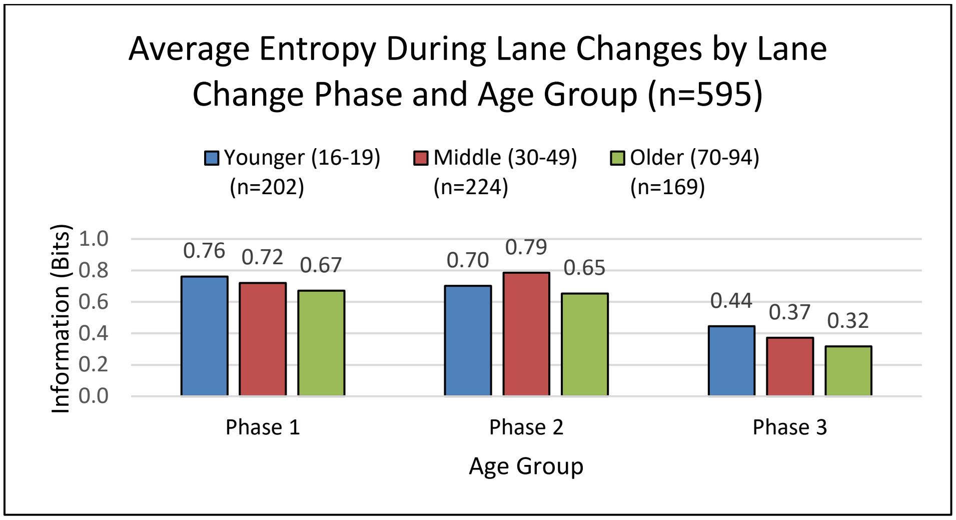


Figure 24. Chart. Average entropy during uninterrupted lane changes.

Errors

Glance Errors

The frame-by-frame glance reduction allowed the authors to derive several possible glance errors from the data. The authors analyzed three types of errors: failure to perform a side mirror check prior to lane change initiation, failure to perform an OTS glance prior to lane change initiation, and failure to activate the turn signal prior to lane change initiation. Errors were treated as binary; either no glance/turn signal activation was made (an error of omission) or a glance/turn signal activation was made (no error) to the location of interest.

Results for uninterrupted lane changes showed that a high percentage of participants failed to perform a side mirror check prior to initiation of the lane change. The authors identified two infrastructural factors that may have afforded the driver a safe lane change without the need for a side mirror check: (1) at the point of lane change initiation, the destination lane was not yet present (new lane forming); (2) when moving from a through lane to an upcoming turn lane (did not yet exist). These lane change events were removed from the analysis (176 events or about 30% of lane change events were excluded). Figure 25 shows the distribution of side mirror check errors during uninterrupted lane changes. Overall, error rates were above 50% for each age group (and direction) except for middle-aged drivers performing a lane change to the left (43%).

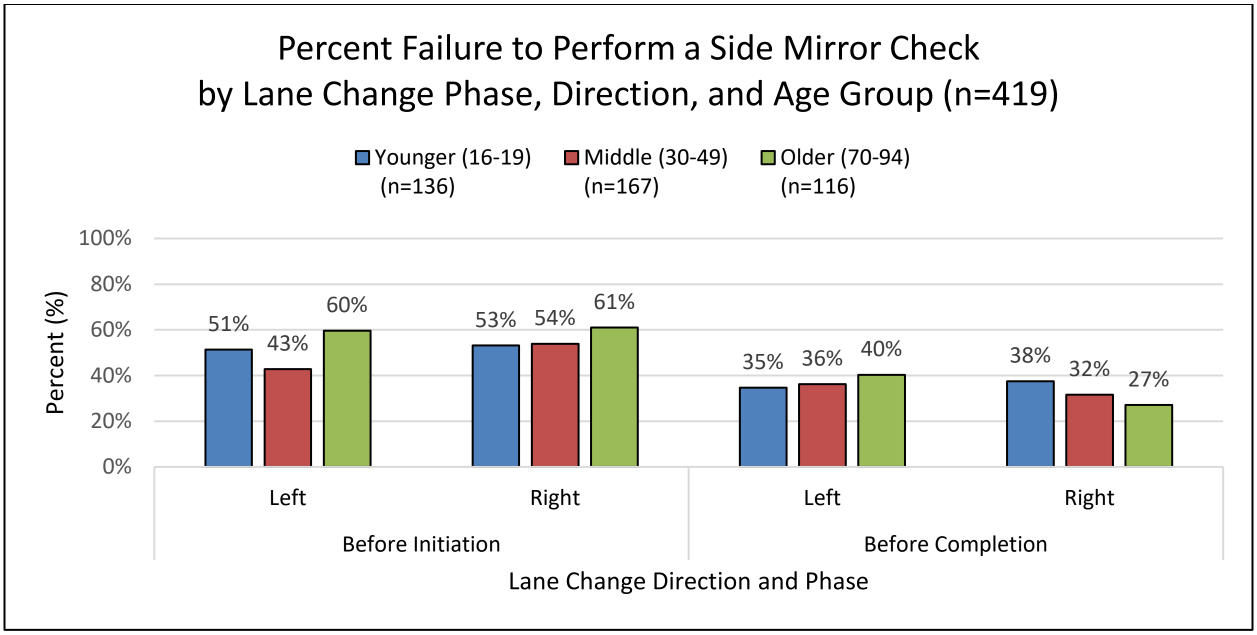


Figure 25. Chart. Percentage failure to perform a side mirror check prior to initiation error.

A very similar analysis for OTS glances was completed as the side mirror check analysis presented above. Overall, each age group showed a very high percentage of lane change events where no OTS glance was executed (see Figure 26). The distribution of failed OTS glances was similar between left and right lane changes. Older drivers showed a higher percentage of side mirror errors for the left (98%) than the right (92%), a trend also seen with younger drivers (86% left and 84% right). Middle-aged drivers, however, showed a slightly elevated error rate to the right (82%) than to the left (80%).

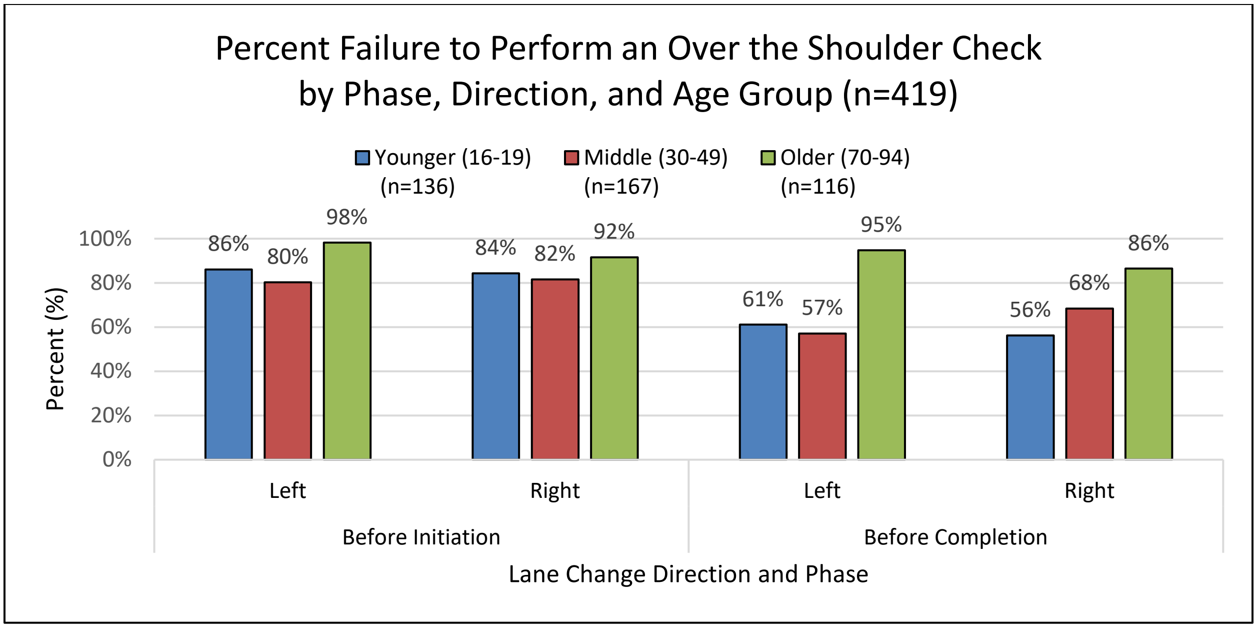


Figure 26. Chart. Percentage failure to perform OTS glance prior to lane change initiation error.

Turn Signal Errors

Fifty-three percent of younger and middle-aged drivers failed to activate the turn signal prior to initiating their lane change. Older drivers showed a higher rate of turn signal activation omission: 60% of their lane changes did not include a signal activation prior to initiating the lane change (see Figure 27). Appendix E shows a breakdown of turn signal activation by phase for each age group.

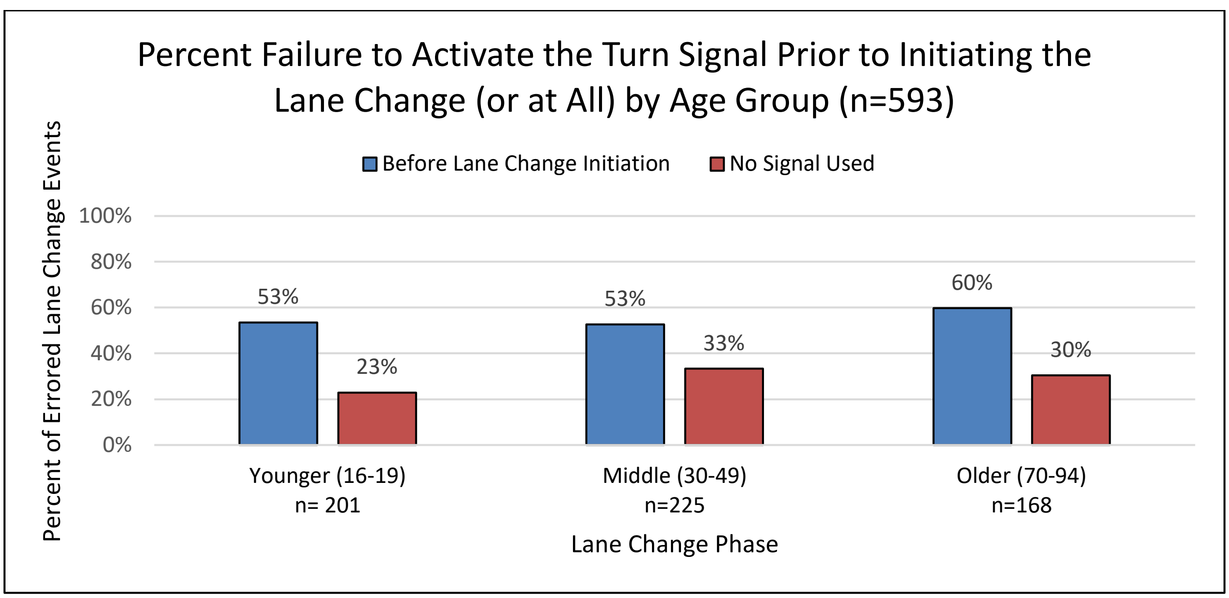


Figure 27. Chart. Turn signal activation prior to initiation of lane change for uninterrupted lane changes.

Improper Spacing Errors

As part of the reduction process, a subjective assessment of cutting-off was attributed to the lane change events by the reductionist. Assessments were based primarily on two factors: (1) hard braking (or other obvious evasive maneuver) from the trailing vehicle in the destination lane and (2) the subject vehicle initiated a lane change maneuver when it was within one car length of the trailing vehicle in the destination lane. Note that all events (in the entire reduction, not just this question) were subject to a quality control process where an additional trained reductionist corroborated all answers. Appendix F shows a breakdown of cut-off behavior by age group. Most of the uninterrupted lane change events did not involve the driver cutting off another vehicle (see Table 4).

Table 4. Percentage of uninterrupted lane change events where driver cut off a trailing vehicle in the destination lane.

Age Group	Did Not Cut Off	Cut Off	Unable to Determine
Younger (16–19)	87%	2%	12%
Middle-Aged (30–49)	88%	1%	11%
Older (70–94)	90%	0%	10%

Environmental Factors

Traffic Density

As part of the reduction process, the level of traffic flow or density was noted. Traffic density takes into account the number of cars, whether they impact the speed and maneuverability of the participant's vehicle, and following distance. A number of objective factors are taken into account to assess level of service. These include the number of cars visible, the distance to those cars, and the number of lanes.

Figure 28 shows an approximately normal-like distribution of uninterrupted lane changes by traffic density (note that traffic density increases as the *x*-axis moves from left to right). Half of all uninterrupted lane changes occurred when traffic density was such that some restrictions to traffic flow existed. Percentages did not differ greatly by age group.

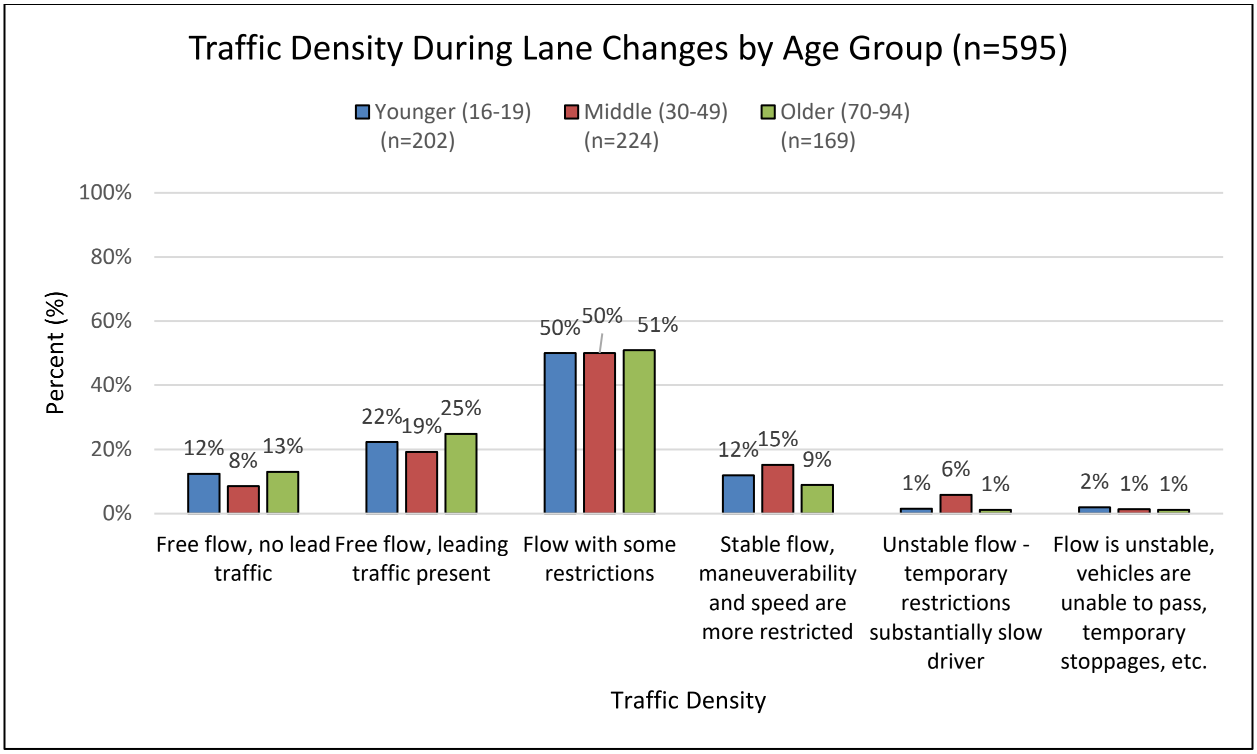


Figure 28. Chart. Traffic density by age group for uninterrupted lane changes.

Figure 29 shows the distribution of crashes associated with uninterrupted lane changes by traffic density. Older drivers had an elevated crash rate in free-flow traffic (50%) compared to moderate traffic density (38%). A review of the data for crashes occurring in free-flow traffic showed that 3 of the 4 events involved striking a curb/median. On the high end of moderate levels of traffic density (where maneuverability and speed are somewhat restricted), older drivers were involved in far more crashes than younger (14%) and middle-aged drivers (0%). For younger and middle-aged drivers, nearly all crashes occurred during low to moderate levels of traffic density.

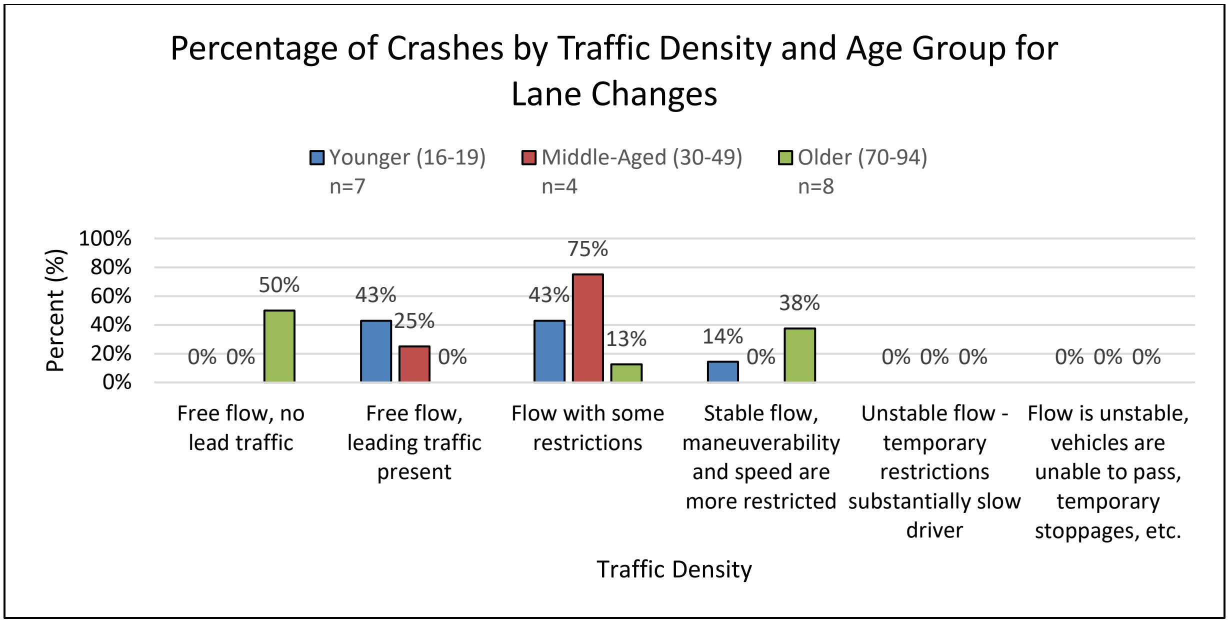


Figure 29. Chart. Percentage of crashes by traffic density for uninterrupted lane changes.

The distribution of near-crashes is presented in Figure 30 below. The majority of near-crashes happened in moderate levels of traffic flow; that is, where flow had some restrictions (48% to 65%). Of interest is that given the higher number of near-crashes (144), a normal-like curve to the distribution is revealed, with the prevalence of near-crashes becoming smaller as the traffic density either becomes less dense or more dense from the moderate levels.

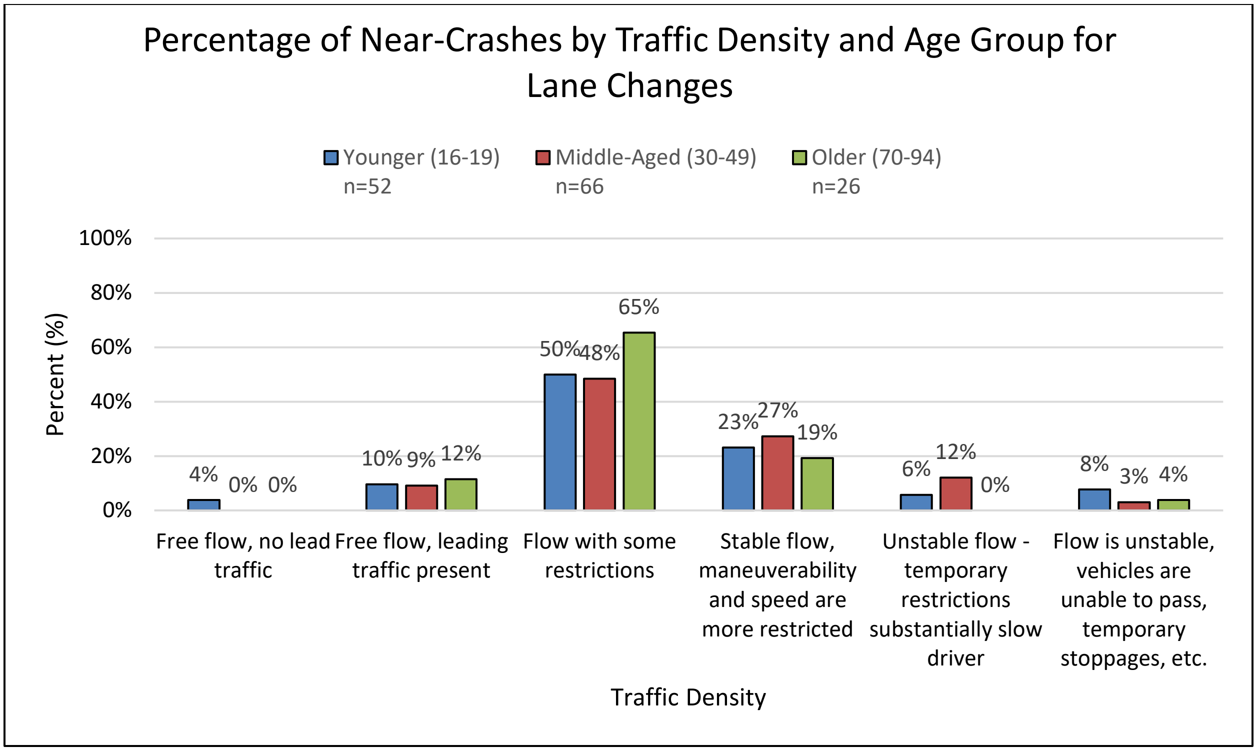


Figure 30. Graph. Percentage of near-crashes by traffic density for uninterrupted lane changes.

Conflict Type

As noted previously, ~73% of lane change events were baseline samples, while the remaining 27% were an SCE (either a crash or near-crash). Those SCE events were used in a subsequent analysis to determine the type of conflict present. Note that these events were only included in the uninterrupted lane change analyses presented above when the lane change was unaffected by the following SCE. The catch-all category of "other" below included events such as changing a lane and hitting debris in the roadway or a run-off-road crash.

Figure 31 shows the distribution of conflict type. The vast majority of events occurred where a leading vehicle was already in or incurring into the destination lane. For middle-aged drivers, 12% of conflicts involved an adjacent vehicle in or incurring into the destination lane, whereas younger and older drivers did not experience any of those events.

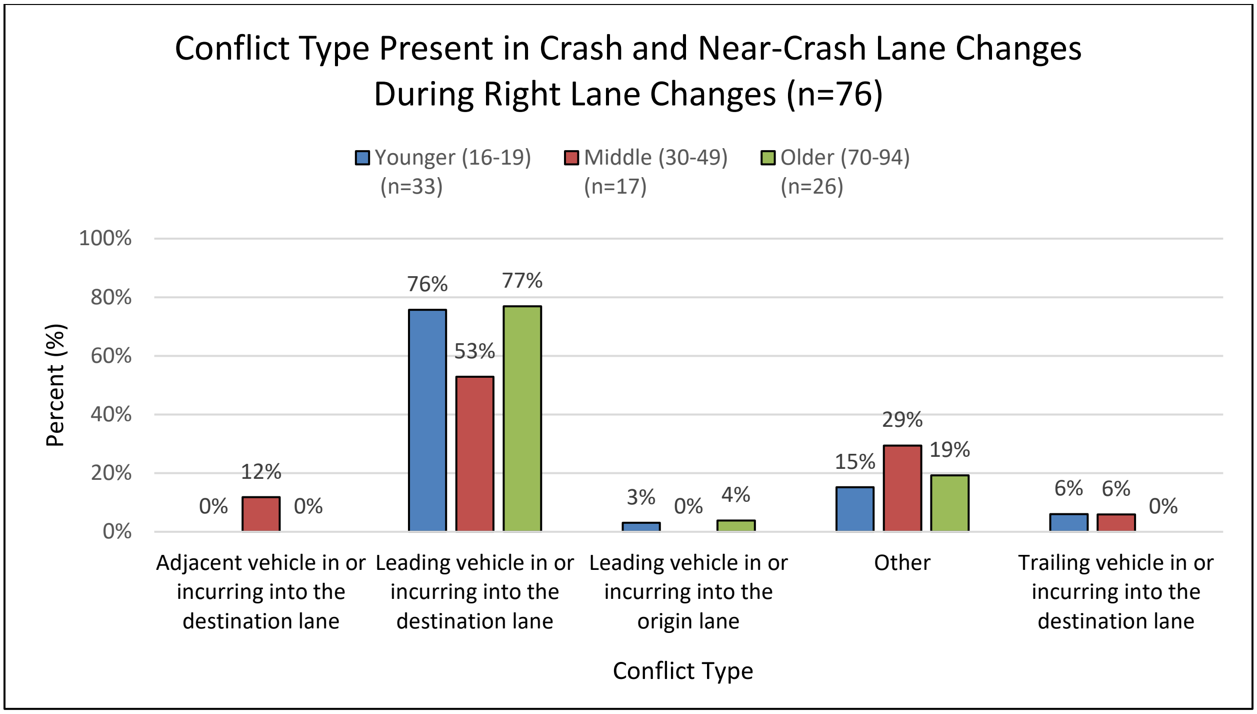


Figure 31. Chart. Conflict type by age group for uninterrupted right lane changes.

Left lane changes showed a very similar predominance of conflicts with a lead vehicle in or incurring into the destination lane. Younger drivers experienced 74% of their conflicts in this category but middle-aged drivers only 53% (see Figure 32). Conflicts in the "other" category were very similar between left and right lane changes, with a small increase in conflicts for trailing vehicles in or incurring into the destination lane, particularly for middle-aged and older drivers (6% to 12% and 0% to 9%).

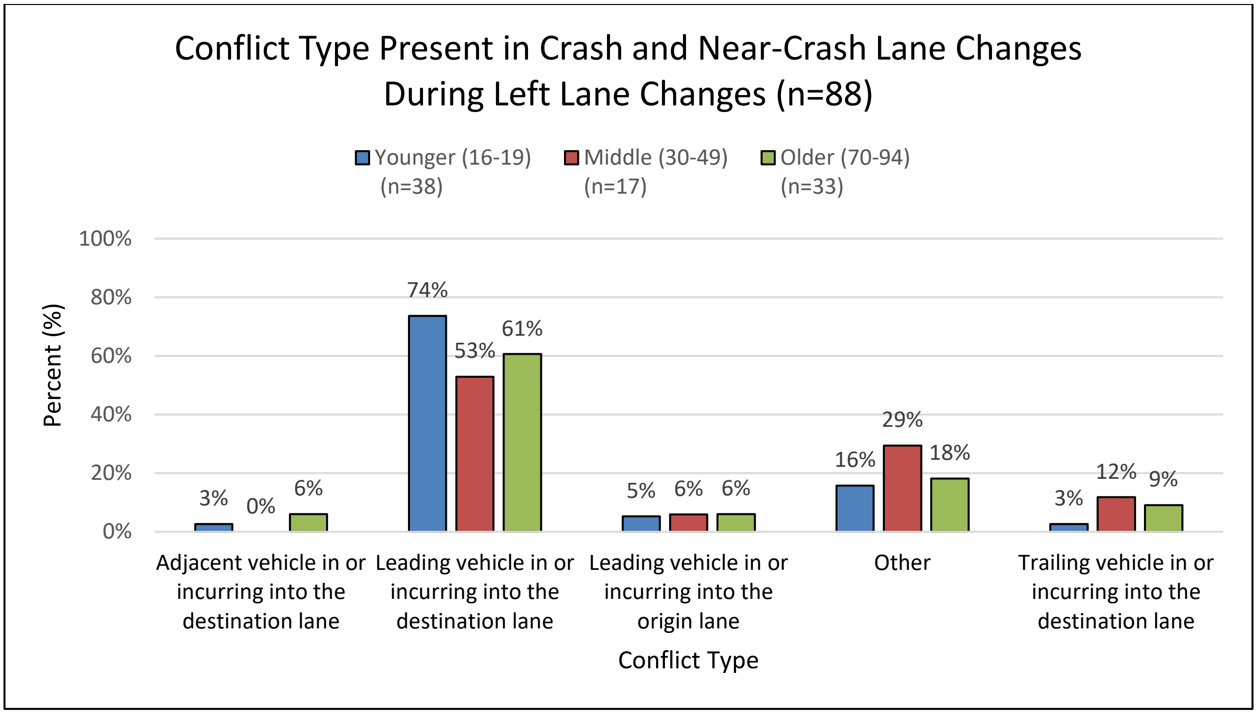


Figure 32. Chart. Conflict type by age group for uninterrupted left lane changes.

Secondary Task Engagement

Secondary task engagement was recorded as part of the data reduction process. Evidence of secondary tasks was investigated from 5 seconds prior to lane change initiation through the duration of the lane change maneuver. Secondary tasks cover a variety of tasks from dialing a phone and eating to conversing with a passenger. For the sake of these analyses, tasks were grouped into similar categories for simplification (cell phone use, talking/singing, eating, hygiene, and other).

During uninterrupted lane changes, younger drivers were more likely to engage in a prior (51%) and concurrent (52%) secondary task. Older drivers were least likely in both categories (28% prior and 23% concurrent) to engage in a secondary task (see Figure 33). A breakdown of types of secondary tasks and percentage of participant engagement can be seen in Appendix G.

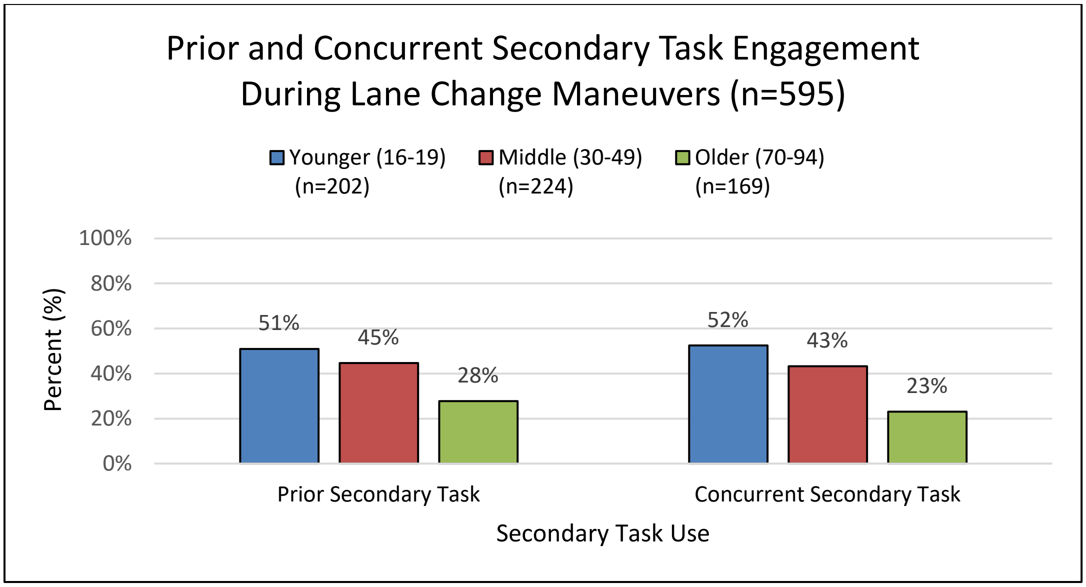


Figure 33. Chart. Secondary task engagement both prior to and during the uninterrupted lane change maneuver.

Discussion and Conclusions

Glance Characteristics

Across the various metrics calculated for glance behavior during lane changes, a similar pattern arose for all of them: drivers relied on side mirrors and the rearview mirror to determine when it was safe to initiate a lane change. When drivers did glance to the various AOIs, they usually did so only once or twice within a given phase (the highest number of glances within a phase was five glances in three events to the forward location). Glances to these locations ranged from ~0.3 seconds to 0.8 seconds, and glances to AOIs (outside of the forward location) were a relatively small proportion of both time and total glances directed during the lane change maneuver. Kiefer and Hankey (2008) showed similar glance durations: mean values of 613 ms to 694 ms with standard deviations ranging from 111 ms to 129 ms.

When comparing left lane changes to the right, we see that drivers spend more time, execute more and longer glances, and devote a greater proportion of glances to left lane changes than right lane changes across all three age groups. This may be due to simple geometry: we sit on the left side of the vehicle in the U.S.; thus it is more difficult (or it takes a sharper turn of the head-neck-shoulders) to determine if the lane is clear for intrusion when looking to one's left compared with to one's right (see Figure 34).

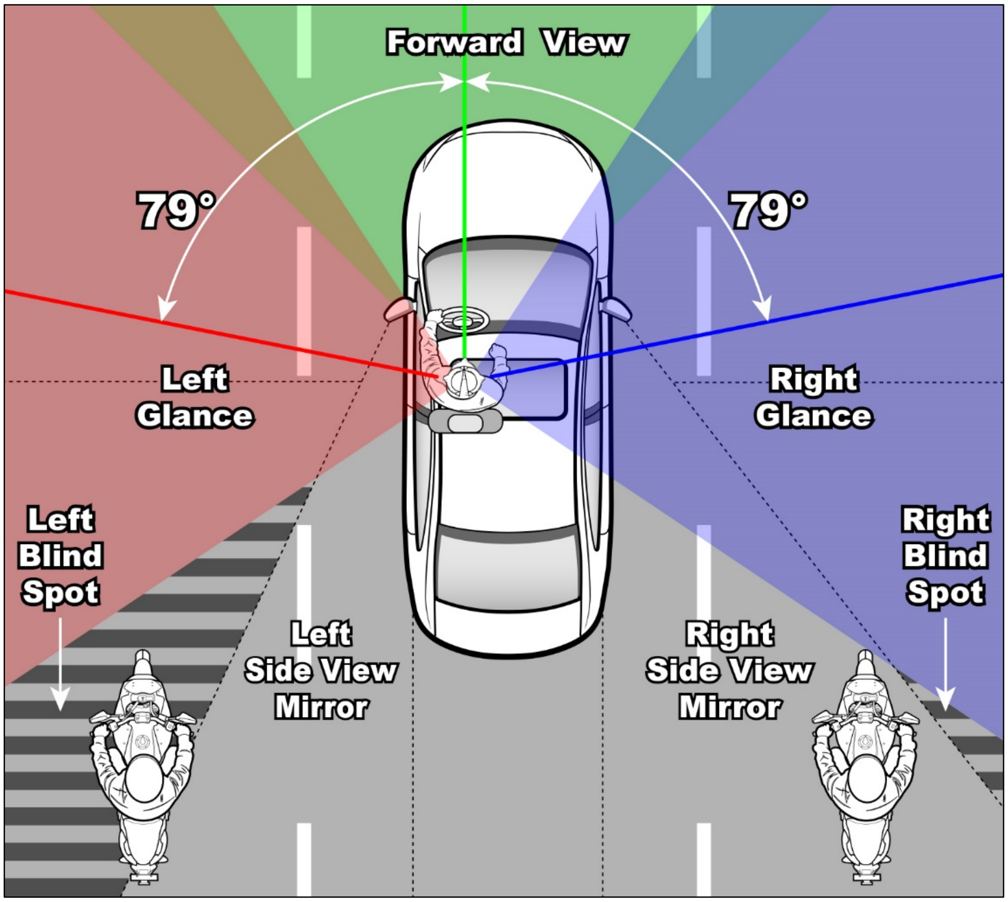


Figure 34. Diagram. Figure showing unequal blind spot size given an equal average head rotation of 79 degrees for middle-aged drivers as reported in Swinkels and Swinkels-Meewisse, 2014.

We also see a greater reliance on the rearview mirror during right lane changes compared with left lane changes across phases. Tijerina, Garrott, Stoltzfus, and Parmer (2005) similarly observed a high transitional glance probability between the rearview and right mirrors during right lane changes. Why drivers use the rearview mirror more for right lane changes is not known. Perhaps the greater reliance could be as simple as exposure. Given that traffic law states that vehicles should drive in the rightmost lanes, any time drivers make a lane change to the left, they must check for approaching traffic from the rear. When making a maneuver back to the right, however, (assuming the subject vehicle passed a slower moving vehicle), the driver is only required to check either the side mirror or rearview mirror and monitor any traffic in front of the slower-moving vehicle. An OTS glance to the right is not required if the driver properly monitored for the presence of another vehicle. However, this would only apply if the right lane change was leading the subject vehicle back into the rightmost lane. If there are any other open lanes further to the right, an OTS glance may be required to properly assess the safety of the maneuver. While behavior can give insight into what the driver is attending to, we simply cannot know for sure whether the participant driver was appropriately attending to any additional traffic. Thus, for this project, we assumed an OTS glance was required for right lane changes as well as left.

Phase 1 and Phase 2 are arguably the most-important phases of the lane change: from the time prior to the initiation of the lane change until the vehicle begins to cross over the lane line. When comparing these phases, it is evident for left lane changes that the percentage of glances and percentage of time both show a modest increase in Phase 2 when compared to Phase 1 for both left and right lane changes. This suggests that drivers begin to allocate more time and more of their glances to the AOIs once they have *already begun* the lane change maneuver rather than prior to initiating the maneuver. Drivers are not typically checking for safe passage and then proceeding, but rather proceeding with the lane change and checking as the maneuver is underway. Glance durations to the forward roadway show a marked decrease from Phase 1 to Phase 2 as well—something necessary to allocate more time to other AOIs as required for a safe lane change. Of note, though, is drivers showed a greater decrease in glance duration to the forward roadway when making left lane changes (from ~3.7 seconds to 1.5 seconds) as compared to right lane changes (from ~3.6 seconds to 2.2 seconds).

Entropy

Older drivers showed a lower overall level of glance dispersion during Phase 1 and Phase 2 of uninterrupted lane changes relative to younger and middle-aged drivers (see Figure 24). The degree of decrement, however, is minimal. Older drivers are often assumed to have less physical flexibility than the younger and middle-aged. Using the SHRP 2 physical questionnaire, the presence of “limited flexibility” or “severe arthritis” was assessed. A quick analysis showed very few drivers experienced limited flexibility (2.2%) or severe arthritis (2.3%).

The finding that older drivers showed lower entropy in our analyses is consistent with previous findings (Bao and Boyle, 2009; Lavalliere, Teasedale, Tremblay, Ngan, Simoneau, and Laurendeau, 2007; and Lavalliere, Laurendeau, et al., 2011). Bao and Boyle showed that during an on-road drive, younger (18–25) and older adults (65–80) exhibited lower entropy levels (glance dispersion) than their middle-aged (35–55) counterparts when progressing through intersections. While the process to traverse an intersection is different from changing lanes, one can imagine a similar need to gather information from a variety of sources and locations to proceed safely.

Lavalliere Teasdale, et al. (2007) showed that older drivers (65–85) directed a decreased number of glances to the side mirrors and OTS glance locations relative to younger drivers (21–31) during a simulated drive. In a study similar to their 2007 work, Lavalliere, Laurendeau et al. (2011) again investigated glance behaviors of older drivers (65–75) in a simulated environment. They found a reduced frequency of glances to the rearview mirror and blind spot for the lane changes when compared with younger (21–31) drivers. When taking the 2008 and 2011 study together, the result of fewer glances (relative to younger drivers) is likely an overall decreased level of entropy for older drivers.

However, the findings from the SHRP 2 physical questionnaire showing that a small percentage of drivers experienced limited flexibility are inconsistent with those of Isler, Parsonson, and Hansson (1997). They evaluated age-related restrictions of head movements and found that the oldest adults (70+) had lost about one-third of the range of motion compared to the younger age groups. They also note that the loss of head rotation was common in many of the drivers in the two oldest age groups (60–69 and 70+). We would expect that if we found the same rate of mobility concerns, the entropy values would likely be at least partially explained by them. However, the difference in entropy results taken with the small percentage of drivers with physical restrictions noted above suggests the lack of OTS glances is either not a primarily a flexibility issue for older drivers or that the flexibility measures employed in the SHRP 2 NDS did not accurately capture any differences. It is also possible that the self-reported measures of mobility were biased, with individuals failing to provide fully accurate data.

Additionally, younger drivers showed a higher level of glance dispersion in Phase 1 than their middle-aged and older counterparts, but slightly decreased levels during Phase 2, suggesting that perhaps younger drivers are more likely to start gathering glance information prior to lane change initiation than once they have begun the maneuver. Middle-aged drivers, however, showed increased glance dispersion (minor) in Phase 2 compared to Phase 1, suggesting they wait until later in the maneuver to gather their glance information (see Figure 24).

Errors

Three main types of errors were evaluated: glance-based errors, turn signal errors, and cut-off errors. Results from each are discussed below.

Glance-Based: Results showed that 43% to 61% of drivers failed to direct a glance to the side mirror location (left for left lane changes and right for right lane changes) prior to initiating a lane change maneuver. While all three age groups had similar results, older drivers were the most likely of the age groups to fail to make a side mirror check prior to initiation; however, they were equally likely to make a side mirror check at *some point* during the maneuver. This suggests that for all age groups, but particularly for older drivers, there is a failure to check the side mirror prior to initiating the lane change, but half to three-quarters do make a side mirror check at some point prior to finishing the lane change (see Figure 25). Taken together, these results suggest that there are still several instances of drivers failing to make a side mirror check prior to initiation of the lane change. If a side-mirror check is included *after* lane-change initiation, it may be useful, but not ideal.

Our results are consistent with Kiefer and Hankey (2008). They found that middle-aged (40–50) and older adults (60–70) used the side mirror 49% of the time for right lane changes and 42% for left lane changes. These values were calculated during the “planning phase” of the lane change, defined as the first obvious sign of driver intent to change lanes until the initiation of the lane change.

Overall, failures to direct an OTS glance prior to initiation of the lane change are high. Prior to initiation of the lane change for uninterrupted lane changes, 64%+ of drivers across all age groups failed to make an OTS glance check. While these numbers decrease for younger and middle-aged drivers when including OTS glance checks made *after* initiation, the values are still quite elevated (particularly for middle-aged drivers and older drivers—that is, younger drivers are more likely to direct an OTS glance after initiation—see Figure 26). Our results are consistent with those presented in Kiefer and Hankey (2008), and Tijerina et al. (2005). Kiefer and Hankey (2008) showed that between 69% of left lane changes and 85% of right lane changes occurred in the absence of an OTS glance during the planning phase (collapsed across age group). Tijerina, et al. (2005) showed similar results as well. During an on-road drive in an instrumented vehicle, drivers (aged 20–60) negotiated a test route. During the test drive, participants failed to direct an OTS glance 59% of the time for left lane changes and 81% of the time for right lane changes. Tijerina et al. (2005), however, described the decision phase of the lane change as the 10 seconds prior to the lane change maneuver, different from our study and that of Kiefer and Hankey (2008). While the data did not include older drivers, the values presented are similar to those found in our study.

Turn Signal Use: Our results were similar to Staplin et al. (1998), which showed that drivers failed to activate their turn signal before 53% to 60% of all uninterrupted lane changes. While 67% to 86% of drivers used a signal at some point during the lane change, this still leaves a number of instances where no turn signal was activated at all, let alone prior to initiating the lane change (see Figure 27). Of note is the lack of observed wrong direction turn signal activation (e.g., signaled left but made a right lane change) occurring with older drivers. The researchers suspect that some amount of turn signal misuse may be present for the older drivers, but this effort failed to find any.

Kiefer and Hankey (2008), however, found that 22% of right lane changes and 23% of left lane changes occurred in the absence of turn signal activation during the planning phase. While the glance-based errors above are similar to our results, the turn signal results differ substantially. Our participants showed at least twice the frequency of lane changes occurring in the absence of turn signal activation. One thing to note is that in our study, including turn signal activation in Phase 2 dramatically increases compliance; however, both Kiefer and Hankey (2008) and our study evaluated turn signal activation *prior* to lane change initiation.

Environmental Factors

Traffic Density: The prevalence of lane changes occurring by level of traffic density resulted in a distribution mimicking a bell curve; that is, most uninterrupted lane changes occurred in moderate levels of traffic density with decreasing numbers as traffic density either increased or decreased (see Figure 28). The resulting normal-like curve shows that drivers may have very little need to change lanes when the traffic density is low (except perhaps to prepare for an upcoming turn or off-ramp) and yet are perhaps restricted too much in making lane changes when traffic density is high. Moderate levels of traffic density showed the greatest percentage of overall lane changes; that is, when there was enough traffic to warrant lane changes but not so much that it greatly restricted freedom of movement.

Conflict Type: The results showed a common theme between both left and right lane changes: that conflict with a *leading* vehicle in (or incurring into) the destination lane was the greatest source of conflict for drivers. When thinking about potential sources of conflict for a lane change maneuver, the commonly associated threats involve vehicles to the sides and rear of the vehicle (i.e., in the blind spots). However these results showed that while drivers allocated more attention to the side and rearview mirrors, less attention was allocated to the scene in front of them. This could be presented as a trade-off. As a driver allocates more attentional resources to adjacent and rearward threats, fewer resources are left to attend to the forward location resulting in increased risk. By attending to the expected location of conflict, drivers allow an increased risk from a less likely direction.

CHAPTER 5. PART B – INTERRUPTED LANE CHANGE RESULTS

GLANCE CHARACTERISTICS

Percentage of Time

Figure 35 presents the percentage of time glancing to AOIs for interrupted left lane changes by phase. Overall, older drivers relied on the left mirror more than younger and middle-aged drivers during Phase 1 (17% vs. 5% for younger and 10% for middle-aged) and Phase 2 (23% vs. 6% for younger and 18% for middle-aged). Younger drivers, however, showed a greater reliance on the OTS location during Phase 2 with a much higher percentage of time (11%) when compared with middle-aged (4%) and older drivers (3%). Younger drivers glanced to the forward location for a greater percentage of time (71%) than the other two age groups (middle-aged 62% and older drivers 65%).

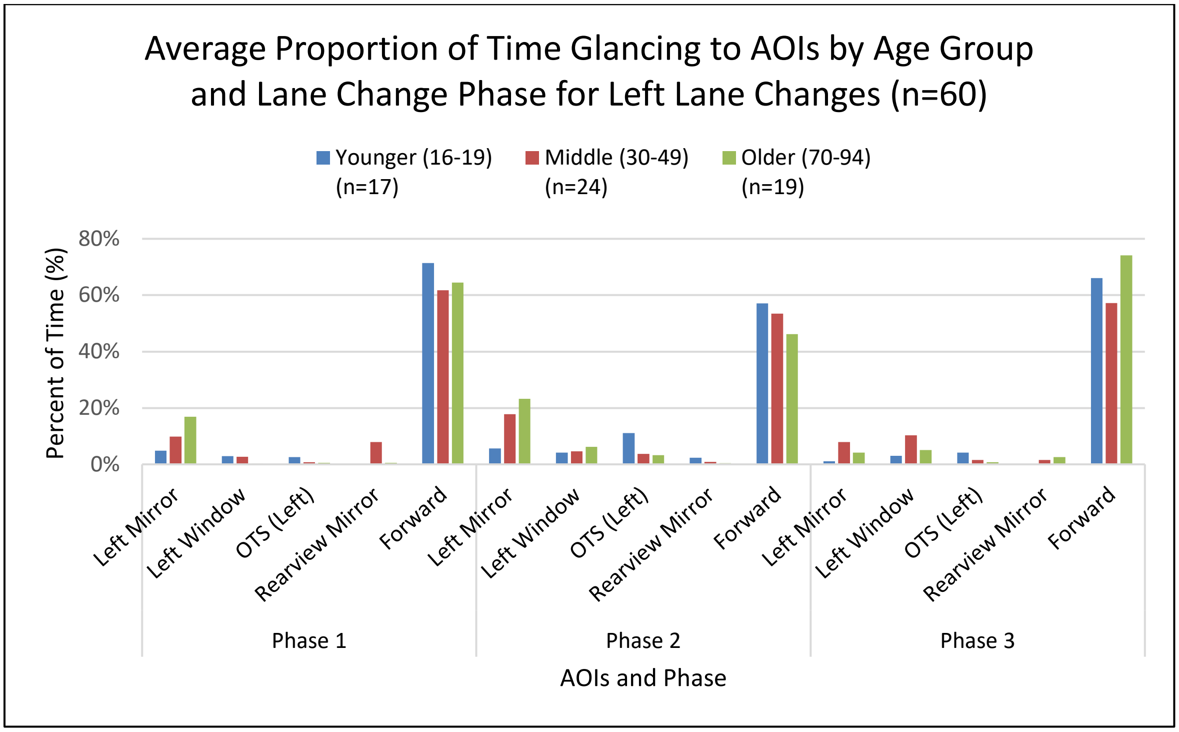


Figure 35. Chart. Percentage of time glancing to AOIs by age group and lane change phase for interrupted left lane changes.

The percentage of time glancing to various AOIs during Phase 1 of interrupted left lane changes shows a trend by age group for the left mirror. While younger drivers only glanced 5% of the time to this location, middle-aged drivers glanced 10% of the time and older drivers 17% (see Figure 36). Additionally, the time spent glancing to the rearview mirror for middle-aged drivers is 8% but 0% and 1% for younger and older drivers. During Phase 1, younger drivers also showed a greater percentage of their time glancing to the forward roadway (71%) than middle-aged (62%) and older drivers (65%).

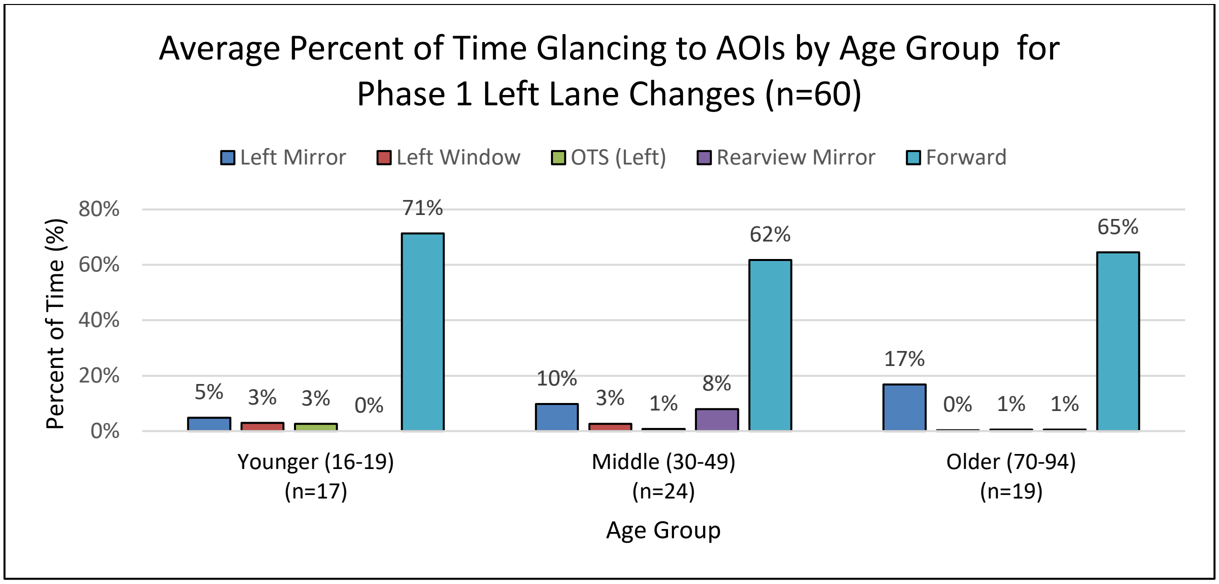


Figure 36. Chart. Percentage of time glancing to AOIs by age group for Phase 1 of interrupted left lane changes.

During Phase 2 of interrupted left lane changes, the same trend from Phase 1 for percentage of time glancing to the left mirror continued. Younger drivers glanced 6% of the time to the left mirror, while middle-aged drivers and older drivers glanced to that location a greater percentage of time (18% and 23%, respectively; see Figure 37). Younger drivers also spent a greater percentage of time on OTS glances: 11% versus 4% and 3% for middle-aged and older drivers. Of interest is that older drivers showed the least amount of time glancing to the forward roadway of the three age groups.

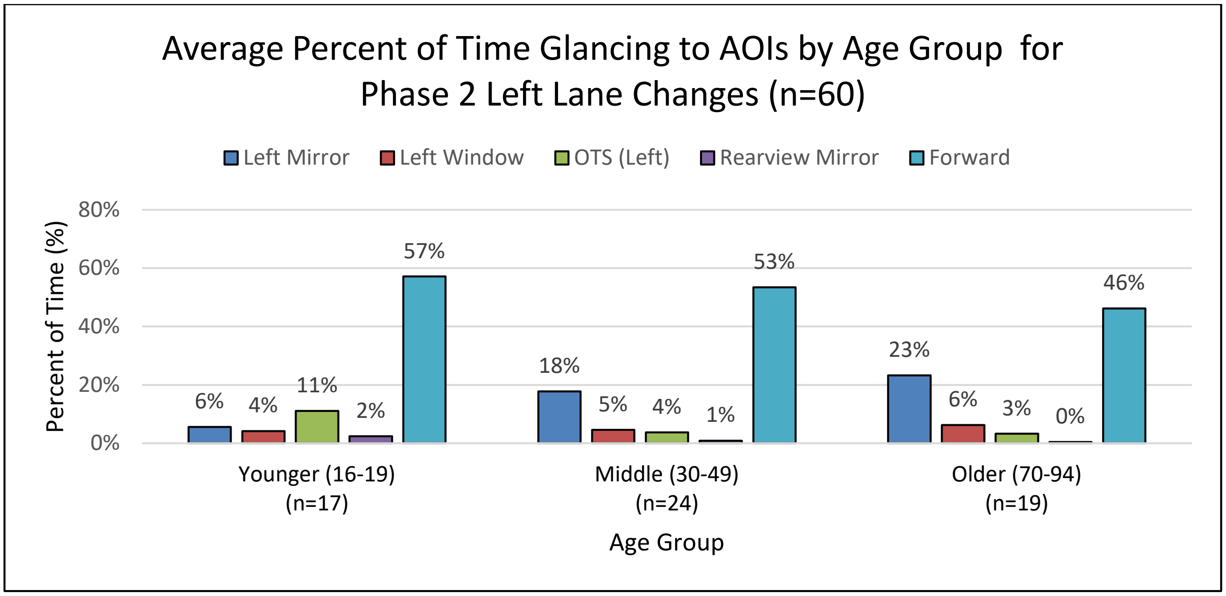


Figure 37. Chart. Percentage of time glancing to AOIs by age group for Phase 2 of interrupted left lane changes.

The average percentage of time that drivers glanced to the various AOIs across all three phases is presented in Figure 38. On average, middle-aged drivers showed a greater percentage of time glancing to the right window/mirror location during both Phase 1 and Phase 2. Middle-aged drivers also exhibited a smaller reliance on the forward location during Phase 1 relative to the other age groups.

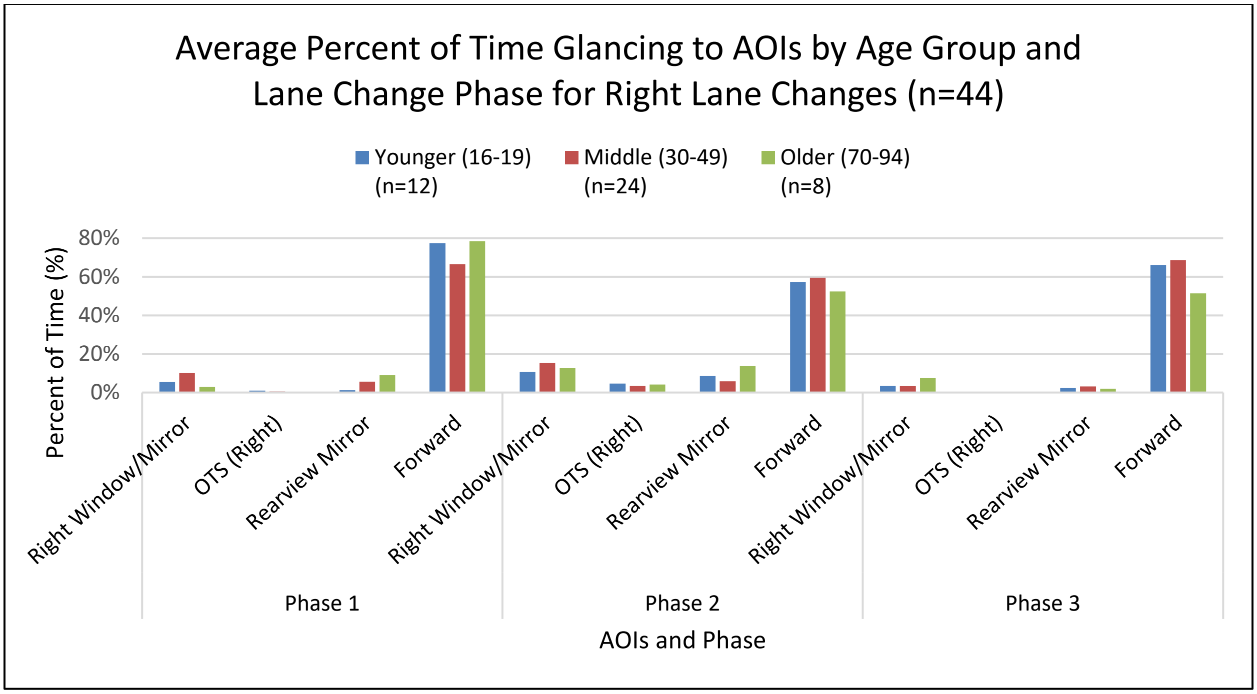


Figure 38. Chart. Percentage of time glancing to AOIs by age group and lane change phase for interrupted right lane changes.

During Phase 1 of interrupted right lane changes, middle-aged drivers spent the largest percentage of their glance time on the right window/mirror location (10%) compared to younger drivers (6%) and older drivers (3%). A lesser reliance on the forward location was evident for the middle-aged drivers. They only glanced 67% of the time to the forward roadway compared with 77% for younger drivers and 78% for older drivers. Also of note was the reliance on the rearview mirror. Older drivers glanced 9% of the time to the location versus 6% for middle-aged drivers and 1% for younger drivers.

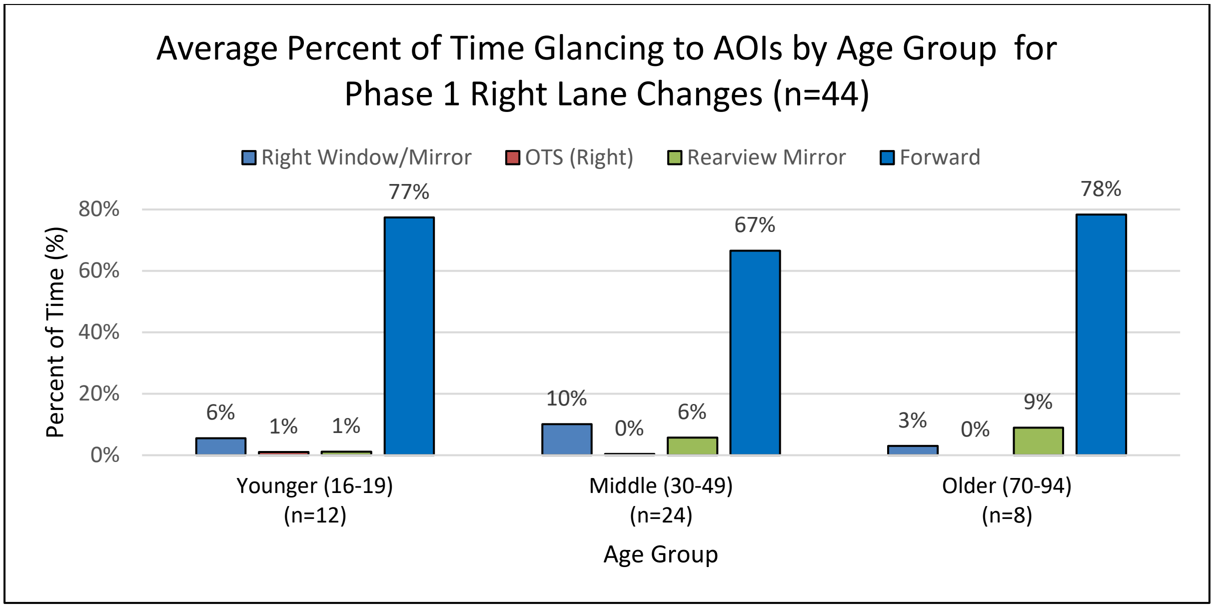


Figure 39. Chart. Percentage of time glancing to AOIs by age group for Phase 1 of interrupted right lane changes.

Phase 2 of interrupted right lane changes showed that middle-aged and older drivers glanced for a similar percentage of time to the right window/mirror (15% and 14% respectively) versus younger drivers who glanced to the right window/mirror 11% of their time (see Figure 40). The percentage of time for glances to the OTS locations remained very similar across age groups at 5%, 4%, and 4% for younger, middle-aged, and older drivers.

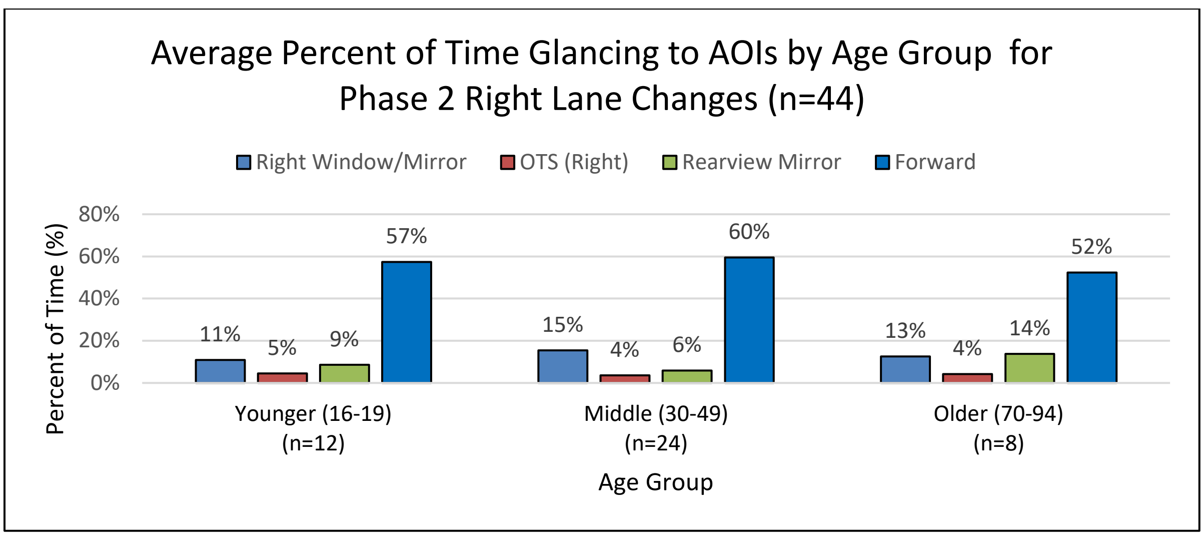


Figure 40. Chart. Percentage of time glancing to AOIs by age group for Phase 2 of interrupted right lane changes.

Percentage of Glances

Figure 41 below shows the percentage of glances to various AOIs by age group across all three lane change phases. Overall, drivers relied on the left mirror during Phase 1 and Phase 2 of the lane change with reliance increasing by increasing age group. However, middle-aged drivers showed a greater percentage of glances to the rearview mirror during Phase 1 (6%) than the others (younger drivers 0% and older drivers 2%).

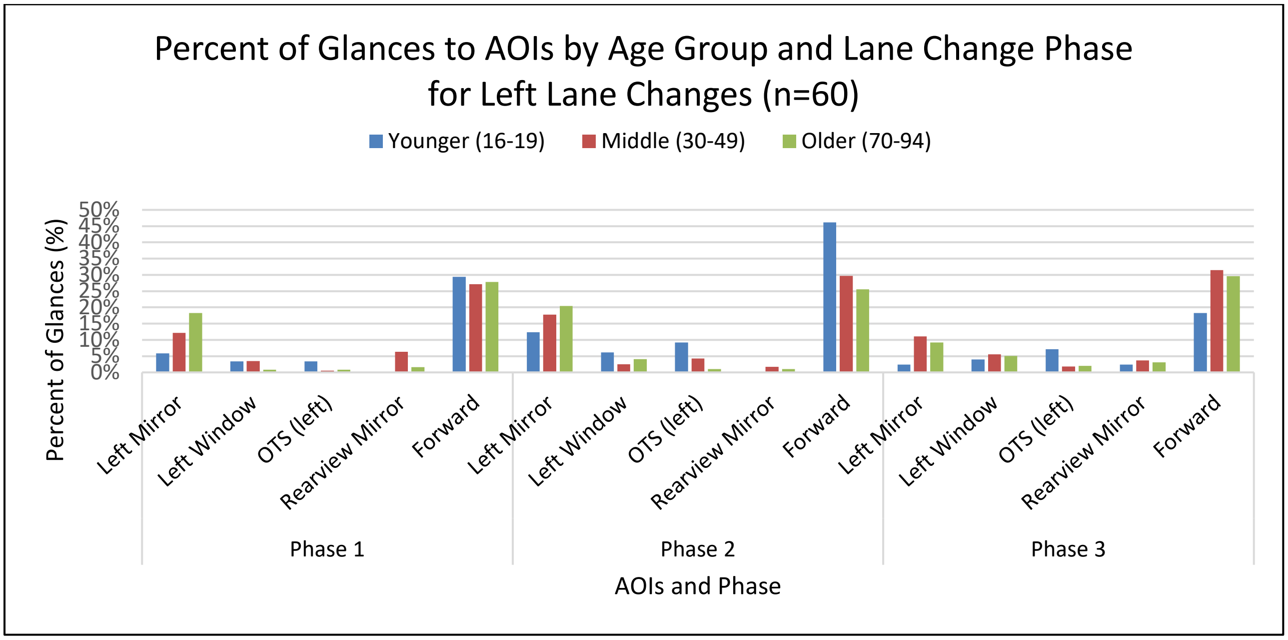


Figure 41. Chart. Percentage of glances to AOIs by age group and lane change phase for interrupted left lane changes.

The percentage of glances to AOIs for Phase 1 of interrupted left lane changes is shown in Figure 42. A trend can be seen showing that an increase in glances to the left mirror increases with age. Six percent of glances by younger drivers were to the left mirror compared to 12% and 18% for middle-aged and older drivers, respectively. Three percent of younger drivers' glances were to the OTS location but only 1% for both middle-aged and older drivers. Middle-aged drivers looked more to the rearview mirror (6% of glances) than younger drivers (0% of glances) and older drivers (2% of glances).

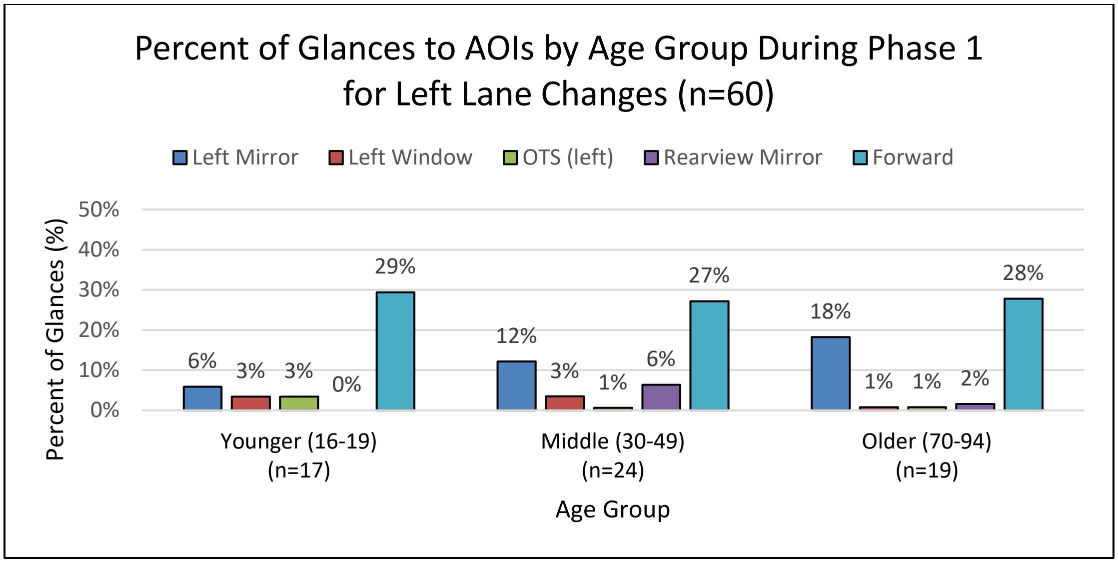


Figure 42. Chart. Percentage of glances to AOIs by age group for Phase 1 of interrupted left lane changes.

Phase 2 showed a similar trend of increased glances to the left mirror by age. While younger drivers performed 12% of their glances to the left mirror, middle-aged drivers directed 18% and older drivers 20% of their glances there (see Figure 43). Younger drivers glanced more to OTS locations (9% of glances) than the other age groups (4% for middle-aged and 1% for older). The percentage of glances to the forward roadway decreases with increasing age group; that is, younger drivers directed 46% of glances to the forward location while middle-aged drivers directed 30% of their glances and older drivers the least with 26%.

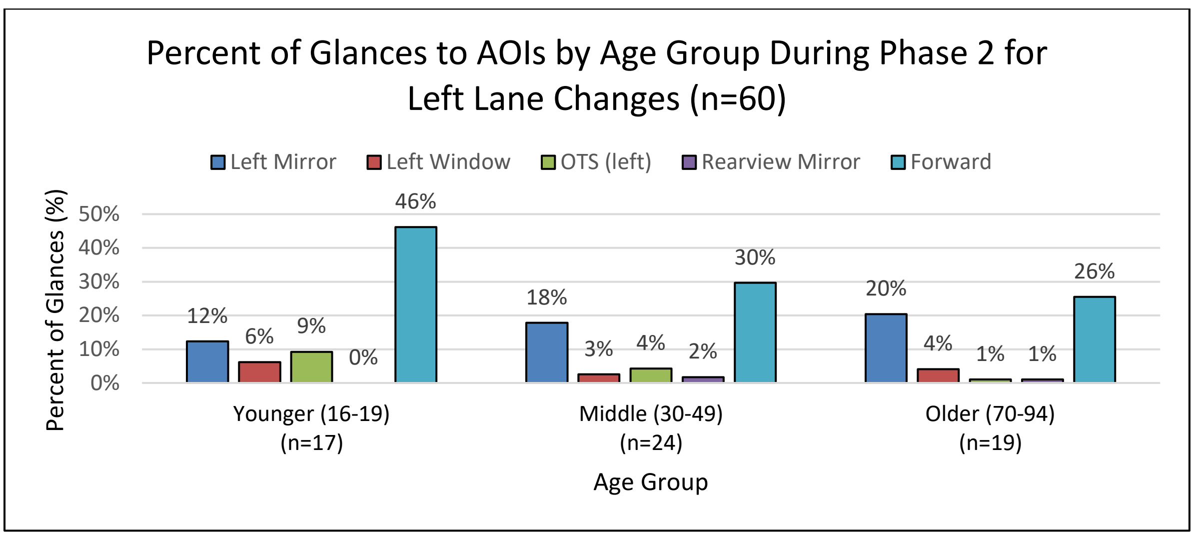


Figure 43. Chart. Percentage of glances to AOIs by age group for Phase 2 of interrupted left lane changes.

The overall percentage of glances to the AOIs by phase is presented in Figure 44. While the reliance on the right window/mirror location decreased with age during Phase 1, it was relatively consistent during Phase 2. During both phases, the reliance on the rearview mirror increased as age group increased.

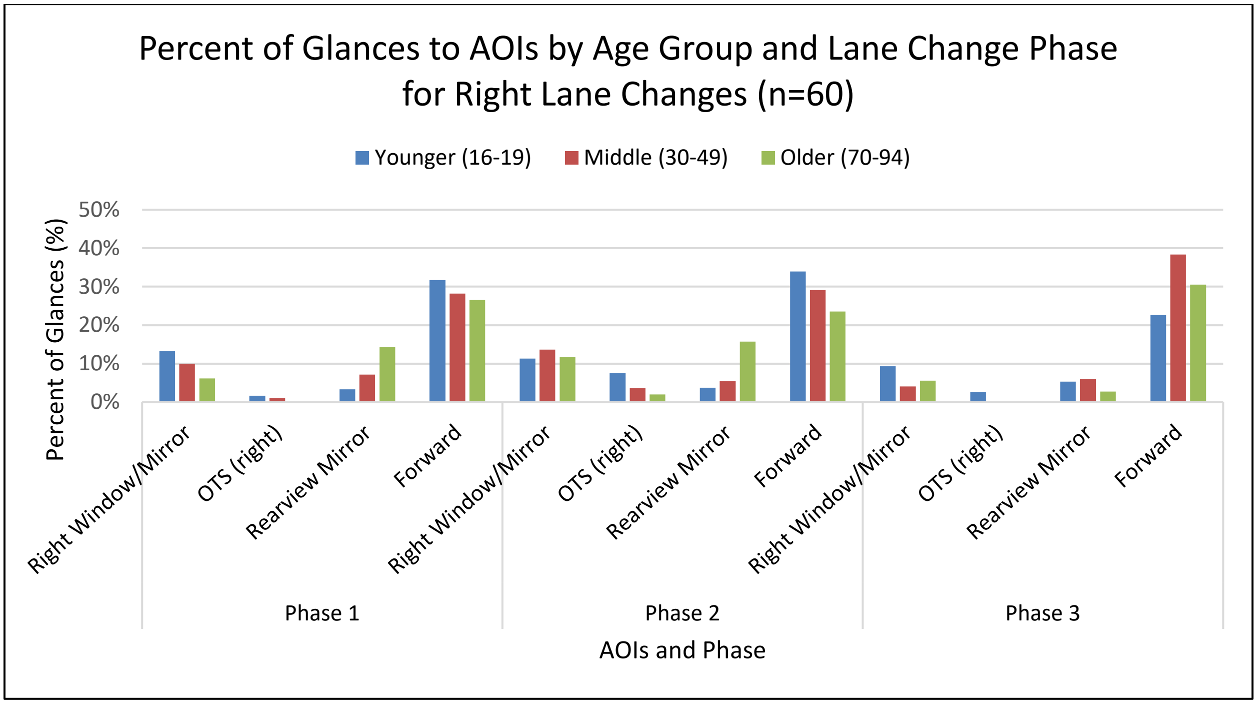


Figure 44. Chart. Percentage of glances to AOIs by lane change phase and age group for interrupted right lane changes.

The percentages of glances to various AOIs for right lane changes during Phase 1 are presented in Figure 45. Overall, younger drivers directed a greater percentage of glances (13%) to the right window/mirror compared to middle-aged (10%) and older drivers (6%). A trend in the opposite direction was revealed for the rearview mirror. Older drivers glanced more to the rearview mirror (14% of glances) than the other two age groups (3% for younger and 7% for middle-aged).

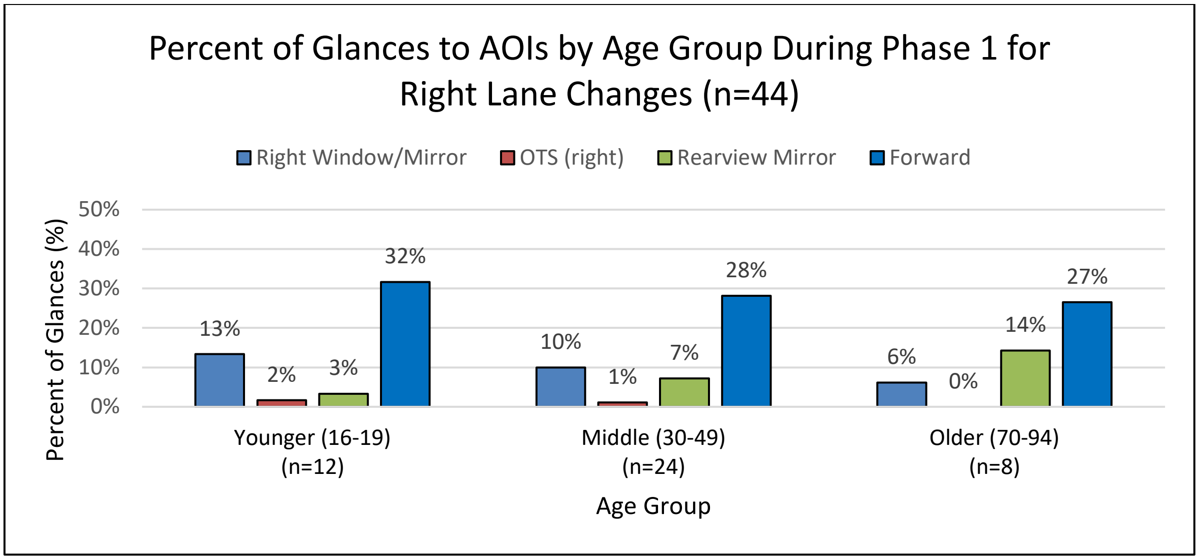


Figure 45. Chart. Percentage of glances to AOIs by age group for Phase 1 of interrupted right lane changes.

During Phase 2 of interrupted right lane changes, the percentage of glances directed to the rearview mirror was highest for older drivers (16%) versus only 4% for younger drivers and 5% for middle-aged drivers (see Figure 46). Younger drivers, however, directed more of their glances to the OTS location (8%) than middle-aged drivers (4%) and older drivers (2%). A decrease in the percentage of glances to the forward location is also revealed as age group increases. A greater percentage of glances were directed to the forward roadway for younger drivers (34%) than for middle-aged (29%) and older drivers (24%).

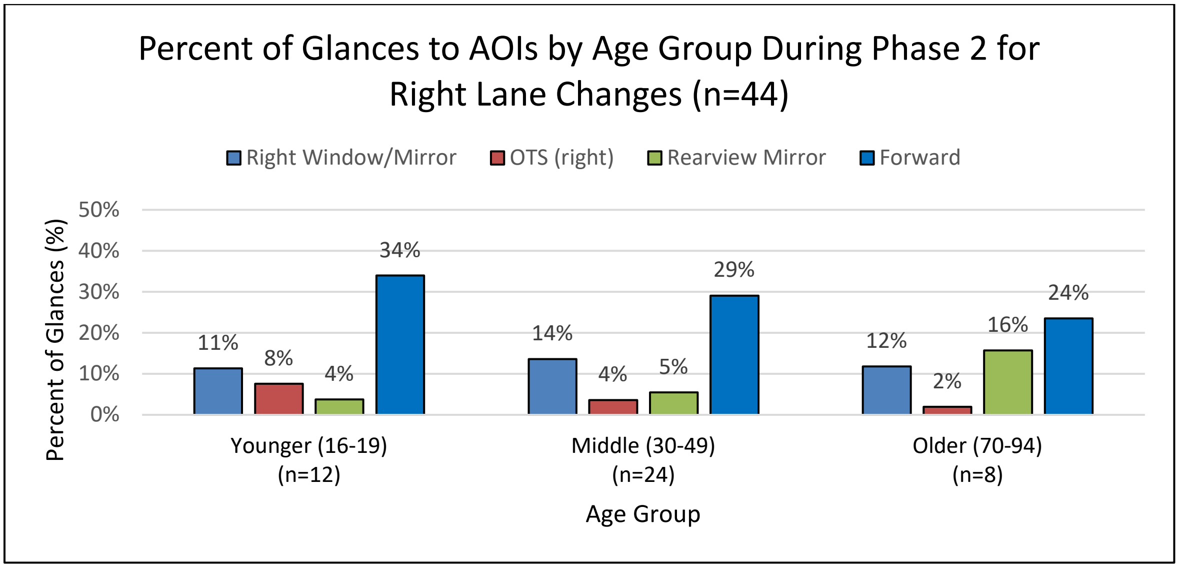


Figure 46. Chart. Percentage of glances to AOIs by age group for Phase 2 of interrupted right lane changes.

Glance Duration

The average glance duration for AOIs across phases for interrupted left lane changes is presented in Figure 47. During Phase 1 and Phase 2, the average glance duration to the left mirror increased with age group (increasing from 0.6 to 1.2 seconds for Phase 1 and 0.3 to 0.7 seconds for Phase 2). A large decrease in the average glance duration to the forward roadway was evident across all age groups when moving from Phase 1 to Phase 2 (from roughly 3.3 seconds to 1.3 seconds).

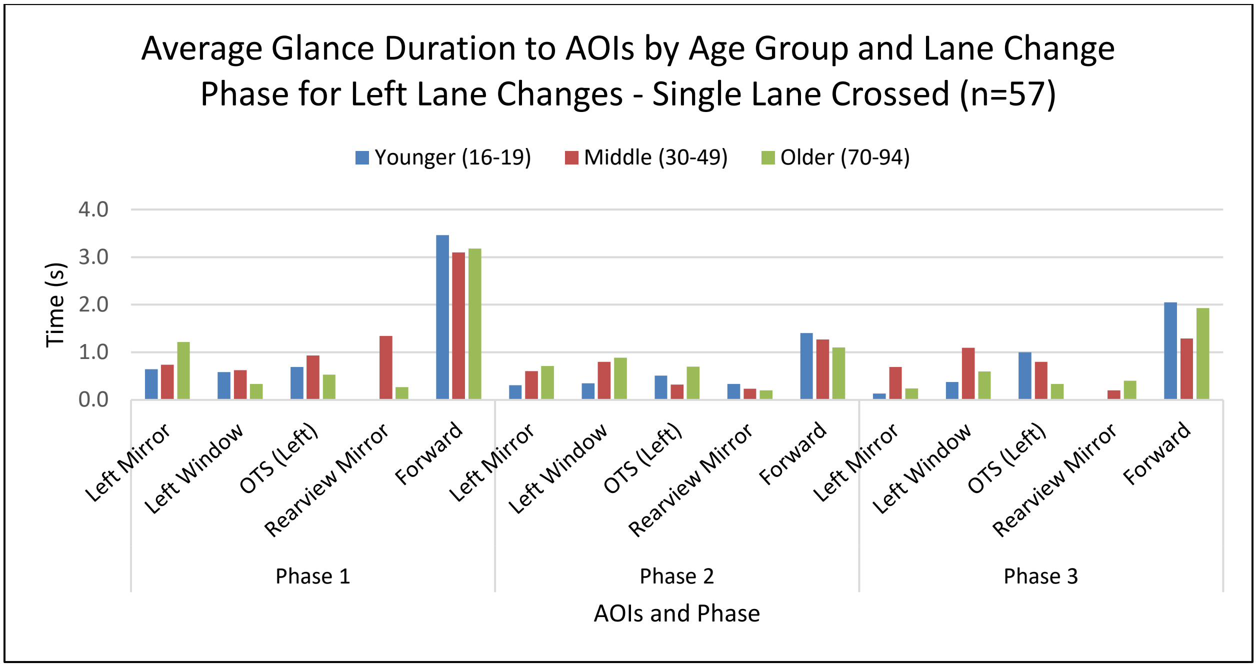


Figure 47. Chart. Average glance duration to AOIs by age group and lane change phase for interrupted left lane changes.

Average glance durations for interrupted left lane changes are shown in Figure 48. As noted in the title of each graph, analyses are limited to a single lane crossed (only about 5% of events were excluded from these analyses). Younger drivers showed a relatively even glance duration to the AOIs except to the rearview mirror, which received no glances (and thus no duration) during Phase 1. The middle-aged group showed the greatest average duration to the rearview mirror (1.3 seconds) compared to younger (0.0 seconds) and older drivers (0.3) seconds. The trend showed a greater reliance on the left mirror with increasing age. Younger drivers showed the smallest duration when glancing to the left mirror during Phase 1 (0.6 seconds) relative to middle-aged drivers (0.7 seconds) and older drivers, who had the longest average duration (1.2 seconds).

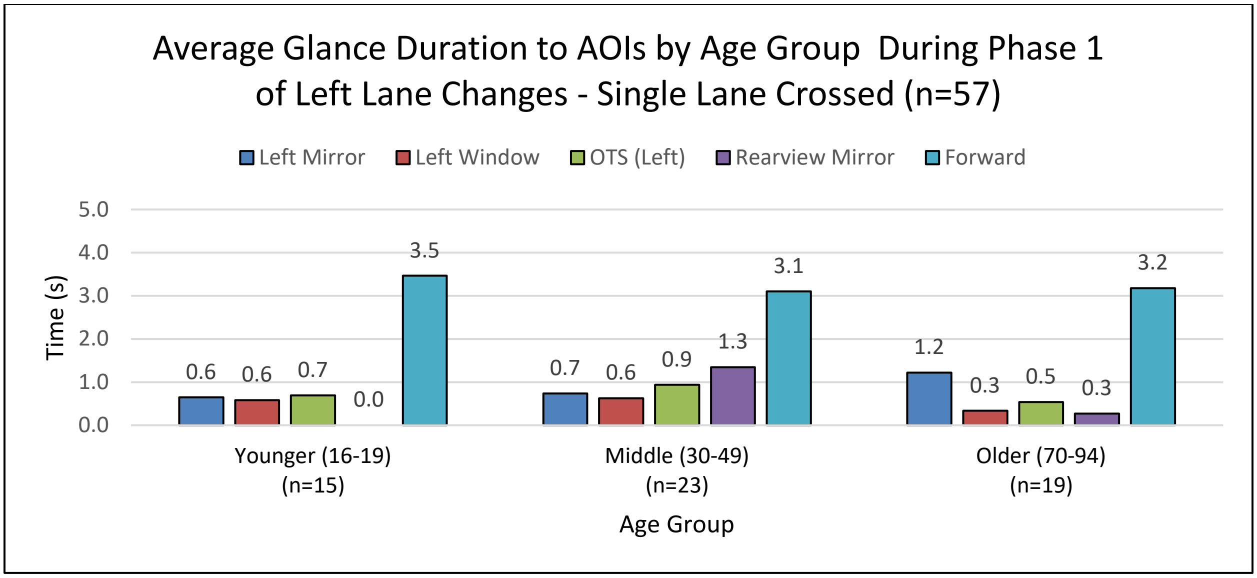


Figure 48. Chart. Average glance durations to AOIs for Phase 1 of interrupted left lane changes.

Average glance durations for Phase 2 of interrupted left lane changes are shown in Figure 49. Younger drivers showed a much lower average glance duration to the left window (0.3 seconds) when compared with middle-aged (0.8 seconds) and older drivers (0.9 seconds). Younger drivers also showed a lower average glance duration to the left mirror (0.3 seconds) when compared with their counterpart groups.

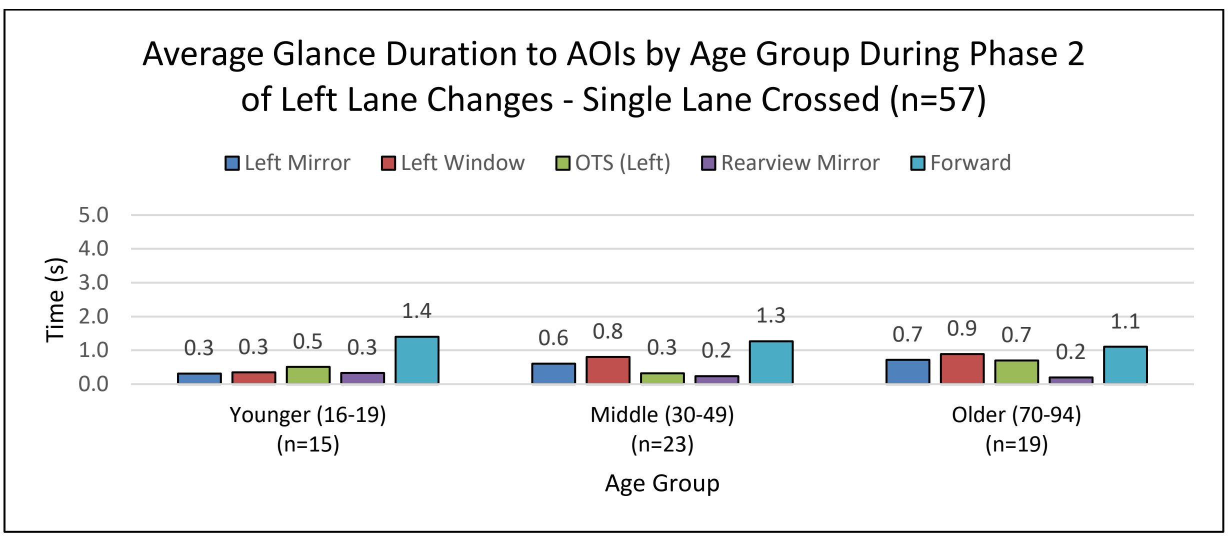


Figure 49. Chart. Average glance durations to AOIs for Phase 2 of interrupted left lane changes.

The average glance duration for AOIs across the three lane change phases for interrupted right lane changes is presented in Figure 50 below. During Phase 1, middle-aged drivers exhibited a smaller average duration to the forward location compared with the other groups (3.3 seconds versus 4.0 for younger and 3.9 for older). The average glance duration to the forward location during Phase 1 (about 3.7 seconds) was reduced greatly during Phase 2 of the lane change (1.5 seconds).

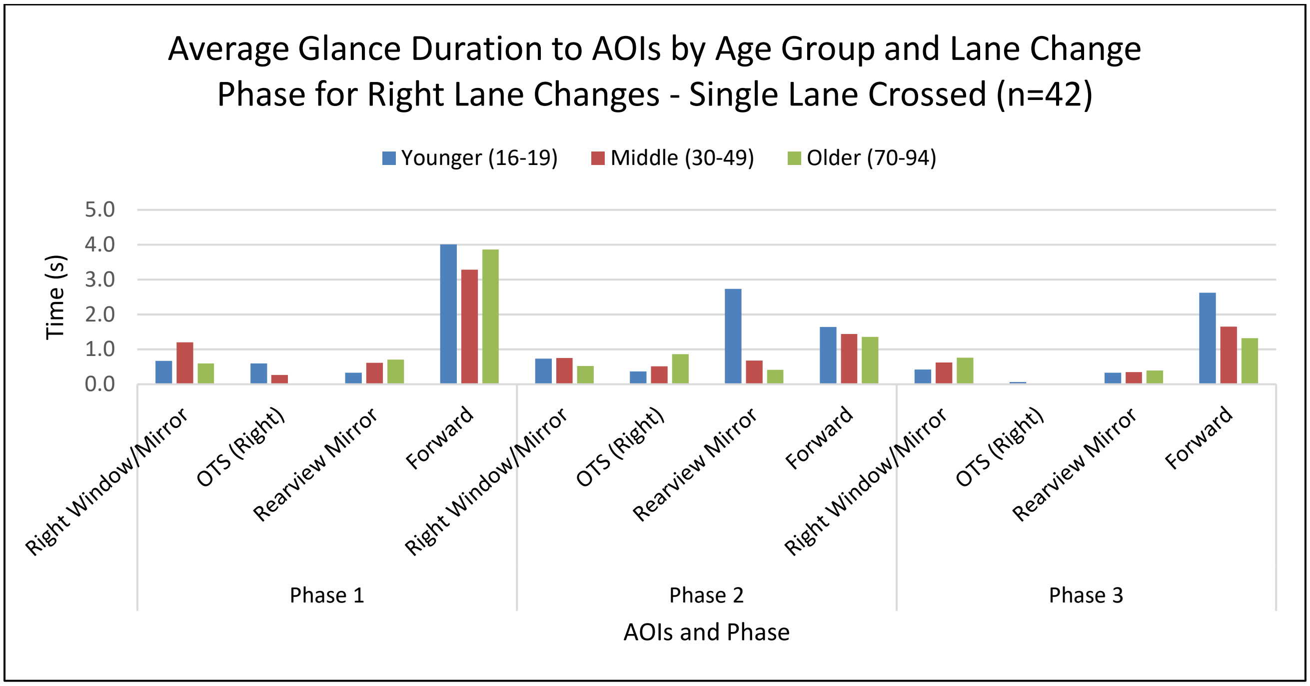


Figure 50. Chart. Average glance duration to AOIs by lane change phase and age group for interrupted right lane changes – note that the average rearview mirror duration for younger drivers in Phase 2 is a single participant.

The distribution of average glance durations during Phase 1 of interrupted right lane changes is presented in Figure 51. Middle-aged drivers showed an average glance duration to the right window/mirror location of 1.2 seconds, which was longer than younger drivers (0.7 seconds) and older drivers (0.6) seconds. Of note is the short glance duration to the rearview mirror by younger drivers (0.3 seconds) compared to the other age groups (0.6 seconds for middle-aged and 0.7 seconds for older drivers). Younger drivers, however, exhibited a greater average glance duration to the OTS location compared to the other groups (0.6 seconds versus 0.3 and 0.0 seconds for middle-aged and older drivers, respectively).

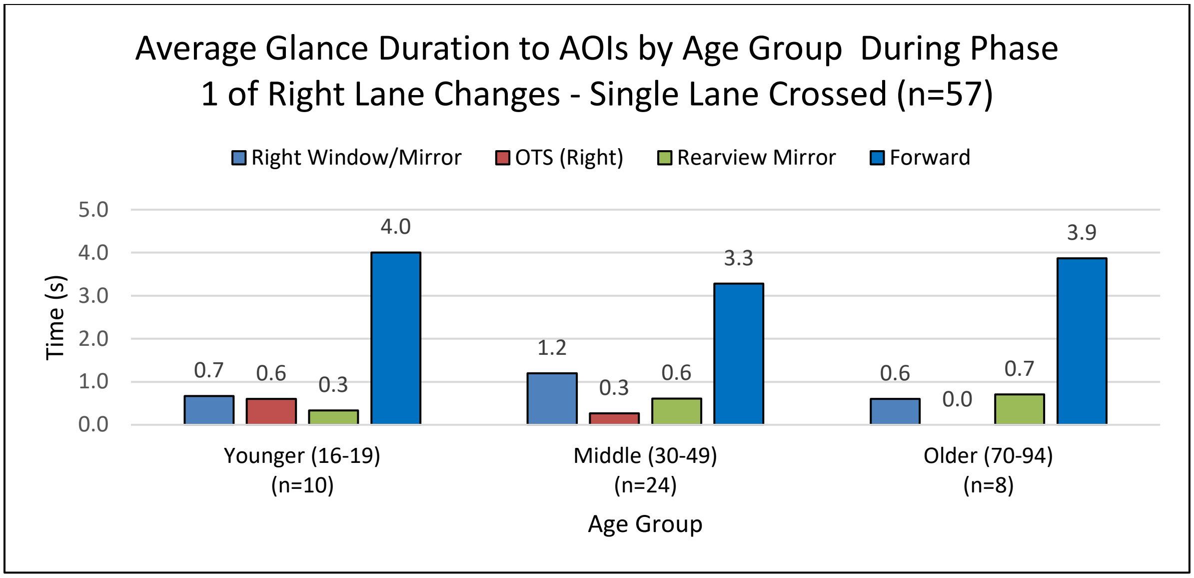


Figure 51. Chart. Average glance durations to AOIs for Phase 1 of interrupted right lane changes.

Phase 2 of interrupted right lane changes showed a possibly interesting results for younger drivers (Figure 52). Although the average glance duration to the rearview mirror for younger drivers was 2.7 seconds, this average is based on only one participant who made a single glance to the rearview mirror. No other younger drivers glanced to the rearview mirror during Phase 2 of interrupted right lane changes.

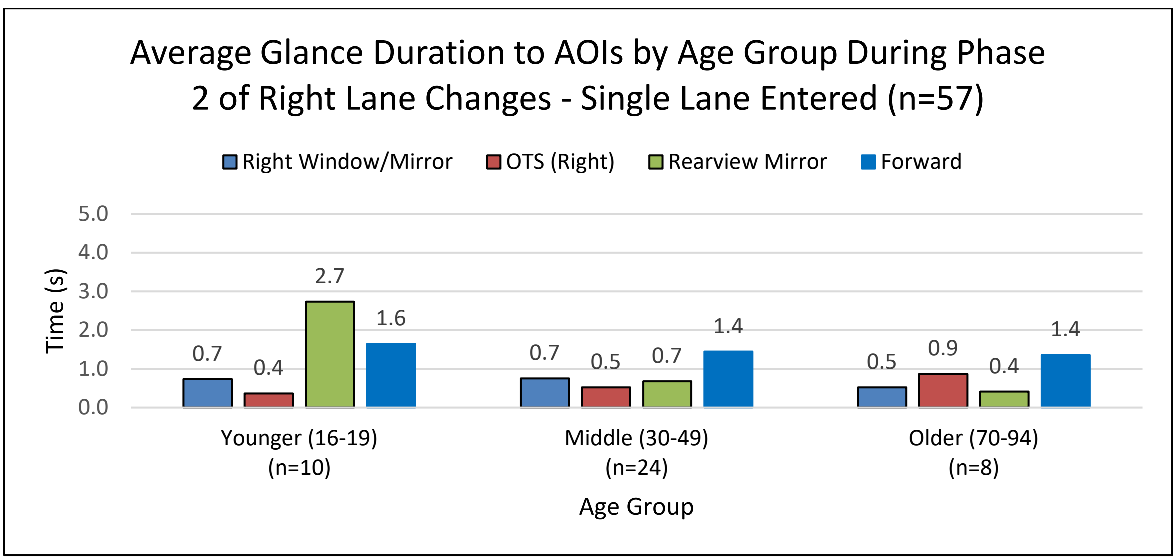


Figure 52. Chart. Average glance durations to AOIs for Phase 2 of interrupted right lane changes.

Probability

Glance probability was also calculated for interrupted lane changes. In addition to the forward location, which showed generally high probability, the left mirror showed elevated probabilities. Older drivers exhibited a greater probability of glancing to that location (0.27) when compared with younger (0.11) and middle-aged drivers (0.18). Additionally, middle-aged drivers had a greater glance probability to the rearview mirror (0.10), while younger drivers did not glance to the rearview mirror (0.00) and older drivers showed a relatively low probability (0.03). Also of note is the low probability (0.01) of glances to the OTS location for middle-aged and older drivers.

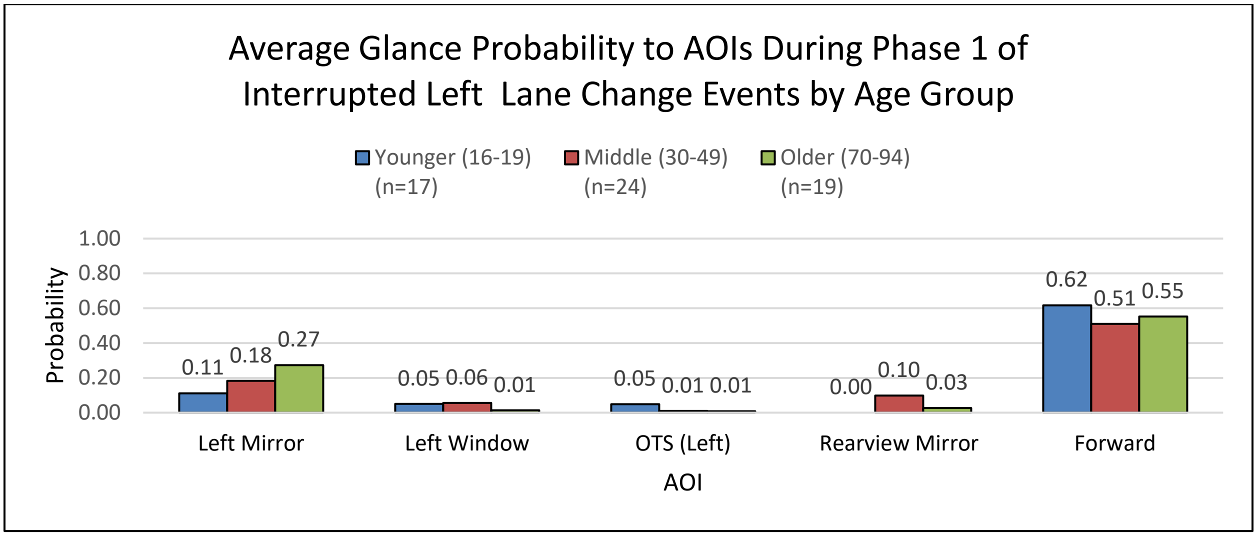


Figure 53. Chart. Average glance probability during Phase 1 of interrupted left lane changes.

Phase 2 glance probabilities are presented in Figure 54. The left mirror location was the most glanced at location of interest. Older drivers showed a glance probability of 0.30 compared with younger drivers (0.13) and middle-aged drivers (0.26). Younger drivers exhibited a higher glance probability for the left window, OTS, and rearview locations compared to the other two age groups. Of note is the OTS glance location: younger drivers showed a probability of 0.16 compared with 0.07 for middle-aged drivers and 0.03 for older drivers.

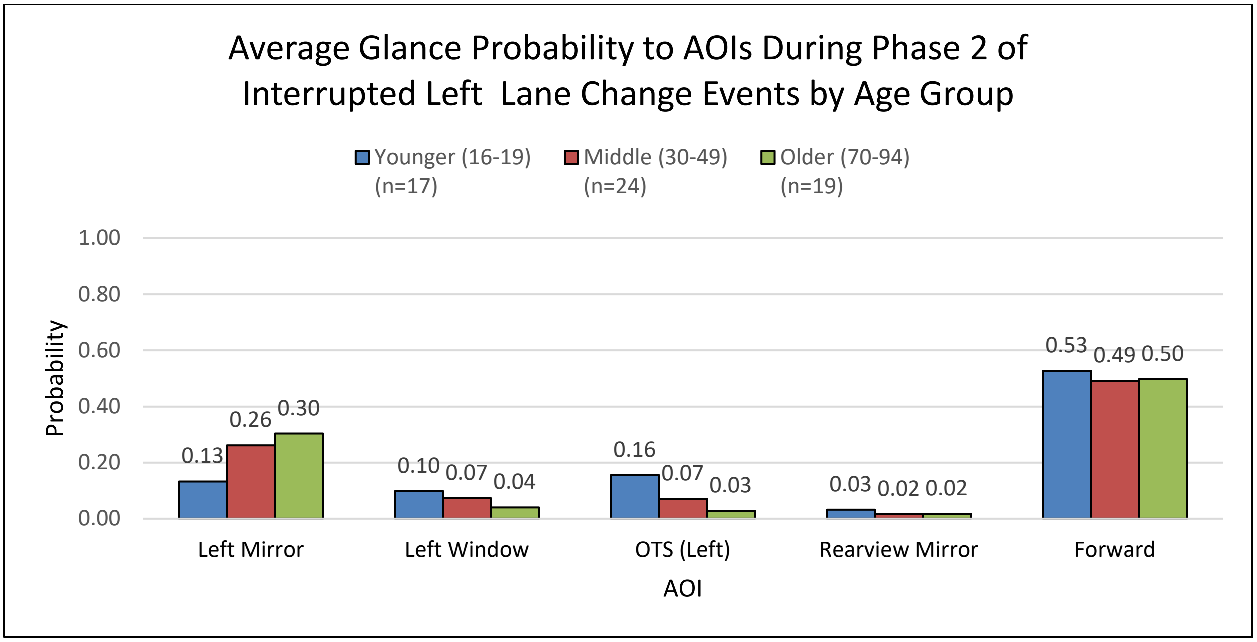


Figure 54. Chart. Average glance probability during Phase 2 of interrupted left lane changes.

For right lane changes, the glance probability of Phase 1 showed that most of the glances occurred to the, forward, right window/mirror, and the rearview mirror locations (Figure 55). Younger drivers were the most likely to glance the right window/mirror (0.18) versus middle-aged drivers (0.15) and older drivers (0.06). A trend in the opposite direction can be seen when investigating the rearview mirror: older drivers showed the highest glance probability at 0.25 with middle-aged drivers at 0.12 and younger drivers at 0.04.

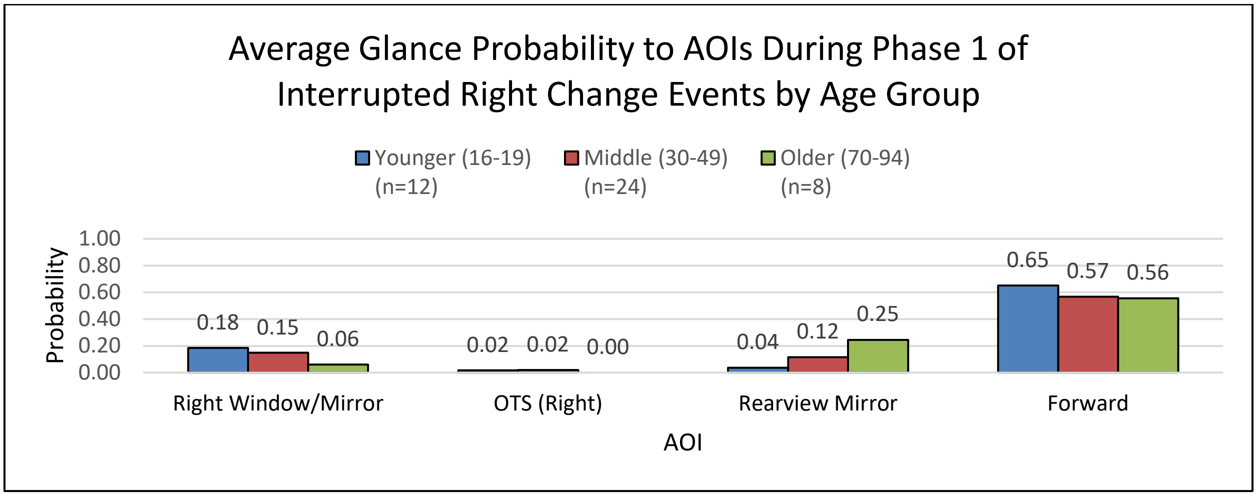


Figure 55. Chart. Average glance probability during Phase 1 of interrupted right lane changes.

The average glance probability calculated during Phase 2 of interrupted right lane changes is presented in Figure 56. While the average glance probabilities to the right window/mirror were similar across age groups, the OTS location and rearview mirror showed differences. Younger drivers exhibited a greater probability of glances to the OTS location (0.12) than middle-aged (0.06) and older drivers (0.04). A trend in the opposite direction was revealed for the rearview mirror location: younger drivers showed the smallest probability (0.04) followed by middle-aged drivers (0.07) and then older drivers (0.27).

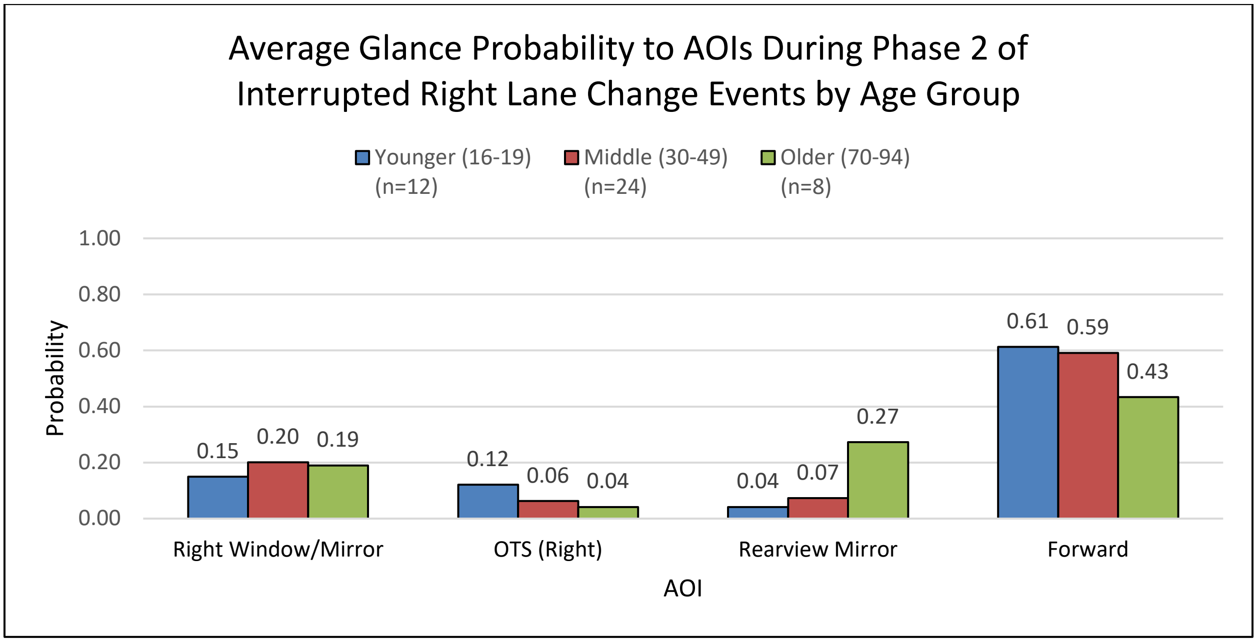


Figure 56. Chart. Average glance probability during Phase 2 of interrupted right lane changes.

Entropy

Glance entropy characterizes the degree of dispersion in a participant's glance pattern as the participant completes the lane change maneuver. The overall level of entropy is shown by age group and lane change phase collapsed across lane change direction (Figure 57). Results showed greater dispersion for middle-aged drivers during Phase 1 than the other age groups, but lower levels during Phase 2 and Phase 3. Older drivers showed a greater level of glance dispersion during Phase 2 (1.02) compared with younger (0.88) and middle-aged drivers (0.81). Overall, the greatest glance dispersion for younger and older drivers was during Phase 2, while middle-aged drivers exhibited their greatest glance dispersion during Phase 1.

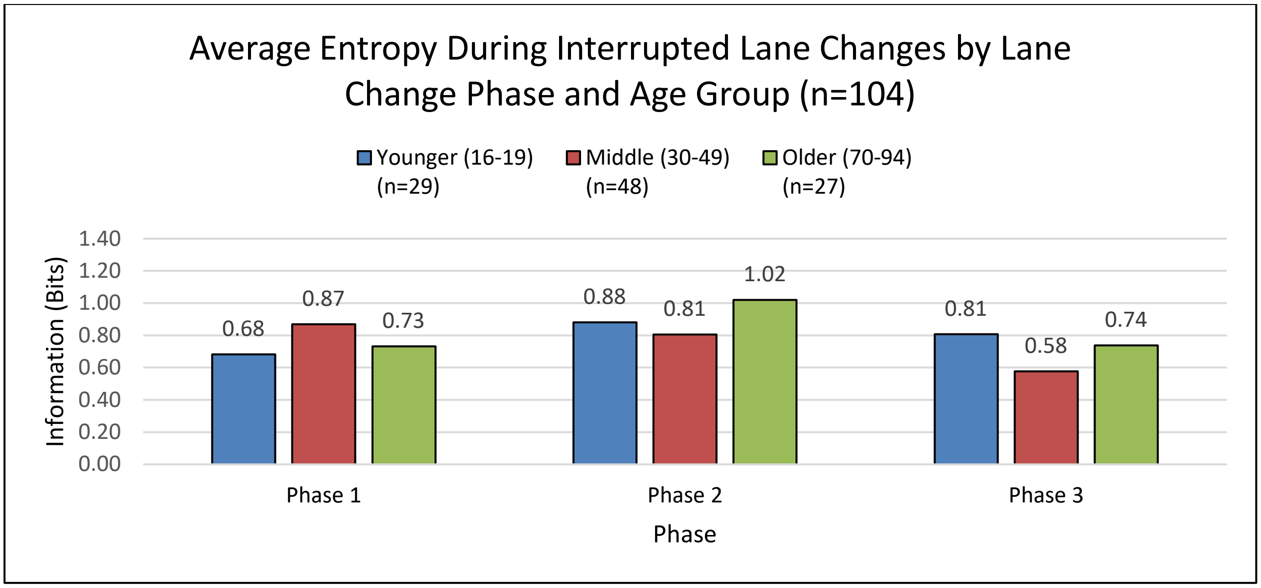


Figure 57. Chart. Average entropy during interrupted lane changes.

Errors

Glance Errors

The percentage of interrupted lane change events where participants failed to direct a side mirror check prior to initiation was investigated (Figure 58). During left lane changes, younger drivers (64%) were the most likely to commit the error (versus 36% for middle-aged drivers and 32% for older drivers). To the right, it was older drivers (75%) who were the most likely (versus 50% for younger drivers and 55% for middle-aged drivers).

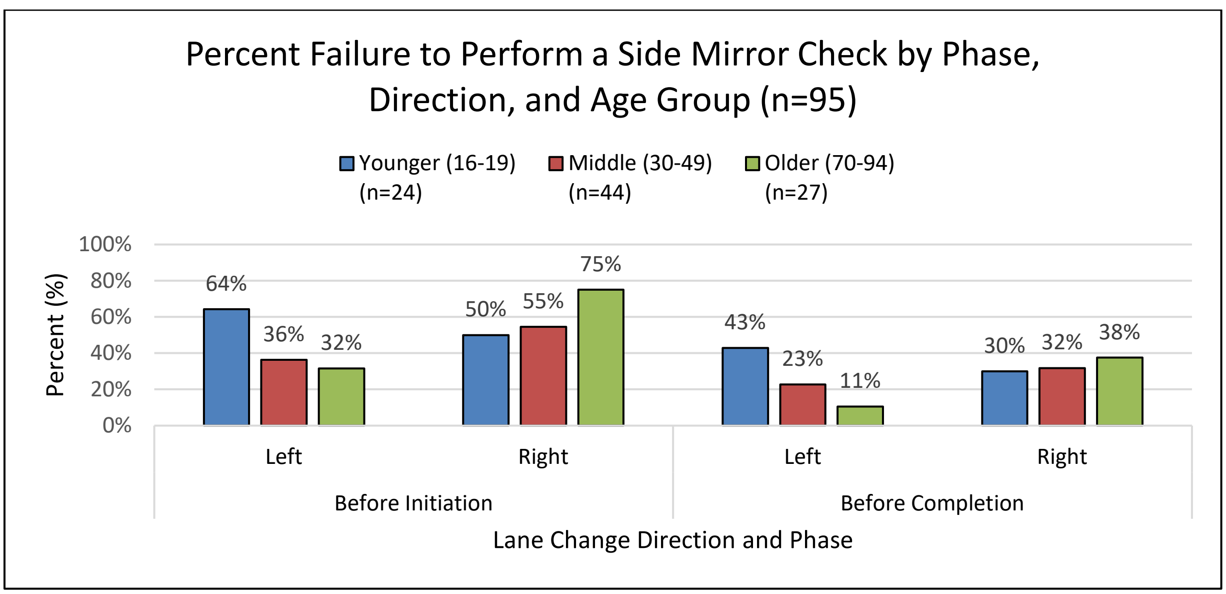


Figure 58. Chart. Failure to perform a side mirror check prior to initiating a lane change for interrupted lane change events.

Another analysis focused on investigating the failure of participants to direct an OTS glance prior to lane change maneuvers for interrupted lane changes. After removing events where an OTS glance may not have been necessary (9 events or about 9% of events removed), younger drivers had the lowest percentage of failure (64% vs. 91% for middle-aged drivers and 95% for older drivers; see Figure 59). For right lane changes, the same pattern is present. Younger drivers failed to perform an OTS check 80% of the time compared to 91% for middle-aged drivers and *100% for older drivers*. It is worth noting that out of all possible events for older drivers (*n* = 27), only five OTS glances were performed.

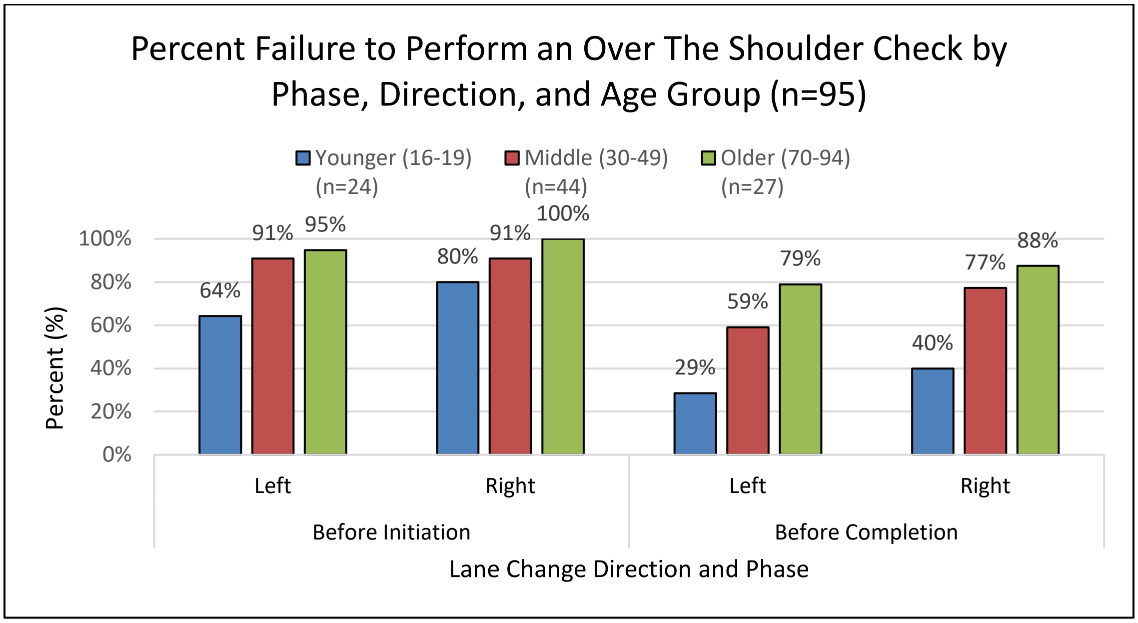


Figure 59. Chart. Failure to direct an OTS glance prior to lane change initiation for interrupted lane change events.

Turn Signal Errors

For interrupted lane changes, older drivers were the least likely to activate their turn signal during the lane change maneuver (70%) compared with younger drivers (86%; see Figure 60). Of interest is that two middle-aged participants engaged their turn signal in the wrong direction a single time each. The other age groups did not exhibit incorrect signal direction. A review of the video showed that both instances of incorrect turn signal direction were situations in which the driver intended to turn one direction and made a last-minute decision to go the opposite direction. A further breakdown of turn signal activation can be seen in Appendix E.

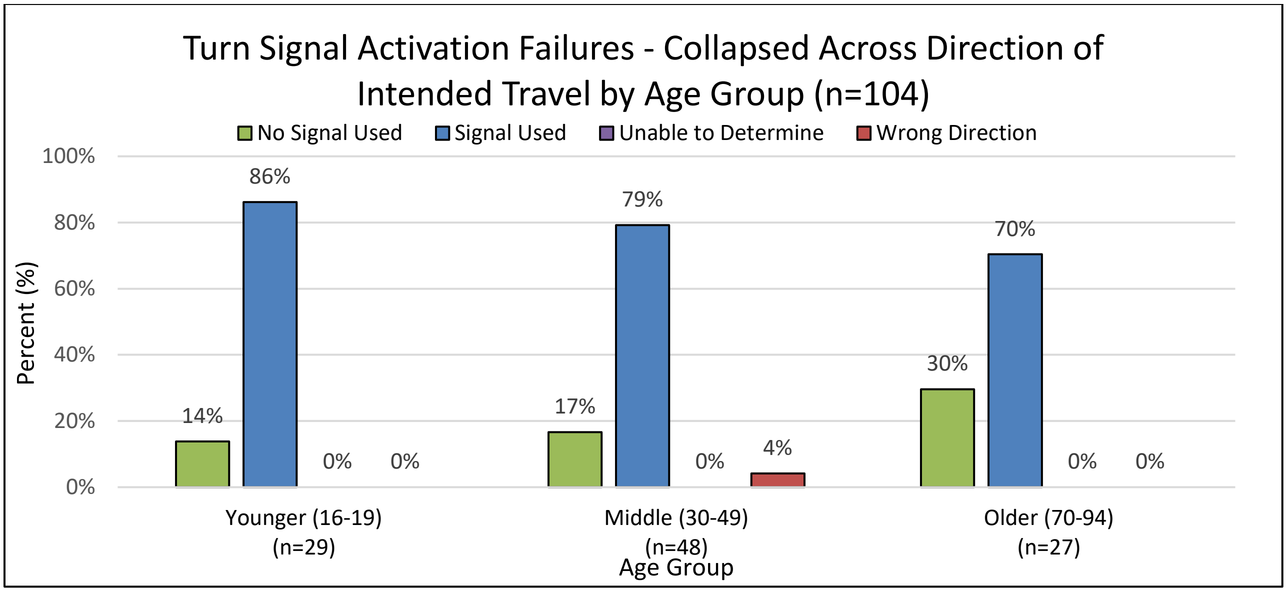


Figure 60. Chart. Turn signal use by age group for interrupted lane changes.

Turn signal activation prior to initiating the lane change maneuver showed that younger drivers were most likely (41%) to engage the signal prior to starting the maneuver, while older drivers were the least likely (26%; see Figure 61). Two drivers were moved from this analysis due to activation of the turn signal in the wrong direction.

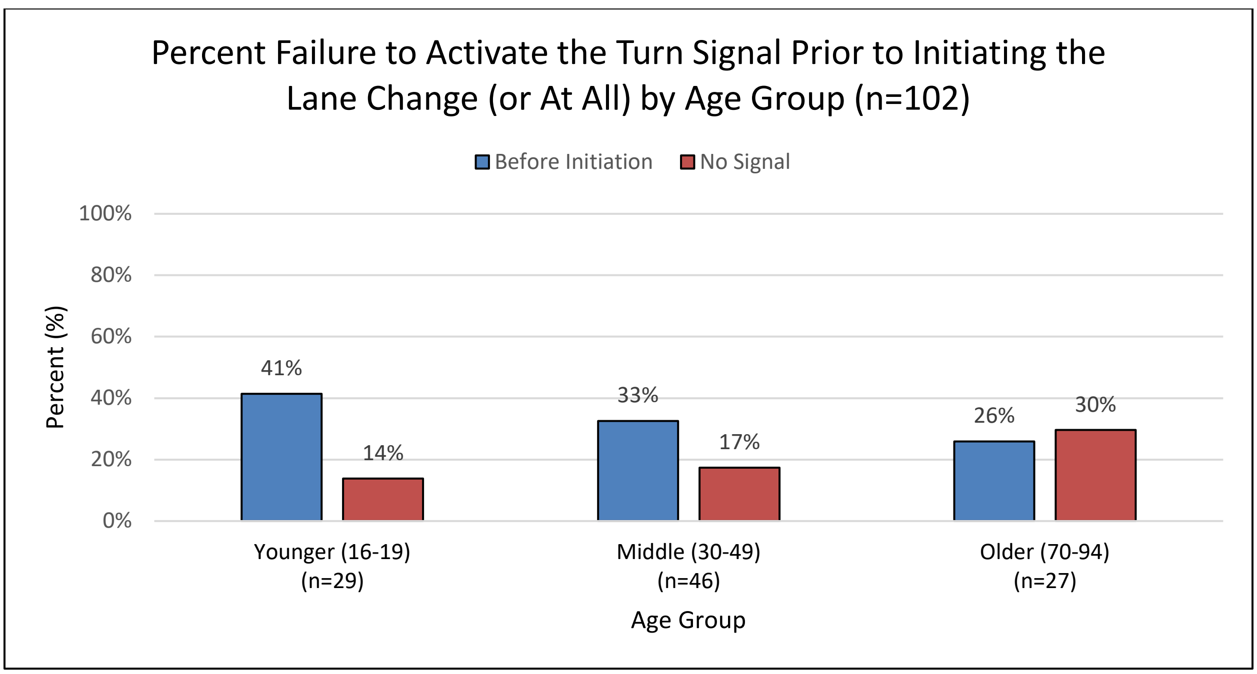


Figure 61. Chart. Turn signal activation prior to initiation for interrupted lane changes.

Improper Spacing Errors

Interrupted lane changes were subject to the same subjective assessment to determine if the participant vehicle cut off a trailing vehicle in the destination lane. Older drivers were most likely to have cut off another vehicle (28%) compared to middle-aged (27%) and younger drivers (19%). Appendix F presents the data in pie chart form.

Table 5. Percentage of interrupted lane change events where driver cut off a trailing vehicle in the destination lane.

Age Group	Did Not Cut Off	Cut Off	Unable to Determine
Younger (16–19)	71%	19%	10%
Middle-Aged (30–49)	62%	27%	11%
Older (70–94)	68%	28%	4%

Environmental Factors

Traffic Density

When traffic density is plotted against percentage of lane change events, a normal-like curve is revealed (much like with uninterrupted lane changes). While there was not much difference between age groups, more interrupted lane change events occurred during flows with some restrictions and greater levels of traffic density (see Figure 62). Only 13% of interrupted lane changes occurred in less-dense traffic for younger drivers, 6% for middle-aged drivers, and 4% for older drivers.

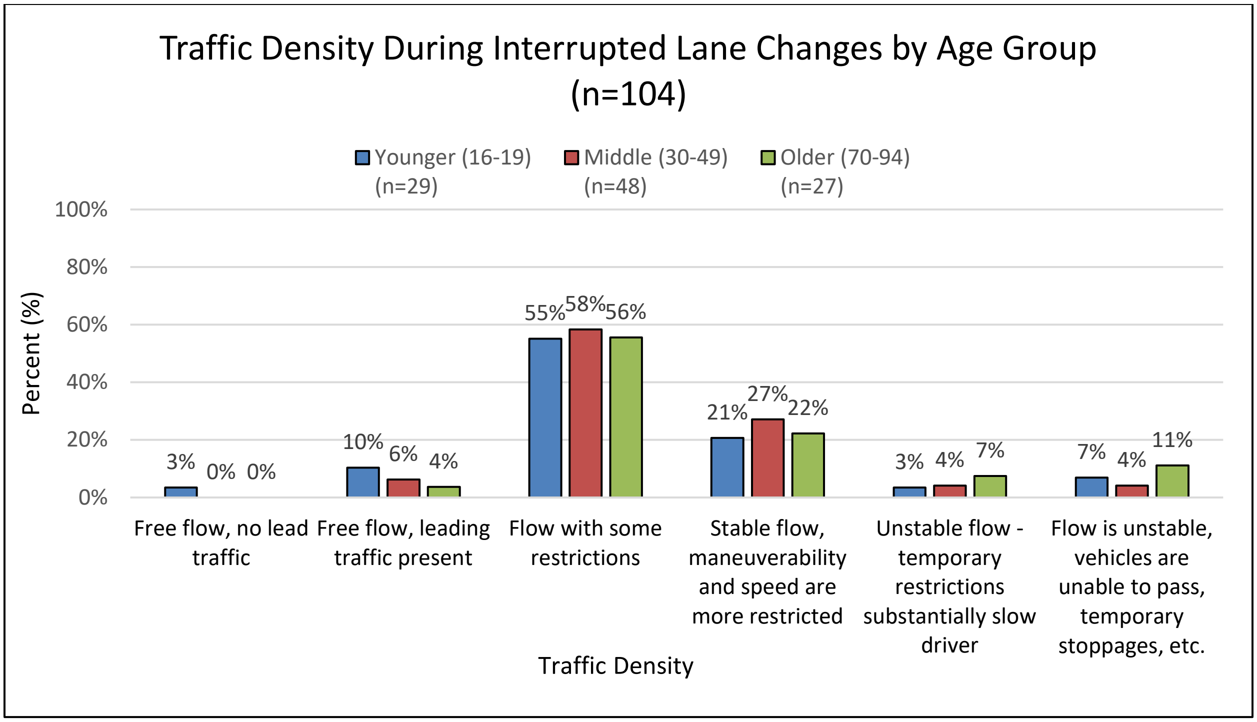


Figure 62. Chart. Traffic density by age group for interrupted lane changes.

Due to the minimal number of crashes (~4% of data) related to the interrupted lane change events, the distribution shown in Figure 63 below is rather simple. Nearly all crashes occurred during flows with some restrictions and flows where speed and maneuverability were somewhat restricted. Without more crashes, it is unfair to draw any conclusions from the presented data.

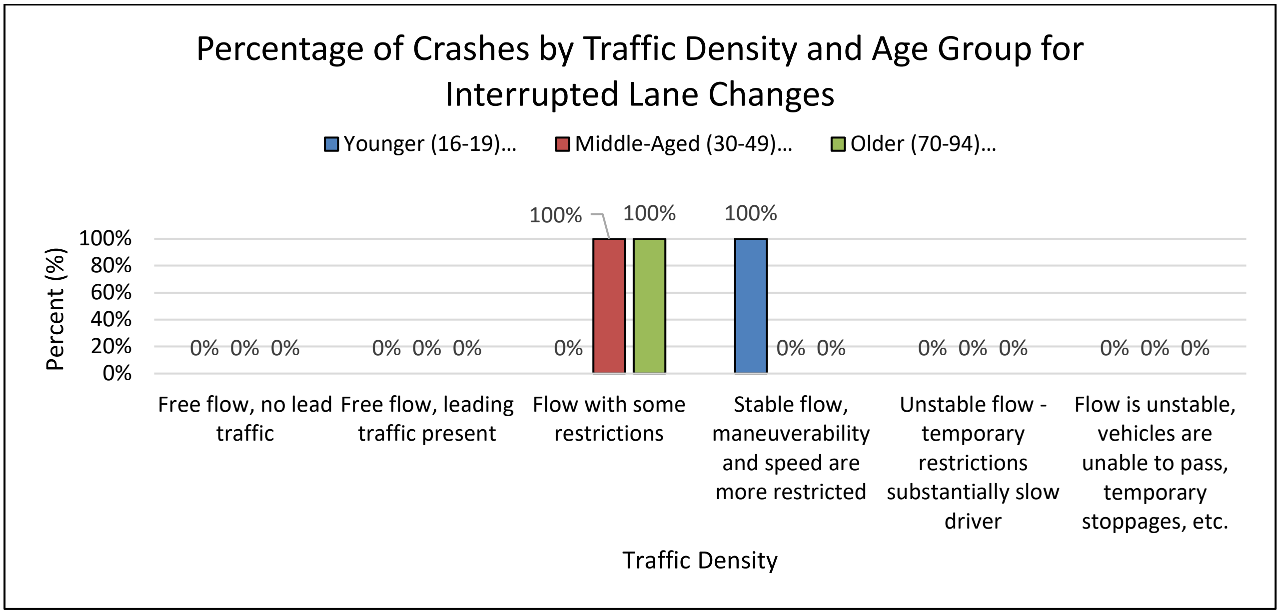


Figure 63. Chart. Percentage of crashes by traffic density for interrupted lane changes.

The distribution of near-crashes related to interrupted lane changes is presented in Figure 64. Near-crashes accounted for ~93% of the data. The vast majority of near-crashes occurred during medium levels of traffic density; that is, flow with some restrictions and flow where maneuverability and speed were more restricted. Older drivers showed a higher percentage of near-crashes in the higher levels of traffic density (20%) than their younger counterparts (12% for younger and 8% for middle-aged). The 4% value for near-crashes for younger drivers in the lowest traffic density represents one event where a vehicle pulled out in front of the participant.

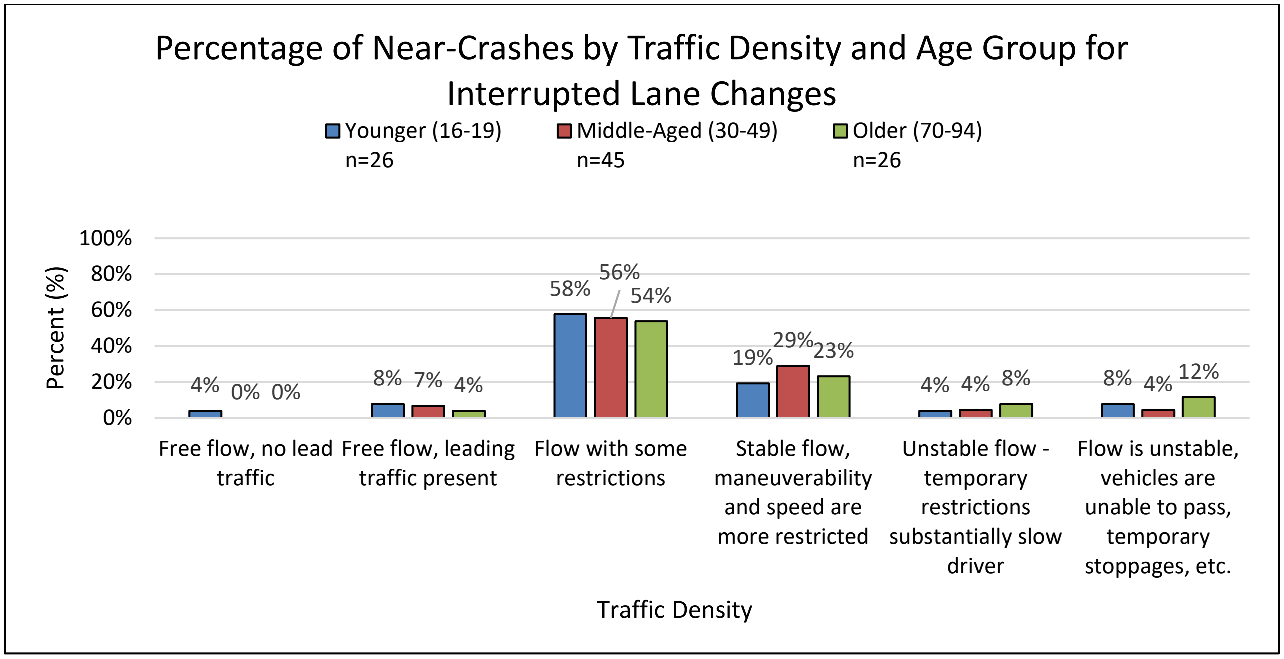


Figure 64. Chart. Percentage of near-crashes by traffic density for interrupted lane changes.

Conflict Type

Conflict type for interrupted lane changes to the right also showed a slant toward leading vehicle in or incurring into the destination lane, with over 50% of conflicts involving this type of event (see Figure 65). Twenty-five percent of younger drivers' conflicts were attributed to the "other" category as compared to middle-aged (4%) and older (13%). Of note is the percentage of events in the trailing vehicle category: 13% to 25% of events fell into this category.

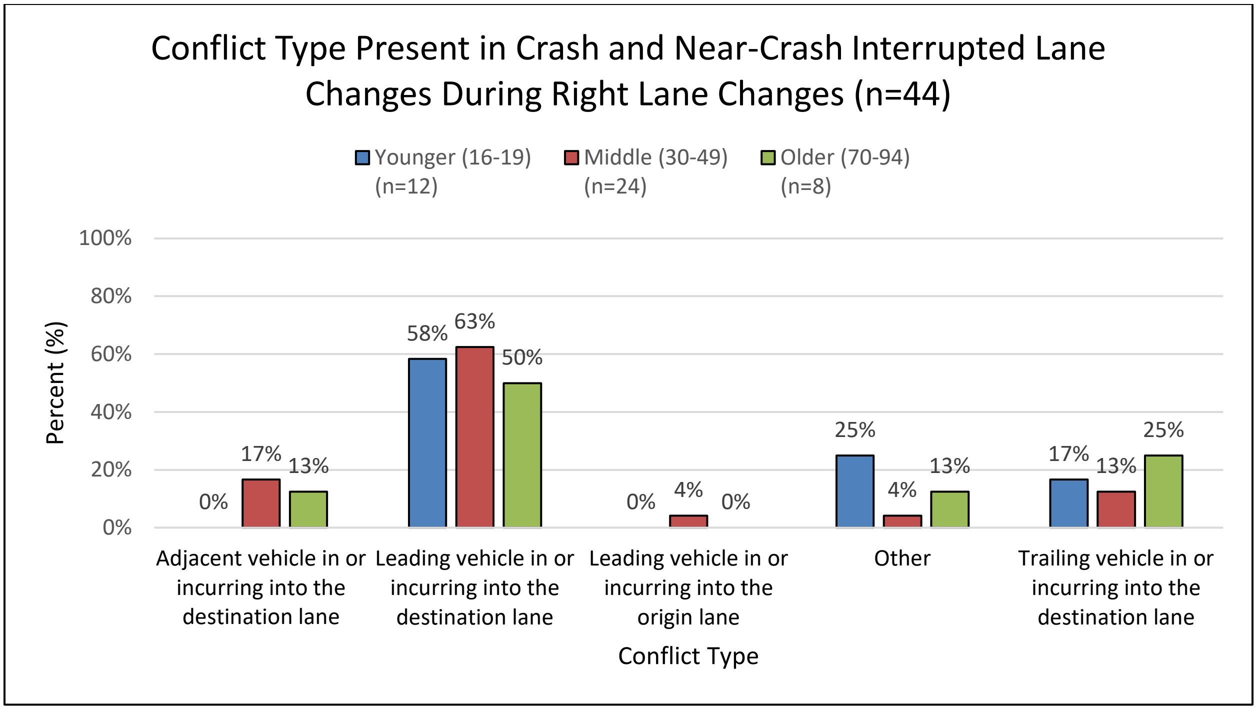


Figure 65. Chart. Conflict type by age group for interrupted right lane changes.

Left lane changes showed a more even distribution of conflict type than right lane changes. A roughly equal distribution of events in adjacent vehicle in or incurring into the destination lane, leading vehicle in or incurring into the destination lane, and trailing vehicle in or incurring into the destination lane is shown in Figure 66. Forty-four percent of conflicts for older drivers occurred where a trailing vehicle was in or moving into the destination lane, more than for younger (27%) and middle-aged drivers (30%).

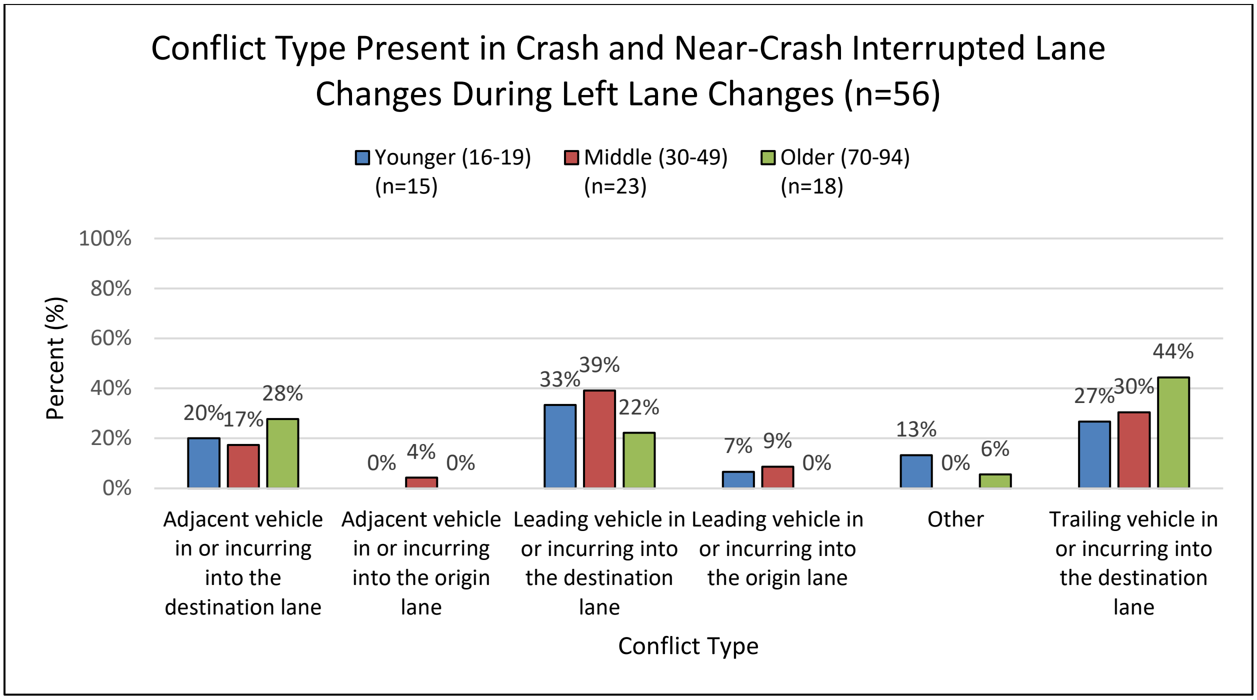


Figure 66. Chart. Conflict type by age group for interrupted left lane changes.

Secondary Task Engagement

During interrupted lane changes, roughly 34% to 46% of drivers engaged in a secondary task in Phase 1 (see Figure 67). Older drivers were the most likely to engage in a prior secondary task (46%), while younger drivers were the least likely (34%). For concurrent secondary tasks, middle-aged drivers were, again, the most likely of the age groups to be engaged in a secondary task, while older drivers were the least likely (15%). Appendix G presents the data in pie chart form.

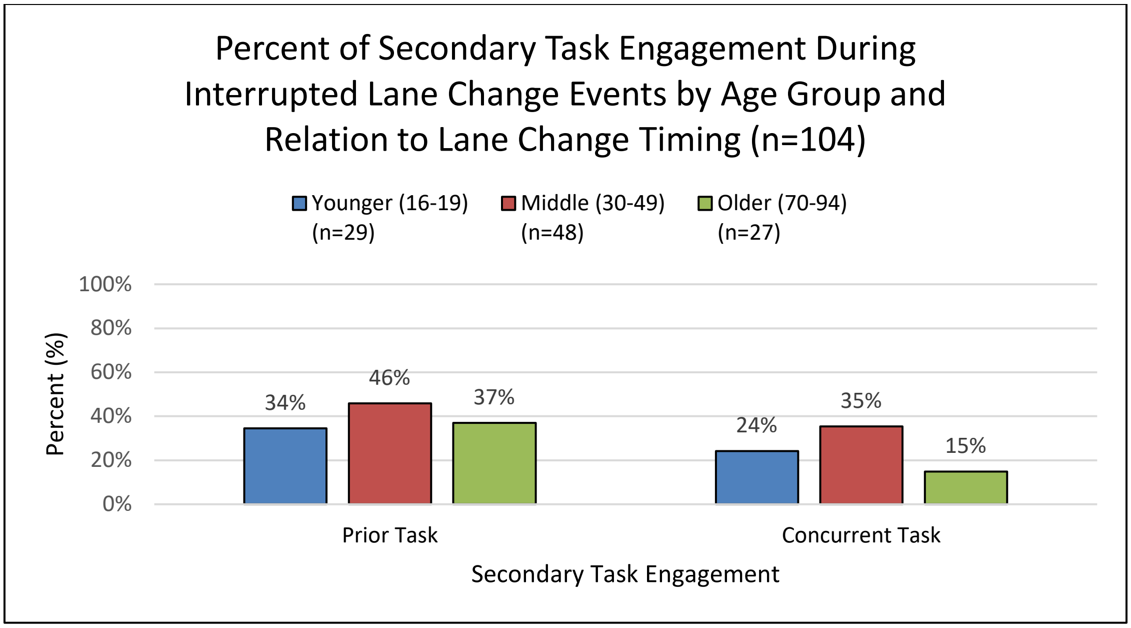


Figure 67. Chart. Secondary task engagement both prior to and during interrupted lane changes.

Discussion and Conclusions

Glance Characteristics

Overall, drivers of all ages directed more time and glances to the left mirror location during an interrupted left lane change relative to OTS glances. During Phase 1 and Phase 2 of interrupted left lane changes, a trend emerged: younger drivers directed a smaller proportion of time and glances to the left mirror than middle-aged drivers, who in turn directed a smaller proportion of their glances to the left mirror than their older counterparts. A strong reliance on the left mirror during an interrupted left lane change in the absence of OTS glances certainly affords a situation where the driver may feel aware of the surroundings but is unaware of other vehicles that may be in the driver's blind spot.

During interrupted right lane changes, drivers apparently rely much more on the rearview mirror and right mirror/window than OTS checks. While the overall durations noted (most were between 0.3 and 1.2 seconds not including glances to the forward location) are consistent with Kiefer and Hankey (2008), a more intensive review of our data revealed an interesting trend. Older drivers direct a greater percentage of time and glances to the rearview mirror during Phase 1 and Phase 2 of interrupted right lane changes than their younger counterparts. While overall duration and number of glances to the rearview mirror did not vary greatly by age, the proportion of time and proportion of glances to that location do. Given the reliance on the rearview mirror for right lane changes and a relative lack of OTS or right mirror glances creates a similar situation discussed above, one in which the driver may feel aware of the surroundings but fails to notice another vehicle in the blind spot (see Figure 68).

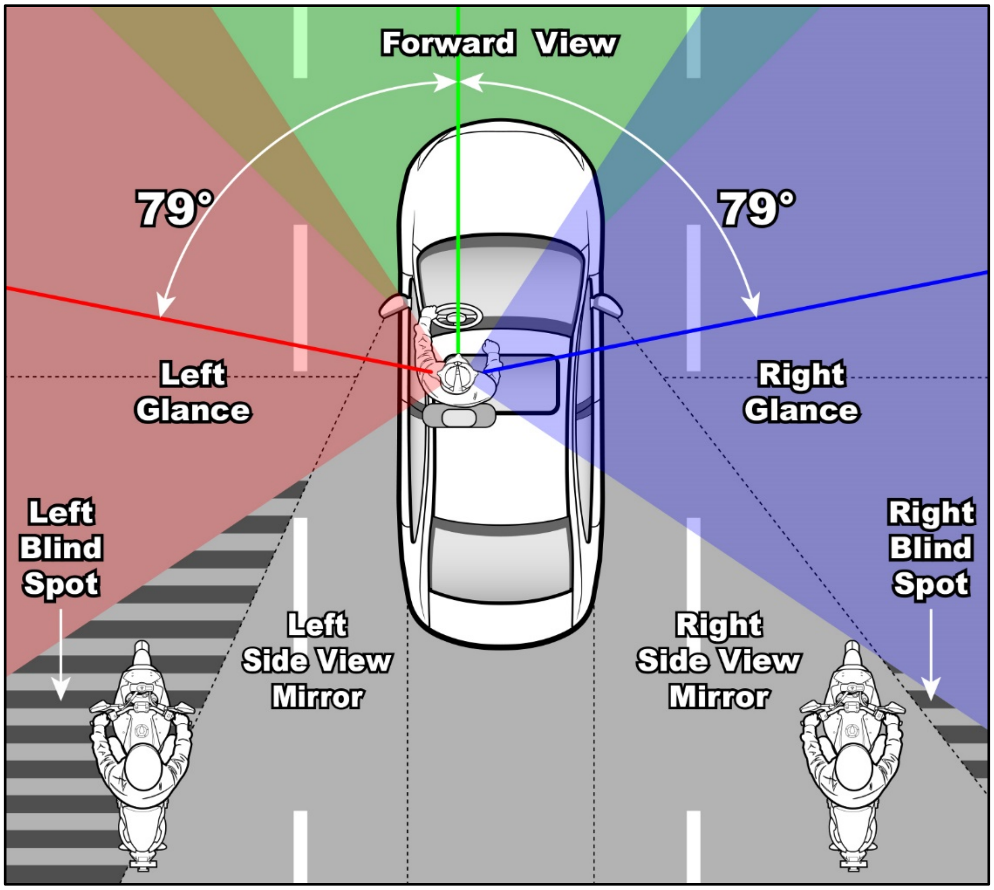


Figure 68. Illustration. Unequal blind spot size given an equal average head rotation by middle-aged drivers as reported in Swinkels, and Swinkels-Meewisse (2014).

Entropy

Levels of glance dispersion during interrupted lane changes varied by age group and by lane change phase. Overall, levels of dispersion were lower during Phase 1 for younger and older drivers (0.68 vs. 0.88 for younger drivers and 0.73 vs. 1.02 for older drivers); however, for middle-aged drivers a higher level of glance dispersion was present for Phase 1 (0.87) compared to Phase 2 (0.81). When collapsed across lane change direction, younger and older drivers demonstrated their greatest level of glance dispersion during Phase 2, whereas middle-aged drivers demonstrated their largest glance dispersion during Phase 1. This suggests that while middle-aged drivers begin searching *prior* to initiating the resultant interrupted lane change maneuver, younger and older drivers fail to increase their dispersion of visual search until *after* initiating the lane change.

The results showing a lower level of glance dispersion for older drivers are consistent with Bao and Boyle (2009), who evaluated entropy for left turns and right turns at an intersection. Results are also consistent with Lavalliere, Teasdale, et al. (2007) who showed that older drivers directed a smaller number of glances to the side mirror and OTS locations when compared to younger drivers in a simulated drive.

However, the high level of entropy for Phase 2 of interrupted lane changes is inconsistent with the above studies. A review of the data showed that it was not just a few outliers who demonstrated elevated entropy during Phase 2; instead, it was rather common. The results are also inconsistent with previous research, which has noted decreased mobility in older adults (Isler et al., 1997). It is, however, feasible that the reduced range of motion noted in Isler et al. (1997) would affect older drivers' ability to direct an OTS glance—something not necessary to affect the overall glance dispersion. Older drivers may still possess the ability to direct glances to various locations within the vehicle, thus creating a high entropy value even in the absence of OTS glances. Isler et al. (1997) also noted that the loss of head rotation was common in many of the drivers in the two oldest age groups (60–69 and 70+). We would expect that if we found the same rate of mobility concerns, the entropy values would likely be at least partially explained by them. However, the difference in entropy results taken with the small percentage of drivers with physical restrictions noted in the SHRP 2 physical questionnaire (2.2% limited flexibility and 2.3% severe arthritis) suggests the lack of OTS glances is either not primarily related to a flexibility issue for older drivers or that the flexibility measures employed in the SHRP 2 NDS did not accurately capture existing real differences. It is also possible that the self-reported measures of mobility were biased, with individuals failing to provide fully accurate data. Given that most interruptions during lane changes occurred in Phase 2, the elevated entropy could also be tied to the evasive maneuver rather than simply some aspect of the lane change for older drivers.

Errors

Three main types of errors were evaluated: glance-based errors, turn signal errors, and cut-off errors. Results from each are discussed below.

Glance-Based: Results showed that 32% to 75% of drivers failed to direct a glance to the side mirror location (left for left lane changes and right for right lane changes) prior to initiating a lane change maneuver during interrupted lane changes.

The analyses revealed differences based on lane change direction and age group during interrupted lane changes. Both middle-aged and older drivers were less likely to perform a side mirror check prior to changing lanes to the right. In contrast, younger drivers were less likely to perform a side mirror check prior to changing lanes to the left than when changing lanes to the right. When couched in terms of side mirror check errors, older drivers were more likely to fail to make a side mirror check when changing lanes to the right (75%) compared to changing lanes to the left (32%). Middle-aged drivers showed a similar directional pattern and were more likely to fail to make to make a side mirror check when changing lanes to the right (55%) than to the left (36%). Younger drivers showed an opposite directional preference: younger drivers were more likely to fail to make a side mirror check to the left (64%) than the right (50%; see Figure 69).

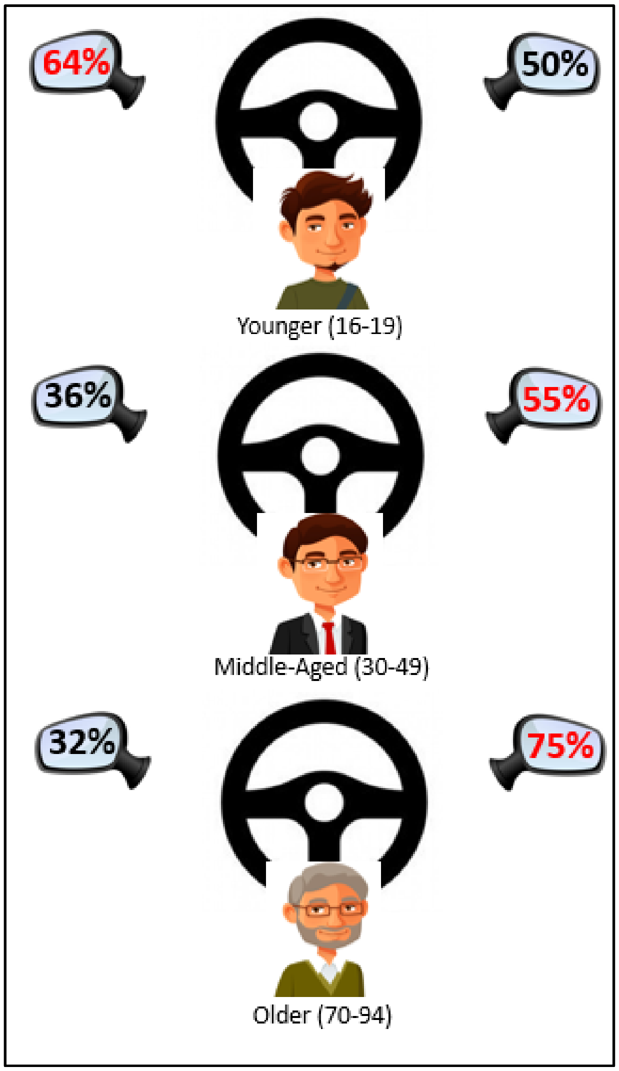


Figure 69. Illustration. Percent failure to perform side mirror checks prior to initiating the lane change by direction and age group.

Overall, failures to direct an OTS glance prior to initiation of the lane change were high. Prior to initiation of the interrupted lane change, 64% to 100% of drivers across all age groups failed to make an OTS glance check. While these failures decrease for younger and middle-aged drivers when including OTS glances made *after* initiation, the values are still quite elevated (particularly for middle-aged drivers and older drivers). Younger drivers, on the other hand, are more likely to direct an OTS glance after initiation. One difference we see between left and right interrupted lane changes is with younger drivers: they were more likely to fail to perform an OTS glance when changing lanes to the right than the left (see Figure 59). Across all age groups, the OTS failure rates observed in this study are consistent with Kiefer and Hankey (2008), who showed failure to direct blind zone glances 68% to 85% of the time during left and right lane changes, except for older drivers in our study who showed a 95% to 100% failure rate.

Taken together, failures to perform a side mirror check and an OTS check prior to initiating the resultant interrupted lane change were high, and these failure rates were even higher when making a lane change to the right than to the left.

Turn Signal Use: Results showed that drivers failed to activate the turn signal during 26% to 41% of interrupted lane changes, *prior to initiating* the maneuver. Younger drivers were the most likely to fail to activate the turn signal prior to lane change initiation (41%) while older drivers were the least likely (26%). Note that these numbers reflect signal usage prior to lane change initiation. When the simple presence of turn signal use during any part of the lane change was evaluated, older drivers were the most likely to fail to activate the turn signal (30% vs. 14% for younger drivers and 17% for middle-aged drivers). One could assume that perhaps older drivers were driving in less dense traffic and thus had a lower need for turn signal activation, but an analysis of the presence of interrupted lane changes by traffic density showed that older drivers were equally represented in moderate levels of density, and even slightly over-represented in high levels of traffic density. Over-representation of interrupted lane changes in highly dense traffic correlates with the over-representation of near-crashes for older drivers in highly dense traffic.

Improper Spacing: Analyses on the percentage of interrupted lane changes where a driver cut off a trailing vehicle showed that 19% to 28% of events included such behavior. An effect of age was seen where younger drivers were the least likely to cut off a trailing vehicle, with middle-aged drivers being elevated at 27%, and older drivers slightly more elevated again at 28% of interrupted lane change events. It is worth noting that another analysis focusing on conflict type present in crashes and near-crashes showed an elevated presence of conflicts with a trailing vehicle in or incurring into the destination lane for both left and right interrupted lane changes. Older drivers were over-represented in conflicts for both lane change directions (25% of events for left and 44% of events for right) relative to the younger age groups.

Environmental Factors

Traffic Density: The prevalence of interrupted lane changes occurring by level of traffic density resulted in a distribution mimicking a slightly skewed bell curve; that is, most interrupted lane changes occurred in moderate levels of traffic density with decreasing numbers of lane changes occurring as traffic density either increases or decreases. The skewed curve shows that more interrupted lane changes occurred in higher levels of traffic density than in lower levels. The presence of a normal-like curve showing percentage of interrupted lane changes by traffic density suggests that when traffic density is low, there is less need for a lane change (thus lowering the likelihood of an interrupting behavior) and when the traffic density is really high, there is less opportunity to perform a lane change. What does emerge is a pattern of higher levels of lane changing behaviors in moderate levels of traffic density where both the need and opportunity for a lane change are available to the driver.

Crash Rate: Crashes related to interrupted lane changes were rare (total of 4), and all crashes happened in moderate levels of traffic density. Near-crashes, however, revealed a normal-like curve to the percentage of lane changes by traffic density for interrupted lane changes. While most near-crashes occurred in moderate levels of traffic density, the normal-like curve is slightly-skewed towards higher densities; that is, the percentage of near-crashes occurring in the low levels of traffic density are very low, but the tail of the curve in the higher densities shows higher percentages of near-crashes. Older drivers are slightly over-represented in the two highest traffic densities compared to their younger counterparts but are not over-represented in any of the other traffic densities. It is worth noting, however, that younger drivers showed an elevated level of near-crashes relative to middle-aged drivers in both the very lowest traffic density and the very highest traffic density.

Conflict Type

During interrupted lane changes, a major source of conflict varied by the direction of the lane change. Interrupted left lane changes showed a high percentage of conflicts with trailing vehicles in the destination lane. Interrupted right lane changes showed a smaller incidence of conflicts with trailing vehicles in the destination lane. An increased prevalence for interrupted left lane changes over right lane changes was evident across all three age groups. Conflict with trailing vehicles in the destination lane during interrupted lane changes may reflect the inherent differences in left and right lane changes. The physical layout of the vehicle and the visual areas covered by mirrors differ by side of the vehicle and could contribute to the differences in conflict type rate by lane change direction.

During interrupted right lane changes, the largest source of conflict was with a lead vehicle in or incurring into the destination lane. For interrupted left lane changes, the major source of conflict was roughly split between lead vehicle in or incurring into the destination lane, trailing vehicle in or incurring into the destination lane, and adjacent vehicle in or incurring into the destination lane. While interrupted right lane changes show a different conflict distribution than interrupted left lane changes, the exact reason is unknown. It is feasible that the differences in glance characteristics between interrupted left and right lane changes could play a role. Recall that during interrupted left lane changes, drivers tended to rely more on the side mirror while drivers changing lanes to the right tended to rely more on the rearview mirror.

CHAPTER 6. GENERAL DISCUSSION

The key focus of this chapter is to compare findings from both the uninterrupted and interrupted lane change analyses. Only the most pertinent findings will be discussed.

GLANCE BEHAVIORS

Given that one of the key findings of this study is the overall lack of OTS glances across age groups, further examination is needed. Why drivers fail to check the OTS location prior to initiation is a difficult question to answer—for instance, do drivers incorrectly believe that correct mirror adjustments completely eliminate the blind spot? While some mirror augmentations are available to increase the visual coverage of side mirrors and rearview mirrors, information about their presence was not collected in the SHRP 2 data set and video was unable to detect any evidence whether or not they were installed on any particular vehicle. Regardless, it is doubtful that a significant portion of the SHRP 2 population had these mirror augmentations, especially at a high enough rate to excuse the lack of OTS glances prior to initiation. Are drivers simply aware enough of their surrounding traffic that an OTS glance is not warranted? If so, why is a double-check glance not employed? A hypothesis of physical limitations also does not explain the poor OTS glance performance as a large number of drivers from all age groups failed to perform OTS glances. When taken with the low prevalence of limited flexibility or severe arthritis noted in the SHRP 2 questionnaires, this suggests physical limitations are not the primary reason for the lack of OTS glances.

While glance error analyses attempted to remove events where infrastructure elements afforded a lane change without OTS or side mirror checks, not all possible situations can be accounted for where a driver can safely make a lane change without these glances. For instance, we are unable to determine the driver’s level of awareness of surrounding traffic. If the driver is on a low-traffic-density pathway and overtakes a couple of vehicles, can we assume that the driver was rightly paying attention to the following vehicle in the adjacent lane ? If so, it may not be fair to assume in all cases that a double-check was warranted.

When examining a number of analyses together, a clear trend emerges: older drivers failed to perform a number of behaviors that could reduce the risk of a lane-change conflict. Specifically, the data show that older drivers failed to perform OTS glances prior to lane changes at a high rate and often failed to activate the turn signal prior to the lane change, possibly leading to a high number of conflicts with a vehicle in the destination lane, many of whom were cut off during interrupted lane changes

Entropy

During the uninterrupted lane change discussion, a lower level of glance dispersion for older drivers was noted during Phase 1 and Phase 2 of completed lane changes. The results from the interrupted lane change analyses showed a lower level of glance dispersion during Phase 1, but *not* during Phase 2. In fact, the level of glance dispersion that older drivers showed during Phase 2 was higher than their younger counterparts. As mentioned previously, an elevated level of entropy is consistent with previous research (Bao and Boyle, 1999; Lavaliere, Teasdale et al., 2007); however, the elevated entropy for older drivers found in Phase 2 of interrupted lane changes is inconsistent. An interrupted lane change maneuver in the current study was defined as one including an evasive maneuver on the part of the driver. By our phase definitions, such an evasive maneuver could only have occurred during Phase 2 or 3. Elevated levels of entropy during Phase 2 may make sense in the context of a lower level during Phase 1. That is, the elevated entropy might be tied to the evasive maneuver rather than simply some aspect of the lane change for older drivers.

IMPROPER SPACING

An interesting trend was revealed when comparing interrupted and uninterrupted lane changes. During interrupted lane changes, a far higher number of lane changes were noted as cutting off another driver. Roughly 19% to 28% of interrupted lane changes involved cutting off another vehicle, whereas only 0% to 2% of uninterrupted lane changes did. Initially this makes sense as one would assume that the vehicle being cut off was the source of the interrupted lane change. The conflict type analysis, however, showed that many conflicts involved a lead vehicle in or incurring into the destination lane (22% to 63% for interrupted lane changes and 53% to 77% for uninterrupted lane changes). Additionally, the traffic density analysis showed very little difference in lane change execution by traffic density between interrupted and uninterrupted lane changes. Taken together, these analyses suggest that the vehicle being cut off is not necessarily the vehicle that forced an interrupting behavior on the part of the participant. For example, the participant may cut off a trailing vehicle in the destination lane but is forced to perform an interrupting behavior due to a slowing lead vehicle in the destination lane.

ENVIRONMENTAL FACTORS

Traffic Density

The prevalence of lane changes occurring by level of traffic density resulted in a distribution mimicking a normal-like curve. For *both* interrupted and uninterrupted lane changes, most lane changes occurred in moderate levels of traffic density, with decreasing numbers as traffic density either increases or decreases. One way the distribution of uninterrupted and interrupted lane changes differed is the level of skewness. During interrupted lane changes, the curve was skewed toward a higher traffic density relative to the uninterrupted lane changes, suggesting that higher levels of traffic density tend to be correlated with more opportunity for interrupted lane changes. Overall, the results show that most lane changes occur when traffic density is high enough to necessitate lane changes, but not so high that the ability to change lanes is hampered by surrounding traffic. This is the first instance the authors are aware of where lane change maneuvers by increasing traffic density are shown to follow a normal-like distribution.

Conflict Type

In both the interrupted and uninterrupted data sets, one conflict type was most prevalent: conflict with a lead vehicle in or incurring into the destination lane. Roughly 53% to 77% of all conflicts fell into this category depending on age group (note that middle-aged drivers were the least likely of the groups to be involved in this type of conflict). For uninterrupted left and right lane changes, a conflict with a lead vehicle in the destination lane was the largest source of conflict, but during interrupted lane changes the pattern does not hold as well.

Left lane changes had another large source of conflict that was not as present for right lane changes: trailing vehicles in the destination lane. Conflict with a lead vehicle could be accounted for by drivers attending to adjacent vehicles and those behind them without allocating as much attention to those in front of them. It could also reflect probabilities of conflict—that the participants believed they were more likely to have a conflict with adjacent and following vehicles. However, conflict with trailing vehicles in the destination lane during interrupted lane changes may reflect the inherent differences in left and right lane changes. The physical layout of the vehicle and the visual areas covered by mirrors differ by the side of the vehicle and could be a source for the differences in conflict type rate by lane change direction.

The more one studies lane changes, the more complex they become. Many actions are occurring at the same time from a number of operators, each pursuant to a countless number of potential variables (both known and unknown). Current lane change augmentations have attempted to increase safety by focusing on alerts indicate when vehicles are in the adjacent lane or the blind spot; however, our results show that vehicles in or moving into the forward part of the target lane may also play a vital role in lane-change safety. For instance, blind spot sensors may alert the driver to the presence of a vehicle in the blind spot, which is often assumed to be an indicator for a safe lane change, but fail to address potential conflict from in front of the vehicle or conflict from another vehicle incurring into the destination lane. Perhaps these systems could be integrated to provide a greater high-level “safe lane change” alert, a system that provides information to the driver that the lane change as a whole is safe to direct. Unfortunately, it is unlikely that such a system will ever be able to fully account for a third-party driver who behaves erratically, unpredictably, or even is simply executing their own lane change independent of the participant.

CHAPTER 7. CURRENT SOLUTION SPACE

FEEDBACK

Lavalliere, Simoneau, Tremblay, Laurendeau, and Teasdale (2012) showed that feedback training for older drivers significantly improved their frequency of OTS glances during a simulated drive. By providing feedback to participants over the course of four training sessions, older drivers improved their frequency of OTS glances related to lane changes from 32.3% to 65.9% compared to the control group, which improved slightly from 12.5% to 13.8%. In a similar study, Romoser and Fisher (2007) provided feedback to both older and younger drivers. Participants completed a simulated drive that involved intersection crossings and lane change maneuvers. Older drivers received feedback on errors related to lane changes more often than their younger counterparts. Older drivers failed to direct an OTS glance three times and merged too close an additional five times (versus one and four, respectively, for younger drivers). While the frequency of errors is quite low, it may be methodologically limited as only 1 of 10 driving scenarios presented to participants involved lane changes. After feedback, older drivers noted that they planned to incorporate the feedback into their driving “much more often.”

Our study showed that a small percentage of drivers across all age groups directed an OTS glance prior to initiating the lane change maneuver. Most who *did* make an OTS glance, did so after starting their maneuver. Clearly, attending to the positions of surrounding vehicles will make any driving maneuver safer and one clear way to do that is glancing to the various mirrors. While the current study showed strong usage of the side and rearview mirrors, drivers still failed to effectively utilize OTS glances. Given the research presented above (Lavalliere et al., 2012), which shows that older drivers can be trained to perform more OTS glances, some form of training needs to be presented to drivers of all age groups showing the importance of an OTS glance in safely determining their surroundings. Future research could focus on a naturalistic study with a training intervention to increase the number of OTS glances; first to verify that training does in fact increase OTS glances, and second to see if the novelty of the training wears off over time and drivers revert back to their previous glance behavior.

BLIND ZONE ALERTS

Kiefer and Hankey (2008) examined the changes to driver glance behavior in the presence of a side blind zone alert system. Both middle-aged (40–50 years old) and older drivers (60–70 years old) navigated a series of on-road drives for which a side blind zone alert system was present for half of the drives. While the rate at which drivers failed to provide OTS glances for a left lane change was similarly high (69%) to the studies listed previously, the data provided by Kiefer and Hankey were collapsed across the two age groups. Of particular interest is that 68% failed to direct an OTS glance in the presence of the alert system in the Kiefer and Hankey study. This suggests that the presence of a side blind zone alert system does not influence the frequency of OTS glances during lane changes.

The effectiveness of warning modality in a collision avoidance system in preventing conflict for both younger and older drivers was evaluated in a simulated environment (Kramer, Cassavaugh, Horrey, Becic, and Mayhugh, 2007). Different warning modalities (visual, auditory, tactile + visual, and visual + auditory) were evaluated along with a control (no warning). During the simulated drive, commands to change lanes were given, but during 33% of these lane changes, an additional vehicle appeared in the driver's blind spot. Kramer et al. (2007) did not find any statistically significant differences between age groups, suggesting that older drivers could potentially benefit as much as younger drivers with the addition of collision avoidance system. A follow-on experiment also discussed in Kramer et al. (2007) showed an age by warning modality interaction when the simulated driving task involved a secondary task. That is, increased driving demand revealed more strongly the safety benefit of a blind zone alert system for older drivers.

The current study showed that 18% to 30% of conflicts during interrupted lane changes were such that some form of a blind zone alert system may have proven useful. While it is difficult to know exactly what the driver is attentive to, we can infer from our glance analyses showing a very small proportion of OTS glances prior to lane change initiation, taken with a moderate percentage of conflicts with trailing vehicles in or incurring into the destination lane, that drivers are not completely aware of their surroundings. While these conflicts did not necessarily result in crashes, a blind zone detection system may have provided the information to the driver earlier, making the situation less dramatic. Future research should focus on glance behaviors of lane changes, but with and without the presence of blind zone alerts. Given that many systems are integrated into the side mirrors, a location where drivers frequently glance during their lane change maneuvers, one would assume the alert information would be readily available. However, one potential issue is the purpose of the glance to the side mirror in this context—is it because of the blind zone alert, or is it a glance to the mirror to determine surroundings? It would be interesting to note any increase in glances to the side mirrors in the presence of an alert system relative to vehicles that do not have such a system.

CURRENT MARKET SOLUTIONS

Several solutions currently exist in production vehicles that attempt to mitigate the risk associated with changing lanes. These systems come from original equipment manufacturers (OEMs) such as GM, Nissan, Ford, Toyota, and several others, as well as from aftermarket sources like Goshers, DrivSafe, TadiBrothers, and Donmar. Current systems present warnings to the driver in various modalities: visual only, visual + auditory, or as visual + auditory and vehicular intervention. Other aftermarket solutions exist as mirror augmentations to provide a wider field of view to the driver. These only provide additional visual information; they do not include an additional warning system to provide alerts to the driver. Lastly, there is some evidence to suggest that proper OEM mirror adjustment can effectively eliminate unsafe blind spots, though it is not clear how many are aware of or implement this approach to mirror arrangement (Platzer, 1995). In fact, this approach requires the driver to be fairly mobile and flexible, making it perhaps less-suited for senior drivers.

Visual Alert Only

Both Ford and GM use a radar sensor-based system for their vehicles. When another vehicle is present in the driver's blind spot, an icon located on the side mirror illuminates. Neither system includes an accompanying auditory alert for the driver. Similarly, the Toyota and Audi systems also only use a visual alert for the presence of vehicles in the blind spot. An icon on the side mirror illuminates when a vehicle is present, and if the driver then attempts a lane change by using the turn signal, the icon will blink to attract the driver's attention.

An aftermarket system from TadiBrothers employs much the same solution as the OEMs presented previously. By utilizing sensors in the rear of the car, the system illuminates an LED light mounted near the side view mirrors. No auditory alert is issued either in conjunction with the light illuminating or when the driver initiates a lane change.

Visual and Auditory

The camera-based system used on Nissan vehicles uses a rear-view camera (with a wide field of view) to detect the presence of traffic on the sides of the vehicle. When the camera detects a vehicle within the blind zone, a light illuminates near the A-pillar of the vehicle to notify the driver of an object in the blind zone. If the driver then attempts a lane change (indicated by turn signal usage), an auditory chime will alert the driver in addition to the flashing light near the A-pillar. Similar to the Nissan system, the radar-based Mazda blind spot detection system uses a visual alert located in the side mirrors followed by a chime should the driver engage the turn signal and attempt a lane change.

Available aftermarket systems from Goshers and DrivSafe both utilize sonar sensors and include an LED icon that illuminates in the presence of a vehicle in the driver's blind spot. The location of the icon may vary based on installation. An auditory alert can be installed as well that provides a chime in addition to the illumination. This system, however, does not issue an auditory alert based on turn signal use, but rather in conjunction with the visual illumination.

Visual, Auditory, and Intervention

Mercedes and Infinity both use a radar-based system in their vehicles. When another vehicle is in the driver's blind spot, a warning icon is displayed on the outside mirror. In the event of an intended lane change, marked by turn signal use, a chime is issued to further alert the driver to the presence of the other vehicle. Should the driver then continue to direct the lane change, the system intervenes by applying brakes to the outside wheels, thus steering the vehicle away from the target vehicle.

Mirror Augmentations

Several forms of mirror augmentation are available in the aftermarket world. These can range from simple stick-on aspheric mirrors and replacement rearview mirrors to rearview mirrors including camera-based video. Other drivers have been known to even install additional mirrors either outside of their vehicle or mounted to the windshield in an effort to eliminate the blind spot. The goal of any basic mirror augmentation is to simply increase the field of view (FOV) of the mirror and capture more of the world around the driver. By mounting an aspheric mirror into the corner of an outside mirror, drivers are able to retain much of their typical FOV using the side mirror with an additional location containing a wide FOV. Ultra-wide replacement rear-view mirrors can be found where the mirror is simply wider than the OEM design in many vehicles. By increasing the width of the mirror, the effective FOV is increased, eliminating or reducing the blind spot.

A camera-based solution from Donmar utilizes small cameras mounted on the bottom of the side mirrors as a feed into an LCD display such as one might find in some aftermarket rearview mirrors. The video feed gets triggered by turn signal use and immediately provides a video image to the LCD display. Unfortunately, mirror augmentations rely only on increasing the visibility for the driver; they do not provide any sort of additional visual or auditory alert.

Alternate Mirror Adjustment

In 1995, Platzer presented a very simple solution to nearly eliminate the blind spot: adjust your mirrors correctly. Most people adjust their side mirrors so that they can side the side of their car, Platzer suggested that by altering the adjustment of the three mirrors in the vehicle (rearview and both side mirrors), the driver could essentially turn two large blind spots into four very small blind spots. With the mirrors adjusted in the suggested fashion, the driver can watch a passing vehicle on the left exit the rearview mirror as it enters the driver's side mirror and then the driver's peripheral vision, all without losing track of the vehicle. It is doubtful that many drivers have used this approach, and it may be especially difficult for seniors as it requires the driver using this alternate mirror adjustment to position him/herself in the middle of the vehicle (which may be very difficult to do from the driver's seat).

REMAINING QUESTIONS

The results show in several ways that drivers of all age groups fail to direct OTS glances and side mirror checks at an alarmingly high rate prior to initiation of lane changes. What we are unable to determine is why drivers are failing to direct these glances. Do drivers keep mental track of the traffic around them? If they do, how accurate is it? Why do drivers believe that a side mirror glance or rearview mirror check is enough to ensure safe passage and if so, is it? Most turn signal activation, when used, occurred after initiation. This, taken with glance characteristics, clearly indicates that drivers do most of their glancing and lane-change behaviors *after* they have already initiated the maneuver. Why do drivers wait until after initiation to begin these tasks?

A number of potential questions can be raised as blind spot warnings have become more common. How often will drivers begin to rely on the alert itself rather than what they are physically seeing in the mirror? A potentially unsafe level of dependence on the alert could arise, depending on how successfully the blind spot warning or other crash mitigation system has been implemented. Are drivers able to cognitively attend to two sources (the alert itself as well as the reflected image in the mirror)? Even if the alert is located in the same physical location as the mirror itself, a driver most likely will not be able to attend to both at the same time, but rather have to switch between the two from a cognitive attention perspective. What affect does inclement weather have on the conspicuity of the alert? Do rain-covered windows and mirrors affect the driver's ability to clearly detect the alert when activated relative to other similarly colored objects (e.g., painted lines, other vehicles, etc.) which may be reflected in a rain-distorted fashion?

LIMITATIONS

While the SHRP 2 data set affords great insight into lane-change behaviors, what it cannot tell us is what the drivers were thinking about during the maneuver and why they behaved as they did. While the researchers tried to determine relevant variables related to the lane-change maneuvers, it is possible that some aspect of a complex maneuver was not recorded or analyzed. Additionally, the largest limitation of the SHRP 2 data set is the inability to determine what a participant was attending to during the maneuver. While they may glance to a given location, and we assume they are cognitively attending to that glance, that simply may not be true, as the participant may have “looked but did not see” a potential hazard. Another limiting aspect of the SHRP 2 data was the relatively low number of older drivers who experienced interrupted lane changes.

This study represents the first known naturalistic descriptive observation of uninterrupted and interrupted lane-change-related behaviors (e.g., glance-related behaviors) where the results were assessed across age groups, including younger and older drivers. Such behaviors were evaluated by lane change phase, direction, traffic density, environmental factors, secondary task performance, and driving errors across young, middle-aged, and older driver age groups. The findings may be useful to those designing lane-change warnings (e.g., blind spot warnings) or lane-keep assist technologies. Other stakeholders, such as those charged with training different age group drivers, may benefit as well.

APPENDIX A. UNINTERRUPTED LANE CHANGE QUESTION REDUCTION

STSCE Senior Driver Lane Change
Question Reduction

Task Name for Logs: Senior Driver Lane Change
Fund to Charge: 500095
Document Location: \\vtti.ad.vt.edu\Data\Projects\500095\Reduction
Software Needed: Hawkeye, Excel
Collections: NEW SHRP2
Security Group(s) Needed: Projects-IRBCertified, Projects-Reductionists, Project-415586-Reductionists, Project-500095-Reductionists
Database Roles Needed: SHRP2_Reductionist

Project Overview:
The goal of this task is to review lane-change events from the SHRP2 data collection effort. Reductionists will review the selected lane-change events and code a number of environmental and behavioral variables. Two efforts will be undertaken: an glance reduction and a question reduction. This protocol provides instructions for the question reduction.

Reduction Log:

1. Location: \\vtti.ad.vt.edu\Data\Projects\500095\Reduction\SeniorLaneChange_QR_Log.xlsx
2. Scroll down to locate the first row that has not been marked complete. Sign out that event.
3. Save the Excel log after signing out each new event.

<u>Setting up Hawkeye:</u>

1. Load Hawkeye
2. Load the NEW SHRP2 collection
3. Copy and paste the File_ID from the Excel log for the file you have signed out into the Trip field in Hawkeye.
4. Open the Event Select menu, and locate the event that you have signed out by matching the Event_ID. For this assignment, the Event Type will always be listed as "**STSCE Senior Lane Change**".
5. Open the question annotation called "Senior Lane Change"
6. It is very recommended that you set graph accuracy to accurate in order to get the most accurate graph readings in Hawkeye. To do this go to File>Options> Visualization > Graphing tab. Check the "accurate" box for graph accuracy and save. This option will not transfer from one workstation to another so you will need to do this every time that you

move to a new computer. (If you need "fast" speed data for any reason during your analysis of the video, you may reverse this setting as needed.) Detailed graph accuracy can slow down Hawkeye, so it may be necessary to close and reopen Hawkeye and load your layout if it is taking a long time for files to load.

7. Load the following views/variables. You may save the layout if you wish for easier loading in the future.
    a. Video views you will need
        i. Face
        ii. Front
        iii. Hands
        iv. Rear
    b. Graphs you will need
        i. Vtti.Network speed (or GPS if Network not available)
        ii. Vtti.Accel Y
        iii. Vtti.Steering wheel angle (if available)
        iv. Cabin Snapshot
        v. Vtti Turn signal
        vi. RoadScout Left Lane Distance to Right Side vii. RoadScout Right Lane Distance to Left Side
        viii. Vtti Radar Range (multiple targets, <u>at least</u> from T0 through T3)
        ix. Vtti Radar Range Rate (multiple targets, <u>at least</u> from T0 through T3)
        x. Vtti Object ID (multiple targets, <u>at least</u> from T0 through T3)

    (See <u>Variable Layout Example</u>)

Reduction Steps:

- <u>Before reducing an event, please check to see if the subject completes the lane change they initiated. If the lane change is not completed, mark the event as invalid in the Excel Log.</u>

<u>Page 1 of question annotation:</u>

1. LaneChangeStart: **Enter the lane change initiation time stamp.** (text box)
    - To determine the start of the lane change, first use the steering wheel video view and/or steering wheel angle variable (if available). The lane change initiation is when the steering wheel is first moved away from neutral in the direction of the planned lane change.
    - If unable to determine the lane change initiation using the steering wheel method, use Accel_Y (first departure from neutral in the direction of the planned lane change) as a second method. Note that a neutral Accel_Y is generally around 0 g, unless the vehicle is negotiating a curve or turn or the sensor is improperly calibrated.

- If neither steering wheel nor Accel_Y methods are helpful, the third and least desirable option is to take the point in the forward video at which the subject vehicle first appears to start moving towards the lane line in the direction of the desired lane change.

2. LaneChangeStartMethod: **Indicate which method was used to determine the lane change initiation time stamp above.** (If multiple variables are used to determine the frame number, code the option that is higher on this list.)
    a. Steering Wheel (first moves from neutral position)
    b. Accel_Y (first moves from neutral)
    c. Forward Video (start of movement toward lane line)

3. LaneChangeLine: **Enter the frame number where the subject vehicle first intrudes into the target lane when completing the lane change maneuver.** (text box)
    - To help determine the frame where the subject intrudes into the target lane, compare the lane line the subject is crossing with the center of the subject vehicle's hood or dash. When the center of the vehicle hits the lane line, we can estimate that the subject vehicle has intruded into the target lane. Do NOT simply use the center of the video to determine when the vehicle hits the lane line, it must be the center of the vehicle.
    - If the subject is going across multiple lanes for the lane change maneuver, code the timestamp for the first lane they intrude into.
    - Please see Center of Vehicle Examples.

4. LaneChangeEnd: **Enter the frame number where the driver has first completed the lane change maneuver.** (text box)
    - To determine the end of the lane change, first use the steering wheel video view and/or steering wheel angle variable (if available). The lane change completion is when the steering wheel has first returned to neutral after settling in the new lane.
    - If unable to determine the lane change end using the steering wheel method, use Accel_Y (first return to neutral after settling in the new lane) as a second method. Note that a neutral Accel_Y is generally around 0 g, unless the vehicle is negotiating a curve or turn or the sensor is improperly calibrated.
    - If neither steering wheel nor Accel_Y methods are helpful, the third and least desirable option is to take the point in the forward video at which the subject vehicle first appears to have settled in the new lane (the start of when the apparent distance to the crossed lane line appears stable).

5. LaneChangeEndMethod: **Indicate which method was used to determine the lane change completion time stamp above.** (If multiple variables are used to determine the frame number, code the option that is higher on this list.)
    a. Steering Wheel (first returns to neutral position)

b. Accel_Y (first returns to neutral)
c. Forward Video (distance to crossed lane line first levels off)

6. LanesEntered: **How many adjacent lanes does the subject enter during the lane change maneuver?** This count should include the destination lane, but not the origin lane.
   - *For example, a typical lane change would be coded as 1 lane, but a driver crossing through a lane before settling into a destination lane would be coded as 2 lanes.* a. 1

   b. 2
   c. 3
   d. 4
   e. 5+

Page 2 of question annotation

7. Direction: **Enter the direction of the lane change maneuver.**
   a. Left
   b. Right

8. AdjLanes: **Enter the number of adjacent, same-direction lanes next to the subject vehicle's origin lane in the direction of the lane change.**
   Count the number of lanes at the point where the destination lane has formed.
   Include in the count all lanes in the subject's direction of travel (plus center-2-way turn lanes) that are not separated from the driver's lane by a median, barrier, or construction cones. Include (if available) center 2-way turn lanes, acceleration/deceleration lanes, and turn lanes. Do NOT include oncoming traffic lanes.

   For example, if there are two contiguous lanes available for travel to the left of the subject vehicle and the subject changes lanes to the left, the answer would be 2.

   a. 0 – (only use when subject is moving into oncoming lane)
   b. 1
   c. 2
   d. 3
   e. 4
   f. 5+
   g. Unknown

9. TypeLaneChange: **What type of lane change is the subject performing? (Origin lane to destination lane).** Make this decision based on the timestamp when the subject vehicle intrudes into the target lane.

- *If the subject is entering a lane that started as a through lane and because a dedicated turn lane, code it according to what you can see in the video. If the subject is visibly approaching the intersection with the dedicated turn lane or if it apparent they are changing into the lane to use as a turn lane, code "From a through lane to an existing turn lane." If they change lanes well before it is apparent that it is a dedicated turn lane, code "From one through lane to another."*
- *If the subject is changing lanes to ultimately occupy a dedicated left turn lane but intrudes into a center 2-way turn lane first, code "From a through lane to an upcoming turn lane."*
    a. <u>From one through lane to another</u>
    b. <u>From a dropped lane to a through lane</u> (includes acceleration lane/deceleration lane to through lane)
    c. <u>From a through lane to an existing turn lane</u>
    d. <u>From a through lane to an upcoming turn lane</u> (turn lane does not yet exist when lane line is crossed)
    e. <u>From a through lane to a center-two-way turn lane</u>
    f. <u>From a through lane to a deceleration lane</u>
    g. <u>From an acceleration lane to a through lane</u>
    h. <u>Other (specify in notes)</u>
    i. <u>Unable to determine</u>

10. DestLanePresent: **Prior to lane change initiation, did the same-direction destination lane already exist, and was it the same type of lane?** In other words, is the destination lane present before the lane change, and if it is, does the destination lane remain the same type of lane? To say that the lane was previously present, the lane must be in the same travel direction as the subject (or be a center-2-way turn lane) prior to lane change initiation. Examples of lane type changes include (but are not limited to) a center-2-way turn lane changing to a dedicated turn lane, a through lane changing to turn lane, and turn lane changing to a through lane.
    a. <u>Yes, destination lane was present and same type</u>
    b. <u>Yes, destination lane was present but different type</u>
    c. <u>No, destination lane was not present</u>
    d. <u>Unable to determine</u>

11. SubjPassVehicle: **<u>In the direction of the lane change</u>, had the subject just passed another vehicle (moving or stationary) within 10 seconds of initiating the lane change?** (Answer Yes only if other vehicle was still at least partially adjacent to the subject within 10 seconds prior to initiating the lane change. This does NOT apply to vehicles that passed the subject; only applies to vehicles that the subject passed. If the subject maneuvers over multiple lanes during the lane change, check to see if the subject passes vehicles in the multiple adjacent lanes)

a. Yes, subject just passed vehicle in destination lane
b. No, not at all or not within 10 seconds
c. Unable to determine
d. Not applicable – destination lane did not exist prior to lane change initiation

12. SignalTimeStamp: **When did the driver engage the turn signal?** (text box) Enter the timestamp when the driver engages the turn signal. Use the turn signal variable to see when the signal is activated, but check the video to see if the signal is engaged a few frames before it shows up in the graph. If no turn signal was used, enter -1 (negative 1). If unable to determine if turn signal was used or when it was activated, enter -99 (negative 99).

     If the subject only uses the turn signal for making at a turn at an intersection instead of using it for a lane change, do not code the turn signal as being used. You must be certain it is not being used for the lane change, and you must leave a note on Page 9 if this happens.

13. SignalDirection: **Was the turn signal engaged for the intended direction of travel**?
    a. Yes, correct direction
    b. No, wrong direction
    c. Unable to determine
    d. Not applicable - no signal used

Page 3 of question annotation – Lead Vehicle Origin Lane

14. LeadOrigPresentBefore: **Is there a lead vehicle present in the subject vehicle's original lane at the initiation of the lane change?**
    - *If a lead vehicle is in the middle of changing lanes at the initiation of the subject's lane change, code the lead vehicle as being in the target lane it is moving into.* a. Yes
    b. No
    c. Unable to determine

15. LeadOrigObjectID: **If Yes above, what is the radar's Object_ID for the lead vehicle during the lane change maneuver?** (text box)
    If there is no lead vehicle in origin lane, enter -1 (negative 1). If lead vehicle is present in origin lane but there is no radar data, enter -99 (negative 99). If Object_ID changes for the lead vehicle during the subject's lane change maneuver, list the sequence of Object_IDs separated by commas (no spaces). If you cannot easily tell which Object_ID is correct, type "Unknown." Do not spend a long time on this variable.

16. LeadOrigDistance: **If Yes above, how far ahead of the subject is the lead vehicle <u>at the initiation</u> of the lane change?**
    - *Keep in mind that the distance from the start of one dashed lane line to the start of another dashed lane line is 40 feet. Simply just seeing 2 dashed lane lines is NOT the full 80 feet.*
        a. <u>Less than 20 feet</u> (within 0.5 dashed line)
        b. <u>20 to 80 feet</u> (within 0.5-2 dashed lines)
        c. <u>More than 80 feet</u> (more than 2 dashed lines)
        d. <u>Unable to determine</u>
        e. <u>Not Applicable</u> – no lead vehicle in origin lane

17. LeadOriginMove: **If Yes above, does the lead vehicle appear to be moving closer to the subject vehicle or further away?** When determining this variable, reductionists should not spend long making a decision. If it is not obviously “Closer” or “Further,” it should be coded as “Keeping Steady.”
    a. <u>Closer</u>
    b. <u>Further</u>
    c. <u>Keeping steady</u>
    d. <u>Unable to determine</u>
    e. <u>Not Applicable</u> – no lead vehicle in origin lane

Page 4 of question annotation – Following Vehicle Origin Lane

18. TrailOriginPresent: **Is there a trailing vehicle present in the subject vehicle’s <u>original</u> lane at the initiation of the lane change?**
    - *If a following vehicle is in the middle of changing lanes at the initiation of the subject’s lane change, code the following vehicle as being in the target lane it is moving into.* a. <u>Yes</u>
        b. <u>No</u>
        c. <u>Unable to determine</u>

19. TrailOriginDistance: **If Yes above, how far behind does the trailing vehicle appear to be?**
    - *Keep in mind that the distance from the start of one dashed lane line to the start of another dashed lane line is 40 feet. Simply just seeing 2 dashed lane lines is NOT the full 80 feet.*
        a. <u>Less than 20 feet</u> (within 0.5 dashed line)
        b. <u>20 to 80 feet</u> (0.5-2 dashed lines)
        c. <u>More than 80 feet</u> (more than 2 dashed lines)
        d. <u>Unable to determine</u>
        e. <u>Not Applicable</u> – no trailing vehicle in origin lane

20. TrailOriginMove: **If Yes above, does the trailing vehicle appear to be moving closer to the subject vehicle or further away?** When determining this variable, reductionists should not spend long making a decision. If it is not obviously "Closer" or "Further," it should be coded as "Keeping Steady."
    a. Closer
    b. Further
    c. Keeping steady
    d. Unable to determine
    e. Not Applicable – no trailing vehicle in origin lane

Page 5 of question annotation – Trailing Vehicle Destination Lane

21. TrailDestPresent: **Is there a trailing vehicle present in the subject vehicle's destination lane at the initiation of the lane change?**
    - *If a following vehicle is in the middle of changing lanes at the initiation of the subject's lane change, code the following vehicle as being in the target lane it is moving into.*
    a. N/A - no lane present
    b. Yes
    c. No
    d. Unable to determine

22. TrailDestDistance: **If Yes above, how far away does the adjacent trailing vehicle appear to be?**
    - *Keep in mind that the distance from the start of one dashed lane line to the start of another dashed lane line is 40 feet. Simply just seeing 2 dashed lane lines is NOT the full 80 feet.*
    a. N/A - no lane present
    b. Less than 20 feet (within 0.5 dashed line)
    c. 20 to 80 feet (0.5-2 dashed lines)
    d. More than 80 feet (more than 2 dashed lines)
    e. Unable to determine
    f. N/A – no trailing vehicle in destination lane

23. TrailDestCutOff: **If Yes above, does the subject vehicle appear to 'cut-off' the adjacent trailing vehicle?**
    a. N/A - no lane present
    b. Yes
    c. No
    d. Unable to determine
    e. N/A – no trailing vehicle in destination lane

24. TrailDestMove: **If Yes above, does the adjacent trailing vehicle appear to be moving closer to the subject vehicle or further away?** When determining this variable, reductionists should not spend long making a decision. If it is not obviously "Closer" or "Further," it should be coded as "Keeping Steady."
    a. N/A - no lane present
    b. Closer
    c. Further
    d. Keeping steady
    e. Unable to determine
    f. N/A – no trailing vehicle in destination lane

Page 6 of question annotation – Lead Vehicle Destination Lane

25. LeadDestPresent: **Is there a lead vehicle present in the subject vehicle's destination lane at the initiation of the lane change?**
    - *If a lead vehicle is in the middle of changing lanes at the initiation of the subject's lane change, code the lead vehicle as being in the target lane it is moving into.* a. Yes
    b. No
    c. Unable to determine

26. LeadDestDistance: **If Yes above, how far away is the adjacent lead vehicle at the initiation of the lane change?**
    - *Keep in mind that the distance from the start of one dashed lane line to the start of another dashed lane line is 40 feet. Simply just seeing 2 dashed lane lines is NOT the full 80 feet.*
    a. Less than 20 feet (within 0.5 dashed line)
    b. 20 to 80 feet (0.5-2 dashed lines)
    c. More than 80 feet (more than 2 dashed lines)
    d. Unable to determine
    e. Not Applicable – no lead vehicle in destination lane

27. LeadDestObjectID: **If Yes above, what is the radar's Object_ID for the adjacent lead vehicle?** (text box)
    If there is no lead vehicle in destination lane, enter -1 (negative 1). If lead vehicle is present in destination lane but there is no radar data, enter -99 (negative 99). If Object_ID changes for the lead vehicle during the subject's lane change maneuver, list the sequence of Object_IDs separated by commas (no spaces). If you cannot easily tell which Object_ID is correct, type "Unknown." Do not spend a long time on this variable.

28. LeadDestMove: **If Yes above, does the adjacent lead vehicle appear to be moving closer to the subject vehicle or further away?** When determining this variable, reductionists should not spend long making a decision. If it is not obviously "Closer" or "Further," it should be coded as "Keeping Steady."

a. Closer
b. Further
c. Keeping steady
d. Unable to determine
e. Not Applicable – no lead vehicle in destination lane

29. DirectAdjVehicle: **Is there a vehicle directly adjacent to the subject vehicle in the destination lane at the initiation of the lane change, and what speed is it going in comparison to the subject vehicle?**

- *Directly adjacent to the subject means at least the front bumper of the adjacent vehicle is lined up with the rear bumper of the subject's vehicle, or the subject vehicle's front bumper is lined up with the rear bumper of the adjacent vehicle. If there is space between the subject's and the other vehicle's bumper, then count the other vehicle as either a leading or trailing vehicle.*

a. Yes, with adjacent vehicle going faster than subject vehicle
b. Yes, with adjacent vehicle going slower than subject vehicle
c. Yes, other
d. No vehicle directly adjacent to subject in destination lane
e. N/A – Adjacent lane not present

Page 7 of question annotation – Environment & Behavior

30. Traffic: **What is the traffic density at the point of lane change initiation?**

a. LOS A1: Free flow, no lead traffic
b. LOS A2: Free flow, leading traffic present
c. LOS B: Flow with some restrictions
d. LOS C: Stable flow, maneuverability and speed are more restricted
e. LOS D: Unstable flow - temporary restrictions substantially slow driver
f. LOS E: Flow is unstable, vehicles are unable to pass, temporary stoppages, etc.
g. LOS F: Forced traffic flow condition with low speeds and traffic volumes that are below capacity
h. Unable to determine

31. Locality: **What locality is this lane change occurring in?**

a. Open Country
b. Open Residential
c. Moderate Residential
d. Business/Industrial
e. Church
f. Playground
g. School
h. Urban
i. Airport

j. Interstate/Bypass/Divided Highway, Controlled Access
k. Bypass/Divided Highway, Access not controlled
l. Other
m. Unknown

32. Alignment: **What is the roadway alignment at the initiation of the lane change maneuver?**
    a. Straight
    b. Curve left
    c. Curve right
    d. Other
    e. Unknown

33. Aggression: **Are there behavioral cues to suggest the subject driver is showing an overall increased level of aggression, before, during, or after the lane change?** a. Yes
    b. No
    c. Unable to determine

34. Sporty: **Are there behavioral cues to suggest the subject driver is engaged in 'sporty' driving before, during or after the lane change?**
    a. Yes
    b. No
    c. Unable to determine

35. Occupants: **How many human occupants are there in the vehicle including the driver?** Use Cabin Snapshot (if available) to help determine the amount of passengers present.
    a. 1 (driver only)
    b. 2
    c. 3+
    d. Unable to determine

Page 8 of question annotation – Secondary Tasks

36. PriorSecondaryTask 1, 2, 3: **What secondary task(s) is the subject driver engaged in during the 5 seconds prior to initiation of the lane change maneuver via steering wheel?**
    a. Please see Secondary Tasks for list of options

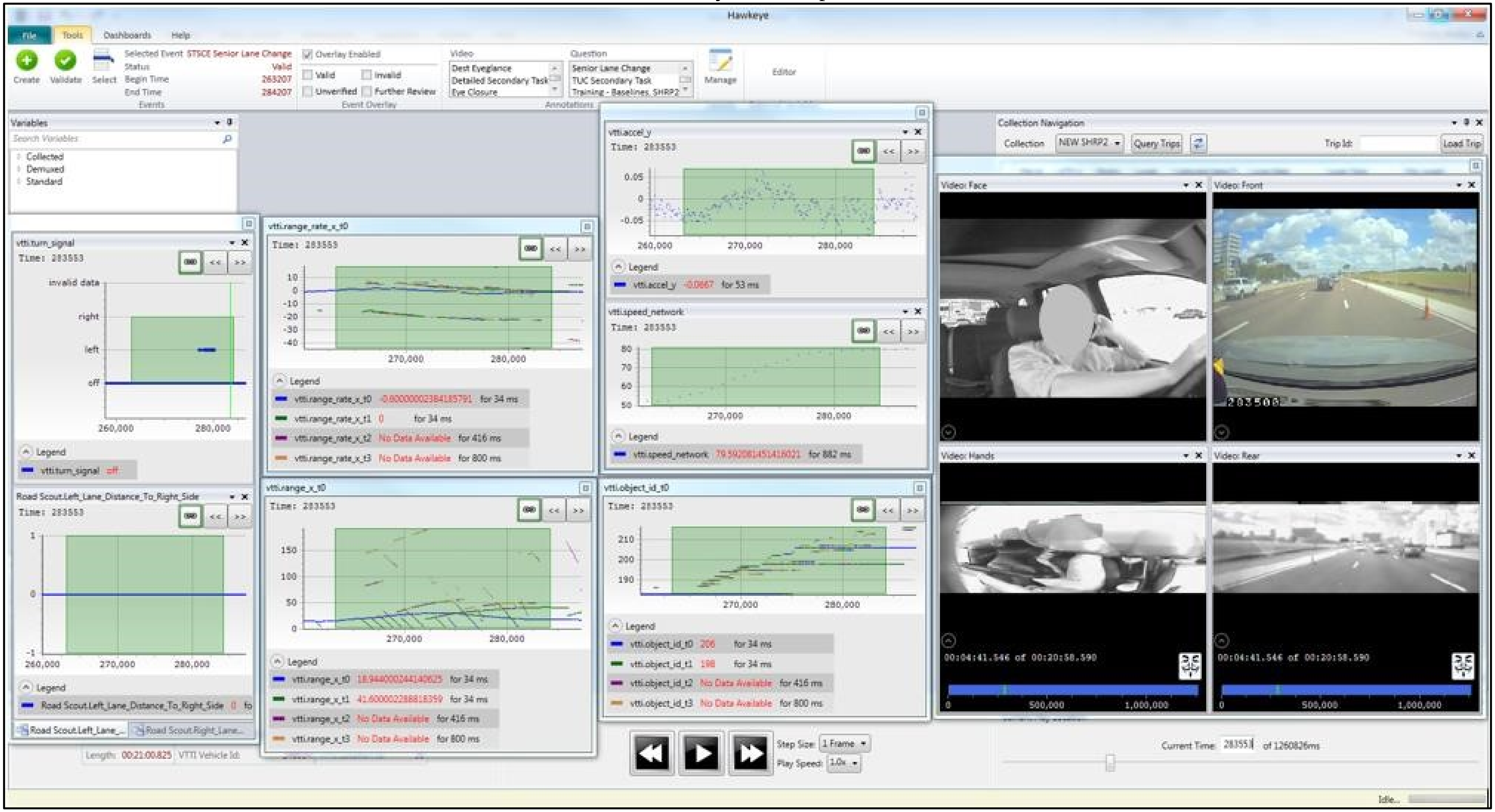
37. DuringSecondaryTask 1, 2, 3: **What secondary task(s) is the driver engaged in during the lane change maneuver?**

a. <u>Please see Secondary Tasks for list of options</u>

Page 9 of question annotation – Notes

38. AdditionalNotes: **Additional Notes.** Provide any additional notes needed to describe the lane change if not covered by previous questions. Also explain any “other” and “unknown” responses.

Variable Layout Example



Center of Vehicle Examples

Some cars have a center dot/marker on the dash of the car (Figure A). This spot is the center of the vehicle dashboard, and thus the center of the vehicle itself. Other cars do not have this marker or it is not in the frame (Figure B), but if you look close, you can see where two vents come near each other suggesting the space between them is the center of the vehicle. Figure C is another example of where the center of the vehicle is by referencing the vents.

Figure A: There is a center dot/marker in the video that shows where the center of the vehicle is.

Figure B and C: There is a gap between the vents on the dashboard that shows where the center of the vehicle is.

Traffic Density

Category	*Category Definition*	*Examples and Hints*
Level-of-service A1: Free flow, no lead traffic	LOS A1 represents a free flow traffic situation when the subject vehicle has no leading traffic in any lane (following traffic may or may not be present). Individual users are unaffected by the traffic stream. Freedom to select desired speeds and to maneuver within the traffic stream is at the highest level possible.	Driving-related decisions are made with virtually no need to consider the presence of other vehicles (due to the lowest traffic density).
Level-of-service A2: Free flow, leading traffic present	LOS A2 represents a free flow traffic with a leading vehicle present in at least one lane. However, individual drivers are still virtually unaffected by the presence of others in the traffic stream. Freedom to select desired speeds and to maneuver within the traffic stream is extremely high. The general level of comfort and convenience provided to the motorist, passenger, or pedestrian is excellent.	Ex. 1: If more than 1 lane is present in the direction of travel, then LOS A2 may apply if there is a lead vehicle in the subject's lane but no vehicles in the adjacent lane preventing the driver from passing the lead vehicle. If there is a lead vehicle, there should be no or very few other vehicles on the road in order to qualify for LOS A, and speed selection should be unconstrained. Ex. 2: If the subject is preparing to exit, merge, change lanes, etc., then no other vehicles should be in position to potentially interfere with this maneuver to be considered LOS A.

Category	*Category Definition*	*Examples and Hints*

<u>Level-of-service B: Flow with some restrictions</u>	LOS B is still in the range of stable flow, but the presence of other users in the traffic stream begins to be noticeable. Freedom to select desired speeds is relatively unaffected, but there is a slight decline in the freedom to maneuver within the traffic stream from LOS A. The level of comfort and convenience provided is somewhat less than at LOS A, because the presence of others in the traffic stream begins to affect individual behavior.	Driving-related decisions are made with a small need to consider the presence of other vehicles (due to a fairly low traffic density). Ex. 1: If only 1 through lane is present, LOS B may apply if a lead vehicle is present at a fairly constant range and the subject is moderating vehicle speed to match that of the lead vehicle, but speeds are still at or near the speed limit. Ex. 2: If >1 through lane is present, then LOS B may apply if there is a lead vehicle as well as an adjacent vehicle preventing the driver from easily passing OR if there are adjacent vehicles on both sides. However, this situation should be transient. The subject driver should not be "boxed" in for a more than a few seconds. LOS B would also apply if several vehicles are present in the mid-range vicinity, even if they are not directly in front of or adjacent to the subject. Driving speeds are still at or near the speed limit and are not persistently affected by surrounding traffic. Ex. 3: If the subject is preparing to exit, merge, change lanes, etc. in an LOS B environment, there will be at least one vehicle that could pose a potential hazard and requires monitoring by the subject, but the maneuver can still be completed fairly easily.

Category	*Category Definition*	*Examples and Hints*
Level-of-service C: Stable flow, maneuverability and speed are more restricted	LOS C is still in the range of stable flow, but marks the beginning of the range of flow in which the operation of individual users becomes significantly affected by interactions with others in the traffic stream. The selection of speed is now affected by the presence of others, and maneuvering within the traffic stream requires substantial vigilance on the part of the driver. The general level of comfort and convenience declines noticeably at this level.	Driving-related decisions are made with a definite need to consider the presence of other vehicles, with a good chance of mishap if such considerations are not made (due to a medium traffic density). Ex. 1: If only 1 through lane is present, LOS C may apply if subject has a lead vehicle AND another car is following the subject. OR, if subject is following multiple vehicles. In either case, the speed is significantly controlled by leading traffic, but the prevailing speed is not more than 10 mph below the speed limit. Ex. 2: If >1 through lane is present, LOS C may apply if the subject is "boxed in" by lead and adjacent vehicles and this condition is not transient (e.g., it persists as the vehicles travel for some time). LOS C would also apply if multiple vehicles are present in the near-range vicinity, and travel speeds are moderately affected (but are not more than 10 mph below the posted speed limit). Ex. 3: If the subject is preparing to exit, merge, change lanes, etc. in an LOS C environment, there will be multiple vehicles posing potential hazards and requiring careful monitoring by the subject. The maneuver will be more difficult, but will generally be completed without incident.

Category	***Category Definition***	***Examples and Hints***
Level-of-service D: Unstable flow - temporary restrictions substantially slow driver	LOS D represents a high-density traffic flow that is beginning to show signs of instability. Speed and freedom to maneuver are severely restricted, and the driver or pedestrian experiences a generally poor level of comfort and convenience. Small increases in traffic flow will generally cause operational problems at this level.	Driving-related decisions are made with urgent need to consider the presence of other vehicles, with a great likelihood of mishap if such considerations are not made (due to a fairly high traffic density). Ex. 1: If only 1 through lane is present, LOS D may apply if subject is following another car AND another car is following the subject. OR, if subject is following multiple vehicles. In either case, the speed is significantly controlled by leading traffic, and prevailing speed is more than 10 mph below the speed limit. Ex. 2: If >1 through lane is present, LOS D may apply if the subject is persistently "boxed in" by lead vehicles and adjacent vehicles, AND the prevailing travel speed is determined by surrounding traffic and is more than 10 mph below the posted speed limit. Ex. 3: If the subject is preparing to exit, merge, change lanes, etc. in an LOS D environment, there will be multiple vehicles posing potential hazards and requiring careful monitoring. The maneuver will not be easy and will likely involve braking, accelerating, or excessive steering on the part of the subject or other vehicles.

Category	***Category Definition***	***Examples and Hints***
Level-of-service E: Flow is unstable, vehicles are unable to pass, temporary stoppages, etc.	LOS E represents operating conditions at or near the capacity level. All speeds are reduced to a low, but relatively uniform value. Freedom to maneuver within the traffic stream is extremely difficult, and it is generally accomplished by forcing a vehicle or pedestrian to "give way" to accommodate such maneuvers. Comfort and convenience levels are extremely poor, and driver or pedestrian frustration is generally high. Operations at this level are usually unstable, because small increases in flow or minor perturbations within the traffic stream will cause breakdowns.	Driving-related decisions are made with an urgent need to consider the presence of other vehicles, with a great likelihood of mishap if such considerations are not made/freedom to direct maneuvers is severely restricted such that drivers must be aggressive in maneuvering (due to a very high traffic density). Ex. 1: If only 1 through lane is present, LOS E may apply if subject is following multiple cars AND multiple cars are following the subject. The speed is significantly controlled by leading traffic, and the prevailing speed is reduced to less than half the posted speed limit. Ex. 2: If >1 through lane is present, then LOS E may apply if the subject is persistently "boxed in" by lead vehicles and adjacent vehicles, AND the prevailing travel speed is determined by surrounding traffic and is less than half the posted speed limit. Ex. 3: If the subject is preparing to exit, merge, change lanes, etc. in an LOS E environment, there will be multiple vehicles posing potential hazards and requiring careful monitoring by the subject. The maneuver will be "forced" and will likely involve braking, accelerating, or excessive steering on the part of both the subject and other vehicles.

Category	*Category Definition*	*Examples and Hints*
Level-of-service F: Forced traffic flow condition with low speeds and traffic volumes that are below capacity	LOS F represents forced or breakdown flow. This condition exists wherever the amount of traffic approaching a point exceeds the amount which can traverse the point. Queues form behind such locations. Operations within the queue are characterized by stop-and-go waves, and they are extremely unstable. Vehicles may progress at reasonable speeds for several hundred feet or more, then be required to stop in a cyclic fashion. LOS F is used to describe the operating conditions within the queue, as well as the point of the breakdown. It should be noted, however, that in many cases operating conditions of vehicles or pedestrians discharged from the queue may be quite good. Nevertheless, it is the point at which arrival flow exceeds discharge flow, which causes the queue to form, and level-of-service F is an appropriate designation for such points.	Traffic flow and related driving decisions are based entirely on the presence and actions of other vehicles (due to the highest traffic density). Ex. 1: Regardless of the number of travel lanes, LOS F represents "traffic jam" or "stop and go" conditions. Ex. 2: If the subject is preparing to exit, merge, change lanes, etc. queues will be forming or present either in the subject's desired lane and/or in the subject's destination lane. The maneuver will be "forced" and will involve braking, accelerating, or excessive steering on the part of both the subject and other vehicles.

Locality

Category	*Category Definition*	*Examples and Hints*
Open country	Other than the roadway, there is nothing but vegetation visible during the time surrounding the Precipitating Event that is described in any of the other categories. Road is not an Interstate or a bypass/divided highway with traffic signals. (Often appears as rural roads, 2 lanes undivided.)	Includes roadways not defined as Interstate or divided highway, when no landmarks mentioned in other categories are visible.

Open Residential	Rural to semi-rural areas where there may be only one or a few houses around (i.e., farmland).	
Moderate Residential	An area where multiple houses or apartment buildings are present, but is not as dense as an Urban Locality.	e.g., residential subdivisions
Business/industrial	Any type of business or industrial structure is present, but is not as dense as an Urban Locality. (If there are also houses visible, this category takes precedence over Open residential and Moderate residential).	
Church	One or more involved vehicle passes a church building at the time of the Precipitating Event.	
Playground	One or more involved vehicle passes any type of playground or children's playing field at the time of the Precipitating Event.	If playground/field is on school grounds, code as School.
School	One or more involved vehicles passes any type of school building or is in a school zone at the time of the Precipitating Event, including adult learning institutions.	Include any training centers, universities, etc. as well as elementary and secondary schools.
Urban	Higher density area where blocks are shorter, streets are a mix of one and two way, and traffic can include buses and trams. (This category takes precedence over others when either businesses and/or residences are present.)	
Category	***Category Definition***	***Examples and Hints***
Airport	Vehicle(s) are traveling within or between or are entering or exiting an airport terminal situation where arrivals and departures create complicated parking and crosslane navigation traffic and pedestrian traffic is likely to be high.	

<u>Interstate/bypass/ divided highway, controlled access</u>	Vehicle is travelling on an interstate, bypass, or divided highway with no at-grade intersections (regardless of what buildings can be seen), at the time of the Precipitating Event. All traffic to and from the roadway must utilize an interchange.	
<u>Bypass/divided highway, access not controlled</u>	Vehicle is travelling on a bypass or divided highway with at grade intersections present (either uncontrolled, stop signs, or traffic signals) and no other category description fits at the time of the Precipitating Event. Traffic to and from the roadway are not required to use an Interchange. (Often appears as "Open Country", but with more lanes and/or as a divided road.)	
<u>Other</u>	Locality at the time of the Precipitating Event is one not described in other categories.	Ex. In campground.
<u>Unknown</u>	Cannot determine the Locality due to limitations in video views, lighting, visual obstructions, or limited perspective.	Ex. Part of the video is missing or there is insufficient information in the video to make a determination.

Secondary Tasks

Category	***Category Definition***	***Examples and Hints***
<u>No Secondary Tasks (or No Additional Secondary Tasks)</u>	The Subject vehicle driver is not engaged in any (or any additional for V38, 42, 46) observable secondary tasks and is attentive to the driving task.	

Talking/singing, audience unknown	Subject vehicle driver is moving lips as if talking or singing, the interaction is not believed to be with a passenger. This category includes whistling, and also includes possible or suspected cases of hands-free cell phone use. (See "Cell phone, Talking/listening, hands free" category for further information.) This category does not include the driver talking to a pedestrian or other known party outside the vehicle, which should be coded as the appropriate external distraction. This also does not include talking (to self or other vehicles) or gesturing in response to the event being analyzed.	Driver may or may not also be interacting with a passenger, but this Secondary Task involves singing with radio, talking to self, using a cell phone through a handsfree medium, etc.
Dancing	Subject vehicle driver is moving his/her arms, head, or other body part seemingly in time with the beat of music.	e.g., tapping hands/fingers on steering wheel, bobbing head, "air drums" or "air guitar".
Reading	Subject vehicle driver is reading material that is in the vehicle, but not a part of the vehicle (i.e., not reading external signs, or center stack display).	This could be reading directions, paper material, packaging. If reading a phone number, record as dialing cell phone.
Writing	Subject vehicle driver is writing with a pen/pencil or using a stylus on a tablet.	Driver could be writing on a piece of paper, making notes on a tablet, etc.

Category	***Category Definition***	***Examples and Hints***
Passenger in adjacent seat - interaction	A front seat passenger is visible or not visible, but the Subject vehicle driver is clearly interacting with a passenger (other than a child) in the adjacent/front seat. This could be talking, listening, reacting to (i.e., laughing), gesturing towards, moving toward or away from the passenger, or reaching to take something from or give something to the passenger. If age of passenger is unable to estimate, use this category.	

Passenger in rear seat - interaction	A rear seat passenger (other than a child, or age unable to estimate) is visible or not visible, but the driver is clearly interacting with a passenger (other than a child) in the rear seat. This could be talking, listening, reacting to (i.e., laughing), moving toward or away from the passenger, or reaching for the rear seat passenger. If age of passenger is unable to estimate, use this category.	
Child in adjacent seat - interaction	Child is visible or not visible, but the driver is clearly interacting with a child in the front adjacent seat. This could be talking, listening, reacting to (i.e., laughing), or moving toward or away from the child (i.e., reaching for a child, not object, or avoiding a pat from the child). If age of passenger is unable to estimate, do not use this category; use "passenger in adjacent seat" instead.	
Child in rear seat - interaction	A child is visible or not visible in the rear seat, and the driver is clearly interacting with a child in the rear seat. This could be talking, listening, reacting to (i.e., laughing), or moving toward or away from the child (i.e., reaching for a child, not object, or avoiding a pat from the child). If age of passenger is unable to estimate, do not use this category; use "passenger in rear seat" instead.	

Category	***Category Definition***	***Examples and Hints***
Look back in Sleeperberth (Truck Only)	The driver is looking back into the sleeperberth (e.g., to interact with a passenger or look for an item).	
Moving object in vehicle, Interact (or on motorcycle)	Any interaction with an object inside the vehicle (or on the motorcycle) which is not being held by the driver or passenger(s) (if present) but is in motion, either due to the motion of the vehicle or due to another passenger throwing the object.	Ex. Driver looks at and/or reaches for an object that fell off the seat when driver stopped hard at a traffic light; or CB cord is dangling and driver reaches up to steady it.

Insect in vehicle, Interact (or around motorcycle)	Interaction with any insect in the vehicle (or around the motorcycle) (e.g., swatting at insect, moving body to avoid insect, looking around trying to locate insect).	
Pet in vehicle, Interact (or on motorcycle)	Any interaction with a pet in the vehicle (or on the motorcycle), including holding, petting, talking to, or moving pet or interacting with pet carrier.	Only code if animal/pet is visible at some point in the trip file or if there is history/context with the driver and the driver is exhibiting behaviors that are appropriate to having a pet in the vehicle.
Object dropped by driver	Subject vehicle driver is initially holding something and drops it and the driver then immediately picks it back up, taking the driver's attention away from the driving task.	This category supersedes other "reaching" categories in the situation of an object being dropped and immediately retrieved.
Reaching for object, other	Subject vehicle driver reaches for an object not described in any other category. Includes objects in storage compartments.	Once the driver has finished reaching for the object and has it in hand (if not being moved for intended usage), then it becomes "object in vehicle, other," as long as it doesn't fit into any of the other categories (e.g., eating, drinking, etc.)
Object in vehicle, other (or on motorcycle)	Subject vehicle driver clearly is looking at, handling, holding, or manipulating an object (visible or not) or thing located in the vehicle or on the motorcycle, other than those listed in other categories.	

Category	***Category Definition***	***Examples and Hints***
Cell phone, Holding	Subject is holding a cell phone but not manipulating it. Could be holding it in hand, lap, or some other way.	
Cell phone, Talking/listening, handheld	Subject vehicle driver is talking on a handheld phone or has phone up to ear as if listening to a phone conversation or waiting for person they are calling to pick up the phone. If driver has an earpiece or headset, the driver must be observed talking repeatedly.	

Cell phone, Talking/listening, handsfree	Subject vehicle driver is talking or listening on a phone using a hands-free device such as a headset, in-vehicle integrated system, or hands-free speaker phone. This category is only used in studies where sufficient information exists and is not used in the current study. Instead, refer to "Talking/Singing, audience unknown" category.	This category cannot be reliably and consistently determined in many naturalistic studies due to insufficient information. Cell phone records, audio recordings, and/or extensive review of extended video footage are required to code this category, none of which were available at the time of the current coding effort.
Cell Phone, Texting	Subject vehicle driver is pressing buttons or a touch screen on the cell phone to create and/or send a text message.	
Cell Phone, Browsing	Subject vehicle driver is pressing buttons or a touch screen on the cell phone to browse the internet or phone applications. May also include voice commands (e.g., Siri).	
Cell Phone, Dialing handheld	Subject vehicle driver is pushing number buttons on a cell phone or touch screen to dial a number or browse/check something else on their cell phone (this would also include reading the phone number from a sheet of paper).	If unsure whether driver is texting or dialing/browsing, code as dialing.

Category	***Category Definition***	***Examples and Hints***
Cell Phone, Dialing handheld using quick keys	Subject vehicle driver is pushing quick key buttons (e.g., speed dial) on a cell phone to dial a number or check something else on their cell phone (this would also include reading the phone number from a sheet of paper). Maximum number of buttons is 6, else code as "dialing hand-held phone".	

Cell Phone, Dialing hands-free using voiceactivated software	Driver speaks into open or activated cell phone, headset, or invehicle integrated device for the purpose of dialing with long, prior delay of no speaking into device (i.e., most likely not in prior conversation) and no more than one or two button presses (e.g., push to begin) on phone, earpiece, headset, or in-vehicle integrated system are made first.	
Cell Phone, Locating/reaching/ answering	Subject vehicle driver is glancing to find cell phone, reaching towards his/her cell phone, and/or flipping phone open or pressing a button to answer a call.	If more than one distraction happens (e.g., driver looks for phone, reaches for it and then answers it), the last frame number would be the last step in this sequence (e.g., answering cell phone). Once phone is at driver's ear or conversation has clearly begun, code as the appropriate "talking" category.
Cell phone, other	Subject vehicle driver is interacting with a cell phone in some manner (e.g., looking at a cell phone or just holding it, but not necessarily manipulating the cell phone in any way), or action does not fit in any other category.	Includes plugging phone into charger, cleaning screen, putting on headset, etc.
Tablet device, Locating/reaching	Subject vehicle driver reaches or starts to glance around for an electronic tablet device (e.g., iPad).	
Tablet device, Operating	Subject vehicle driver is pressing buttons on or using the touch screen on the electronic tablet device.	

Category	***Category Definition***	***Examples and Hints***
Tablet device, Viewing	Subject vehicle driver is holding and looking at an electronic tablet device, but not pressing any buttons.	
Tablet device, Other	Subject vehicle driver is interacting with an electronic tablet device in some manner not described in other categories.	Includes plugging tablet into charger, cleaning screen, headset, holding without manipulating, etc.

CB Radio, Interact (Car/Truck Only)	Subject vehicle driver is reaching for, manipulating, talking into, or listening to a CB Radio.	
Intercom, Interact	Subject vehicle driver is reaching for, manipulating, talking into, or listening to an intercom system (e.g., announcement/PA system on a bus).	
Electronic dispatching device, Interact with (Truck Only)	Subject vehicle driver is interacting in some way with an electronic dispatching device.	
DAS, Interact	Subject vehicle driver is reaching for, manipulating, or otherwise interaction with the Data Acquisition System.	
Other electronic device, Interact with	Subject vehicle driver is interacting in some way with an electronic device that is not included in other categories and is not integral to the vehicle (e.g., calculator, camera, nomadic GPS).	
Adjusting/monitoring climate control	Subject vehicle driver interacts with in-vehicle climate control system either by touching the climate control buttons, glancing at the climate control on dashboard, or adjusting climate control vents.	
Adjusting/monitoring radio	Subject vehicle driver interacts with in-vehicle radio/audio system either by touching the radio buttons on dashboard or steering wheel, or glancing at the radio on dashboard.	

Category	***Category Definition***	***Examples and Hints***
Inserting/retrieving CD (or similar)	Subject vehicle driver picks up CD, cassette, or other music storage device (other than MP3 player) in vehicle and/or inserts it into radio, presses any subsequent buttons to get device to play/rewind/fast forward and then play, or driver presses button to eject device and then places it somewhere in vehicle.	
Adjusting/monitoring other/unknown Instrument Panel device	Subject vehicle driver interacts with a manufacturer-installed Instrument Panel device other than those listed in other categories (or an unknown device), either by touching or glancing at the device. Does not include driving-critical tasks, such as turn signal, wipers, headlights, gear shift, speedometer. Instrument Panel can include any integral device or control on or around the steering wheel, on the dashboard, or on the center stack.	Includes integrated Navigation systems.
Adjusting/monitoring other devices integral to vehicle	Subject vehicle driver interacts with a manufacturer-installed device other than those listed in other categories, either by touching or glancing at the device. Does not include drivingcritical tasks, such as turn signal, wipers, headlights, gear shift, speedometer.	Includes interaction with seat belt, door locks, window controls, sun visors, rear view mirror, etc. Does not include retrieving objects inside storage compartments.
Looking at previous crash or incident	Subject vehicle driver is looking outside of the vehicle in the direction of what is obviously an accident or similar incident.	Only mark if it is clear that the driver is tracking a specific external distraction as they drive by. Quick glances are not categorized in this category; code these according to where the driver is glancing (ex., mirror or window).
Looking at pedestrian	Subject vehicle driver is looking outside of the vehicle in the direction of a pedestrian (not in a construction zone) either on the side of the road or in front of them (i.e., using a cross walk or riding a bike at a red light).	

Category	*Category Definition*	*Examples and Hints*
Looking at animal	Subject vehicle driver is looking outside of the vehicle in the direction of an animal either on the side of the road (this would not be used for an animal crossing the road).	
Looking at an object external to the vehicle	Subject vehicle driver is looking outside of the vehicle in the direction of an object (not in a construction zone) on the side of the road (e.g., a box).	
Distracted by construction	Subject vehicle driver is looking outside of the vehicle in the direction of a construction zone. A construction zone would be defined as the presence of a barrel, person in a hard hat, construction equipment or vehicles.	
Other external distraction	Subject vehicle driver is looking outside of the vehicle for purposes not described in previous categories, or for an unknown reason when glance is not considered to be part of the driving task.	Includes looking at vehicle ahead in adjacent lane.
Reaching for food-related or drink-related item	Subject vehicle driver is looking for or reaching for any item related to eating or drinking. If the driver is already in the process of eating, and is just picking up food repeatedly to put in mouth, code as the appropriate eating category. This reaching task is for the initial locating, reaching, and preparing food or drink to be eaten.	Ex. reaching for cup, utensils, plate, food. Once the item is in hand and being moved with the intent to use, code as appropriate usage category (e.g., eating).
Eating with utensils	Subject vehicle driver has food that will be put in his/her mouth via a utensil like a fork, spoon, knife, chopsticks, etc.	
Eating without utensils	Subject vehicle driver has food that will be put in his/her mouth and a utensil is not used to place the food in the driver's mouth.	
Drinking with lid and straw	Subject vehicle driver uses a straw to drink from a container that has a cover on it and cannot easily spill if it tips over.	Ex. Fountain drink with lid and straw, sippy water bottle

Category	*Category Definition*	*Examples and Hints*
Drinking with lid, no straw	Subject vehicle driver drinks from a container that has a cover on it and cannot easily spill if it tips over (not using a straw).	Ex. coffee mug with lid that closes
Drinking with straw, no lid	Subject vehicle driver uses a straw to drink from a container that does not have a lid.	Ex. uncovered fountain drink with a straw
Drinking from open container	Subject vehicle driver drinks from a container that does not have a lid (not using a straw).	Ex. uncovered cup, coffee cup, water bottle with lid off, soda can
Reaching for cigar/cigarette	Subject vehicle driver reaches or starts to glance around for cigar/cigarette or related items.	Once the item is in hand and being moved with the intent to use, code as appropriate usage category (e.g., lighting).
Lighting cigar/cigarette	Subject vehicle driver is in some stage of the process of lighting cigar/cigarette.	
Smoking cigar/cigarette	Subject vehicle driver has a lit cigar/cigarette either in their mouth or hand.	
Extinguishing cigar/cigarette	Subject vehicle driver puts out his/her cigar/cigarette, hands it to someone else, or tosses it out the window.	
Tobacco, other	Subject vehicle driver is using some other form of tobacco not included in other categories such as chewing tobacco (putting it in mouth, spitting).	If chewing tobacco and tobacco is simply in mouth at during the analysis window (not reaching, spitting, etc.), do not code as a secondary task.
Reaching for personal body-related item	Subject vehicle driver is reaching for any item related to personal hygiene, health, or adornment.	Ex. reaching for comb, brush, makeup, razor, dental floss, contact lenses, glasses (not currently being worn), hat (not currently being worn). Once the item is in hand and being moved with the intent to use, code as appropriate usage category.
Combing/brushing/ fixing hair	Subject vehicle driver is adjusting, or combing/brushing hair, except for quickly swiping hair out of eyes or idle twirling of hair.	

Category	*Category Definition*	*Examples and Hints*
Applying make-up	Subject vehicle driver is in some stage of applying any body product to body.	Ex., lotion, make-up, lip balm, perfume
Shaving	Subject vehicle driver is using any appliance with a blade to remove hair from body.	Ex., razor (electric or manual)
Brushing/flossing teeth	Subject vehicle driver is using any appliance to brush, floss or otherwise clean teeth or mouth.	Ex., includes toothbrush, floss, toothpick, etc.
Biting nails/cuticles	Subject vehicle driver is biting nails or cuticles.	
Removing/adjusting clothing	Subject vehicle driver is removing, adjusting, or putting on clothing, including jackets, shirt, pants, shoes, socks, hats, gloves, neckties, and scarves.	
Removing/adjusting helmet (MC only)	Subject rider is removing, putting on, or adjusting helmet (including visor).	Includes adjusting visor up or down, adjusting chinstrap, converting three-quarter helmet, wiping visor, applying or removing tape from visor, interacting with helmetmounted camera. If adjustment is related to operation of other peripherals (such as cell phone or radio), code as appropriate (e.g., answering cell phone) rather than this category.
Removing/adjusting jewelry	Subject vehicle driver is removing or adjusting jewelry, including watches.	Ex., rings, necklaces, bracelets, watches, earrings or other piercings.
Removing/inserting/ adjusting contact lenses or glasses	Subject vehicle driver is removing or inserting contact lens(es) from eye(s) or putting on/taking off/adjusting glasses or sunglasses.	

Other personal hygiene	Subject vehicle driver is engaged in some other personal hygiene activity(ies) not described in previous categories.	Ex., checking oneself in mirror without the preceding tasks, trying to get something out of one's eye.
Category	***Category Definition***	***Examples and Hints***
Other non-specific internal glance	Subject vehicle driver glances away from the direction of travel at something inside the Subject vehicle/on the motorcycle, but cannot determine a specific glance location.	
Other known secondary task	Subject vehicle driver is engaged in a recognizable secondary task that is not listed in other categories.	Includes cases where the vehicle is traveling in reverse and the driver is looking out the forward or side windows (other than side mirrors), rather than the roadway behind the car, which is now the direction of travel.
Unknown type (secondary task present)	Subject vehicle driver is clearly distracted from the driving task, but the specific distraction is unknown.	
Unknown	Cannot determine whether the Subject vehicle driver is engaged in a secondary task due to limitations in video views, lighting, visual obstructions, or limited perspective.	Ex. Part of the video is missing or there is insufficient information in the video to make a determination.

APPENDIX B. GLANCE REDUCTION PROTOCOL

STSCE Senior Driver Lane Change Transition Glance General Protocol

Document Location: Senior Driver Lane Change Glance
Fund to Charge: 500095
Document Location: \\vtti.ad.vt.edu\Data\Projects\500095\Reduction
Software Needed: Hawkeye, Excel
Collections: NEW SHRP2
Security Group(s) Needed: Projects-IRBCertified, Projects-Reductionists, Project-415586-Reductionists, Project-500095-Reductionists
Database Roles Needed: SHRP2_Reductionist

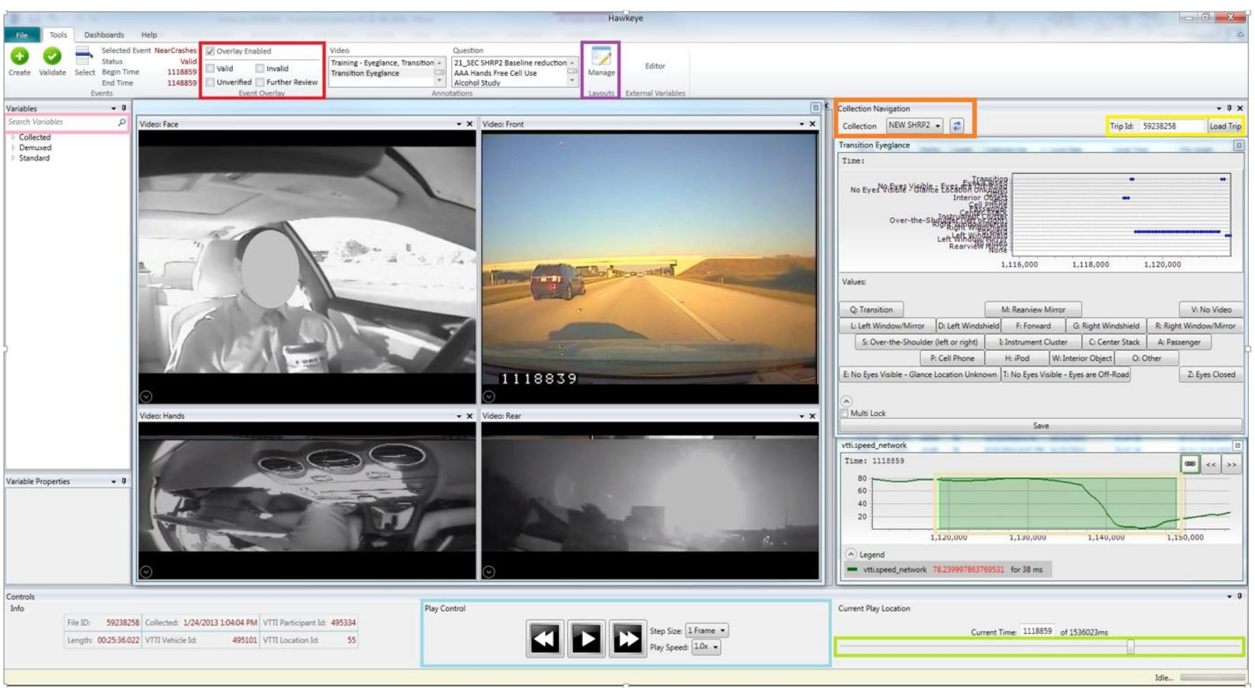
Project Overview:
Transition glance reduction will be performed in Hawkeye. Using primarily the "Face Video", the data reductionist will code where the driver is looking for every video frame within the event window. This edition of glance includes "transition glances".

Note: this glance reduction task has somewhat different glance location definitions than VTTI's standard. Specifically, the left window/mirror location is split into two categories (Left window and Left mirror) and over-the-shoulder is split into two categories (Over-the-shoulder, left and Over-the-shoulder, right).

Hawkeye Setup and Use:

1. Hawkeye must be installed and opened from here \\vtti.ad.vt.edu\Data\Projects\Applications\HawkEye\Release
    a. Once installed, it is recommended to create a desktop shortcut to easily find the program later.
2. Once installed, load the Hawkeye program.
3. The "Collection Navigation" can be found on the right side of the program window and is used to select the applicable collection (shown on the following page in the orange box).
4. Use the "Collection" drop down menu to select New SHRP2 collection.
5. Go to the Excel Log located at \\vtti.ad.vt.edu\Data\Projects\500095\Reduction\Senior Lane Change Glance\Senior Lane Change EG.xlsx, sign out an event, copy the File_ID that was signed out, and then paste it into Hawkeye's "Trip ID" field in the "Collection Navigation" window (shown on the following page in the yellow box).

6. Click “Load Trip” or hit “Enter” to load the file.
7. The “Tools” tab is automatically selected when Hawkeye is opened.
    a. From within the “Event Overlay” section of the “Tools” ribbon, select the “Overlay Enabled” check box (shown on the following page in the red box).
    b. Doing this creates a colored box on the variable graphs to make the event window more visible (shown on the following page in the tan box).
8. On the left side there is a “Variables” search bar, use this to find and open the following variables (shown below in the pink box).
    a. Video (Available videos will vary with collection, but Front, Face, Hands/Dash, and Rear are most common. The data reductionist should open all of these.)
    b. VTTI.Speed_Network (or VTTI.Speed_GPS if network speed is not available) 9. Arrange the variables so that they can be easily viewed without being moved around.
    a. Variables can be docked together by clicking on the title bar of one variable window and dragging it over top of another variable window. This will cause an organization icon to appear over the variable window. Hovering over sections of the icon and releasing will sort the windows accordingly.
    b. Variables can be organized into tabs using the organization icon as well.
    c. Video variables MUST be kept on the main desktop window (not a secondary monitor) to avoid repeated program crashes.
    d. Graph variables can be moved to the adjacent monitor.

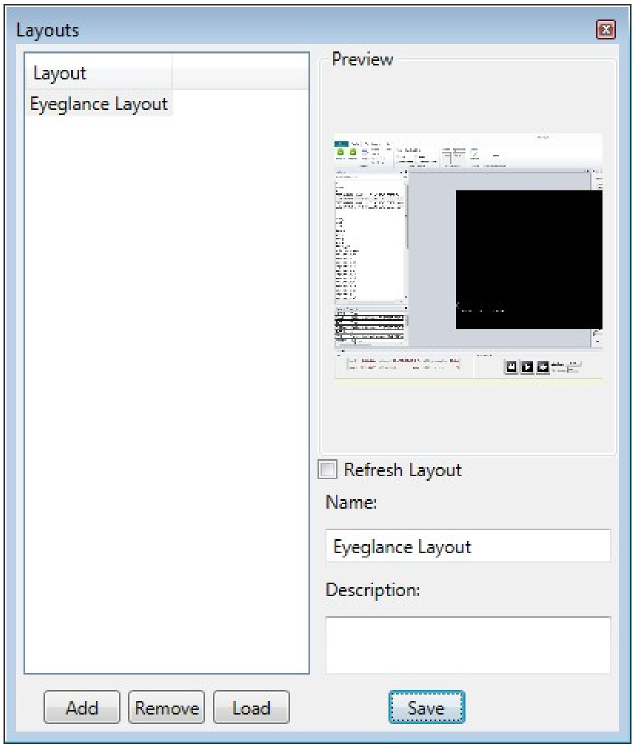


Example image of Hawkeye, with views setup for Transition Glance

10. Saving layouts (optional)

a. From the ribbon at the top, in the “Layouts” section, select the “Manage” icon (shown in the purple box above).

b. The “Layout” box will open (shown on the following page).



Example image of Hawkeye’s Layouts menu window.

c. Once the variables windows are organized as desired, click “Add” to preview the layout and give it a name. Then click “Save”.

d. To change the layout later, organize the variables into the desired layout, select “Refresh Layout” and then “Save”.

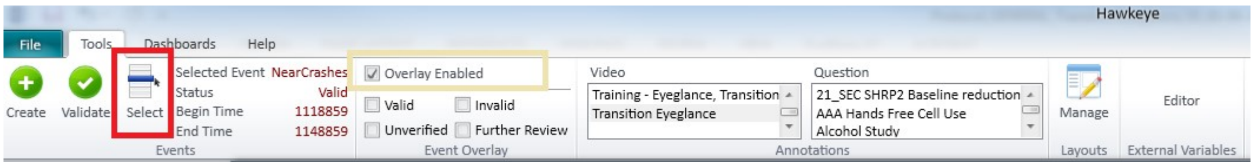
e. To open a saved layout, simply select the desired layout from the list on the left and select “Open”.

   i. Sometimes this will bring up error messages about certain variables not being available. Often, these variables can still be opened directly from the variable list.

   ii. The layouts function in general is glitchy. It may be necessary to “Remove” the layout, restart Hawkeye, reload variables, and then “Save” again to fix this.

11. Selecting an Event

a. Click on the “Select” box that can be found in the top ribbon, under the “Tools” tab, in the “Events” section (shown below in the red box).



Example image of the “Select” button

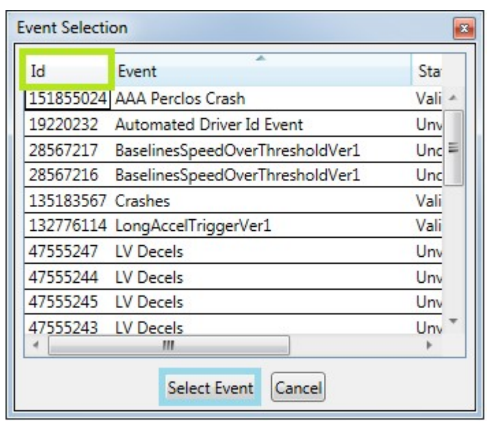
b. The “Events Selection” window will open (shown below).

c. The list of events is displayed on the left and can be sorted in different ways by clicking on any of the column heading (shown below in the green box).

d. Locate and select the “Id” number that matches the Event_ID that was signed out on the reduction log by either double clicking the desired event, or single clicking the desired event and then clicking the “Select Event” button (shown below in the blue box).

e. Hawkeye will automatically take the video and data charts to the timestamp where the event begins.

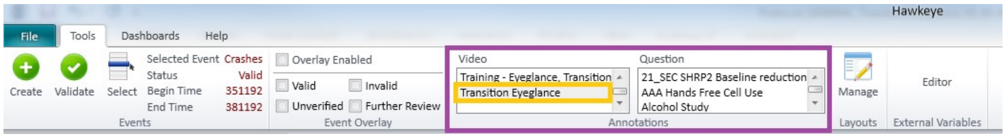
f. If there is an event window, it will appear as a shaded box on Hawkeye’s variable graphs if “Overlay Enabled” box is checked (shown on the previous page).



Example image of the “Event Selection” window

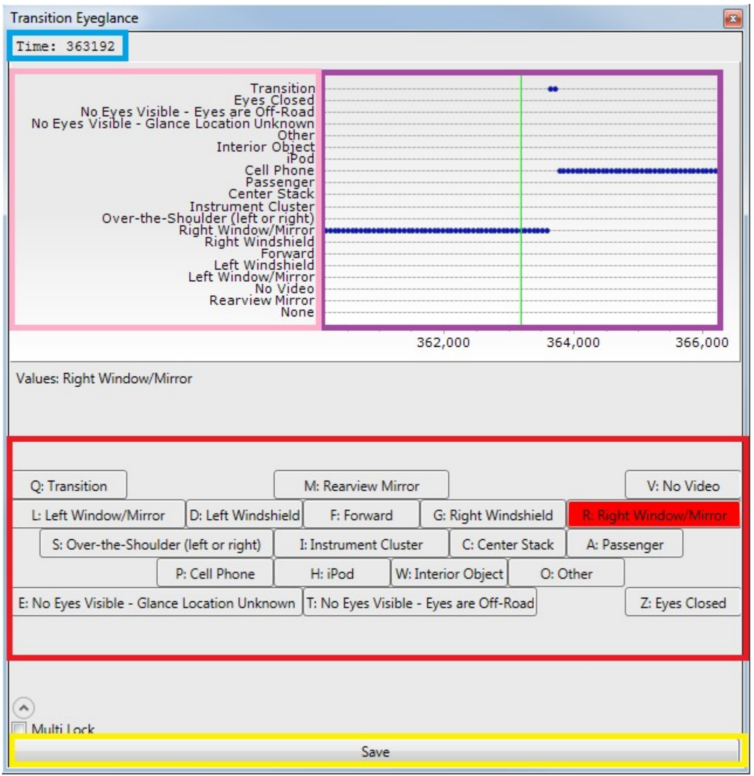
12. Using Video Annotation

a. Select the “Senior Lane Change Glance” video annotation (shown below in the yellow box) from the “Tools” tab, in the “Annotations” section (shown below in the purple box), under “Video”.



Example image of the “Transition Glance” annotation location

b. The “Senior Lane Change Glance” video annotation window should pop up.
c. The current timestamp is located at the top of the window (shown on the following page in the blue box).
d. Below that is where the annotation can be viewed (shown below in the purple box).
e. The vertical green line represents the current location within the event window.
f. The blue dots represent previously reduced data points that correspond to one of the locations listed on the left (shown below in the pink box). When an unreduced video annotation is first opened, these dots will be present only in the “None” category.
g. The lower portion of the window contains the keys that must be pressed on the keyboard to code the various locations the driver is looking (shown below in the red box).
h. The “Save” button is at the bottom and should be used frequently while reducing an event to avoid losing unsaved work should the program crash unexpectedly (shown below in the yellow box).

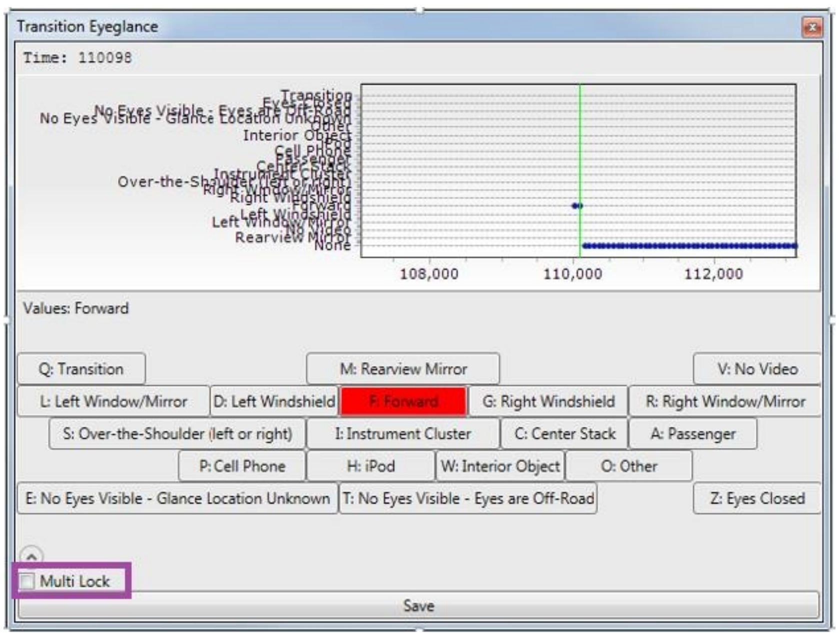


Example image of a previously reduced "Transition Glance" video annotation window. *Note that this figure does NOT include the new locations unique to this reduction task (Left Window, Left Mirror, Over-the-shoulder, right and Over-the-shoulder, left.*

Reduction Steps:

1. Depending on the study and the length of the event, the data reductionist may want to watch the event at regular speed first to become familiar with the driver and his/her behavior.
    a. To do this, make sure the "Play Speed" in Hawkeye is set to "1.0x" and select "Play".
    b. Watch primarily the "Face Video" to get an idea of the type of glances made during the event, as well as the other video views to gain context for the glances.
        i. For example, seeing that the driver is trying to change lanes by watching the "Forward Video", or seeing that a driver is seeking a new radio station by watching the "Hands Video".
    c. Also note that some studies may collect audio data. If audio is present, it can only be heard when the video is played in regular speed (1.0x). Sometimes, listening to the audio can help explain glance sequences (e.g. a new song comes on and driver looks over to XM radio to see title). **Audio is not needed for this reduction task and is likely not present for most of the events to be reduced.

2. When ready to begin entering in glance data, ensure that the cursor is located at the start of the event requiring reduction. The “Senior Lane Change Glance” video annotation will not allow reduction outside of the event window.
3. With the “Senior Lane Change Glance” video annotation open and active, use the right/left arrow keyboard keys to move to the first timestamp in the event. From there, enter in the first glance location using the keyboard.
4. When a key is tapped to code a corresponding glance, the video will move forward one frame and code one data point.
5. If a key is held down, Hawkeye will continuously code the corresponding glance location for as long as the keyboard button is pressed, though some people find it helpful to make separate keyboard presses to further control the playback speed of the video.
6. Notice that when a specific key is pressed, the corresponding button will be highlighted in red on the “Senior Lane Change Glance” video annotation (shown below).



Example image Hawkeye hightlighting the coded glance in red

7. If the “Multi Lock” check box is checked, further glance reduction will not be possible (shown on the previous page in the purple box). This option is used for different types of reduction and is not discussed in this protocol
8. To go back and review coded data along with the video, use the left and right arrows on the keyboard to shuttle the video and the corresponding glance entries frame by frame using single taps or holding down the arrow keys.
9. If upon review, a coded glance location needs to be changed, shuttle the video to the location of the erroneous entry, and re-key in the correct glance location. This will overwrite the previous data.

10. Continue reducing until the end of the event window is reached, and then “Save” the video annotation. (Remember to also save frequently during reduction to prevent losing any work).
11. Leave a note in the Excel Log comments section regarding
    a. Any situations that are unique and might affect interpretation of the glances.
        i. For example, note anything unusual in any camera view, or reasons for any unusually long glances to glance locations off of the roadway (e.g. the participant looks at the radio continuously for 5 seconds because he/she is stopped at a red light).
    b. Details about any “Other” glances.
        i. Included an explanation for what the driver is believed to be looking at and include timestamps.
12. Date the event in the Excel Log and move on to the next available event.

Glance Location Definitions and Codes

Glance: a glance is defined as the location a driver is fixated on for at least 2 consecutive video frames.

A glance can begin at the beginning of the transition away from previous glance location and end once the eyes have fixated onto a new location (this time period should be coded as “Transition”), or it can begin at the start of a fixation and end once the eyes start transitioning to a new location.

Normal blinks (less than five consecutive video frames) are not recorded in glance. Glance location should be coded straight through blinks. However, blinks can be useful indicators of a transition. Drivers will often blink just before, during, or at the end of a transition. Therefore, many blinks will be coded as part of “Transitions”. NOTE: Blinks are often mistaken for glances to the instrument cluster (speedometer, etc.). Watching the video at full speed is often helpful in telling the difference.

In the case where it is difficult to see the driver’s eyes for a prolonged portion of the event (e.g. constant sun glare on the left window, visor is down and covers the eyes, the driver is wearing heavy rimmed glasses), talk to the lab manager to see if glance reduction should be undertaken or the event omitted.

	Glance Location	Standardized SHRP2 Definitions	Additional Information and Tips
Q	Transition	Any frame that is between fixations as the eyes move from one fixation to the next. NOTE: that the eyes often fixate while the head is still moving. This category is based on the eye’s fixation rather than the head’s movement, unless sunglasses preclude the eyes from being seen.	Glances must be at least 2 video frames long, and are usually longer. If the eyes are not fixated on one place for at least 2 frames, then the eyes are likely still in transition. For example, if the participant is looking forward and shifts their gaze to the center stack, the analyst would mark Forward until their eyes start to transition, Transition while their eyes are moving, and Center Stack once their eyes have fixated again. The driver’s eyes will often fixate on a new glance location before their head stops moving. Similarly, the head may move (nod, etc.) while the eyes remain on forward. Glance should be focused on where the eyes are looking, not on where the head is pointing. The only exception to this rule is if the driver is wearing dark sunglasses; sunglasses are handled differently in different projects, and this should be addressed in each project’s specific protocol. NOTE: that it is NOT required to include a transition between all glance fixations. If the transition is fast enough so that two sequential video frames show fixation on two different points for at least two consecutive frames each, then no transition is needed.

F	Forward (Center)	Any glance out the forward windshield directed towards the direction of the vehicle's travel. Note that when the vehicle is turning, these glances may not be directed directly forward but towards the vehicle's heading. Count these as forward glances. NOTE that when the vehicle is driving in reverse, forward will be out the back window (see "Special Cases").	For identifying when the driver is turning, keep an eye on the "Hands Video", and see when the wheel begins to turn. Once they have begun engaging the turn, any glances in the direction of the turn should be coded as "Forward" "Forward" glances do not specifically refer to the forward windshield. Unlike other glance categories, "Forward" should be used when the driver is looking in the vehicle direction of travel, including when they are turning or driving in reverse. When there is a passenger present, the driver will sometimes turn their head towards them to show they are listening, but their eyes remain forward. Glance reduction should focus on the direction of their eyes, not the direction of their head. Therefore, this will be coded as "Forward".
M	Rearview Mirror	Any glance to the rear view mirror or equipment located around it. This glance generally involves movement of the eyes to the right and up to the mirror. This includes glances that may be made to the rearview mirror in order to look at or interact with back seat passengers.	For most studies, the camera has been placed right behind the rearview mirror. Therefore, any glance directly at the camera will be a "Rearview Mirror" glance. Depending on the height of the driver, this glance might include a slight upward angle.*If the camera is mounted somewhere else, that information will be provided in the project-specific protocol.* When there are passengers in the back seat, the driver may interact with them by looking at the rearview mirror. Code these as "Rearview Mirror" glances, and not as "Passenger" glances. If the driver actually turns physically to look at a passenger in the backseat, then it would be coded as "Passenger".
D	Left Windshield	Any glance out the forward windshield where the driver appears to be looking specifically	

		out the left margin of the windshield (e.g., as if scanning	

	Glance Location	Standardized SHRP2 Definitions	Additional Information and Tips
		for traffic before turning or glancing at oncoming or adjacent traffic). This glance location includes anytime the driver is looking out the windshield, but clearly not in the direction of travel (e.g., at road signs or buildings).	
G	Right Windshield	Any glance out the forward windshield where the driver appears to be looking specifically out the right side of the windshield (e.g., as if scanning for traffic before turning, at a vehicle ahead in an adjacent lane, or reading a road sign). This glance location includes anytime the driver is looking out the windshield, but clearly not in the direction of travel (e.g., at road signs or buildings).	
K	Left Window	Any glance to the left side window.	
L	Left Mirror	Any glance to the left side mirror.	
R	Right Window/ Mirror	Any glance to the right side mirror or window	For this study, the right side mirror and right side window glances have been merged into a single category.
S	Over-The-Shoulder (Left)	Any glance over the participant's left shoulder. In general, this will require the eyes to pass the Bpillar on the driver's side of the vehicle. The eyes may not be visible, but this glance location can be inferred from context. NOTE: If it is clear from context that an over-theshoulder glance is being made NOT to check a blind spot but instead to interact with a rear seat passenger (e.g., food/toy is being handed back), then code the glance as Passenger. If context cannot be known with a	B-Pillar is a vertical part of the vehicle frame providing support and separating the front doors from the rear doors of the vehicle. A common example is when the driver checks their blind spot before merging or changing lanes. Remember to take direction of travel into consideration. If they are looking over their shoulder and the vehicle is moving backwards then the glance would count as Forward.

		high level of certainty, then code as Over-the-Shoulder.	
X	Over-The-Shoulder (Right)	Any glance over the participant's right shoulder. In general, this will require the eyes to pass the Bpillar on the passenger side of the vehicle. NOTE: If it is clear from context that an over-theshoulder glance is being made NOT to check a blind spot but instead to interact with a rear seat passenger (e.g., food/toy is being handed back), then code the glance as Passenger. If context cannot be known with a high level of certainty, then code as Over-the-Shoulder.	B-Pillar is a vertical part of the vehicle frame providing support and separating the front doors from the rear doors of the vehicle. A common example is when the driver checks their blind spot before merging or changing lanes. Remember to take direction of travel into consideration. If they are looking over their shoulder and the vehicle is moving backwards then the glance would count as Forward.

	Glance Location	Standardized SHRP2 Definitions	Additional Information and Tips

A	Passenger	Any glance to a passenger, whether in front seat or rear seat of vehicle. Context is required (e.g., they're talking, or handing something) in order to determine this in some situations. NOTE: This does NOT include glances made to rear seat passenger via the rearview mirror. Such glances should be coded as "Rearview Mirror". NOTE: If the driver is looking at something that the passenger is handing to them, code the glance as Passenger, until the object is fully in the driver's hand, then code as Interior Object (or Cell Phone or Portable Media device, if applicable). If the driver is looking at something that the passenger is holding (but never hands to the driver), code as passenger glance (not interior object).	A way to figure out if there is a passenger in the vehicle is paying close attention to the "Hands Video". Usually the arm or leg of a passenger can be seen at some point in the file. If passenger presence is not obvious, the cabin view may also be utilized. Use "Variables" section of Hawkeye and enter "cabin" into the search bar and open the "Cabin" variable under the "Snapshots" section. Not all collections/vehicles have a Cabin snapshot variable available. "Right Window" glances and "Passenger" glances can be hard to differentiate. A good indication for this is be paying attention to the driver's mouth to see if they are talking, laughing, or nodding. Watch the video at full speed to gain context. If the passenger is holding an object and showing it to the driver, code as a "Passenger" glance. Once the passenger hands something to the driver and the driver glance at it in their own hand, then code "Interior Object", "Cell Phone", or "Portable Media Device".
I	Instrument Cluster	Any glance to the instrument cluster underneath the dashboard. This includes glances to the speedometer, control stalks, and steering wheel.	Glances to the speedometer are often mistaken for blinks, because it usually appears as a sudden downward glance. It is a good idea to play the video at full speed to gain better context for differentiation. Glances towards the steering wheel itself also go under this category (including glances associated with the use of steering wheel buttons and controls).

C	Center Stack	Any glance to the vehicle's center stack (vertical). Not to be confused with center console (cup holder area between driver and passenger), which is discussed under "Interior Object".	"Center Stack" typically includes things like GPS, stereo, and climate control. Center console (coded as "Interior Object") includes cup holders and small storage space.
P	Cell Phone (electronic communications device)	Any glance at a cell phone or other electronic communications device (e.g., Blackberry), no matter where it is located. This includes glances to cell phone related equipment (e.g., battery chargers).	

	Glance Location	Standardized SHRP2 Definitions	Additional Information and Tips
H	Portable Media Device	Any glance at a Portable Media Device (e.g., mp3 player, iPod, other personal music or video device), no matter where it is located. Does not include cell phones with video or music capability (coded as Cell Phone) or any manufacturer installed devices (which would most likely be coded as Center Stack if installed in that location).	If unable to differentiate between "Cell Phone" and "Portable Media Device" glances, it is best to assume it is a "Cell Phone" and leave a note in the spreadsheet with the applicable timestamps.

W	Interior Object	Any glance to an identifiable object in the vehicle other than a cell phone. - These objects include personal items brought in by the participant (e.g., purse, food, papers) - Any part of their body that may look at (e.g., hand, ends of hair) - Electronic devices other than cell phones (e.g., laptop, PDA) - OEM installed devices that don't fall into other categories (e.g., door lock, window and seat controls). - Glances to the center console (cup holder area between passenger seat and driver seat) will also be included in this category. The object does not need to be in the camera view for a specific frame to be coded with this category. If it is clear from surrounding video that the participant is looking at the object, this category may be used. This category can be used regardless of whether the participant's hands are/aren't visible. NOTE: If the driver is looking at something that the passenger is handing to them, code the glance as Passenger, until the object is fully in the driver's hand, then code as Interior Object (or Cell Phone or Portable Media device, if applicable). If the driver is looking at something that the passenger is holding (but never hands to the driver), code as passenger glance (not interior object). Individual studies may ask reductionists to identify objects in logs or drop down menus, or may categorize specific objects as Systems of Interest.	"Interior Object" is coded for glances towards the center console or towards items in the center console. Remember, this is the area that starts from the bottom of the "Center Stack" and runs between the driver and the passenger seats where the cup holders are. If a phone is located in this area, it will be coded as "Cell Phone", and not as "Interior Object". This includes cell phone accessories as well, such as chargers, headphones, and the like. All interior controls such as the window buttons, sun visors, and the ceiling lights will be coded as "Interior Object". Sometimes glances towards the window controls on the armrest are mistaken for side mirror glances. Paying attention to the "Hands Video" will provide better context. Sitting idly at a stoplight and looking down into their hands or nails will also be coded as "Interior Object".

	Glance Location	Standardized SHRP2 Definitions	Additional Information and Tips
Z	Eyes Closed	Any time that BOTH the participant's eyes are closed outside of normal blinking (e.g., the subject is falling asleep or rubbing eyes). As a rule of thumb, if the eyes are closed for five or more timestamps (1/3 a second) during a slow blink, code it as Eyes Closed. Otherwise, code it as the glance location present before the eyes closed, or as part of a transition if the eyes are fixated on a new location upon opening. If one eye remains open, code the location according to the open eye. If only one eye is visible, code according to the visible eye.	Normal blinks are typically not coded during glance analysis, unless specified to do so by the project-specific protocol. A normal blink is anything up to 5 timestamps. Anything more than that should be coded as "Eyes Closed". A good tip for differentiating blinks is playing the video at full speed. Other common things that fall into the Eyes Closed category are sneezes or the driver actually falling asleep provided that the 5 frame minimum duration criterion is met.
O	Other	Any glance that cannot be categorized using the above codes. Prior to using this category, please inform a supervisor for appropriate follow-up.	Some pre-approved uses of the "Other" option are listed below: - When the driver is looking forward, and then looks straight up at the sky as if watching a plane fly by. - When the driver is tilting head back to drink and the eyes leave the forward glance but do not really focus on anything at all. - Looking distinctly up at a traffic signal - Looking distinctly up at a highway or road sign - When a driver rolls their eyes "Other" should be used when the driver's eyes leave the Forward position but cannot be considered a glance to any other position and are also not a transition.

E	No Eyes Visible – Glance Location Unknown	Unable to complete glance analysis due to an inability to see the driver's eyes/face. Video data is present, but the driver's eyes and face are not visible due to an obstruction (e.g. visor, hand,), or due to glare. <u>Use this category when there is no way to tell whether the participant's eyes are on or off the road</u>. This is the default and most often used "unknown" option, but there may be times with the "off road" option listed below may be appropriate.	"Glance Location Unknown" can be caused by several things. - The rim of a baseball cap when the driver's head is angled down. - When the sun may be shining directly on the driver's face, and due to the excessive glare the eyes and/or face cannot be seen. - When the driver is going under a bridge or through a tunnel and the shadow falls on their face and the eyes cannot be seen. Even if the glance location can be guessed due to the angle of the driver's head, because the uncertainty of eyes not visible requires it to be coded this way.
T	No Eyes Visible – Eyes Are OffRoad	Unable to enter in specific glance location due to an inability to see the driver's eyes/face. However, it is clear that the participant is not looking at the roadway.	"Eyes Are Off-Road" can be caused by several things. - The sun visor blocking a large portion of the face.
	Glance Location	**Standardized SHRP2 Definitions**	**Additional Information and Tips**
		Video is present, but the driver's eyes and face are not visible due to an obstruction (e.g. visor, hand), head position, or due to glare. <u>Use this category when the eyes are not visible, the analyst cannot be sure what the participant is looking at, but it is obvious that the eyes are not on the roadway.</u>	- Hands blocking the face or camera view. Looking in the vehicle at an unknown object in the backseat.
X	No Driver	The driver is not in the driver seat during the indicated video frame. The vehicle must be in park and the driver must be out of the driver seat (or in the process of getting out or in) to use this category.	-

V	No Video	Unable to complete glance analysis because the face video view is temporarily unavailable. NOTE: this sometimes occurs for 1-2 frames at a time, and a "video not available" message may appear. If the glance location is the same before and after this occurs and the period is only 1-2 frames long, then code through this period as the glance location present before and after. If the "video not available" period is longer than 2 frames OR it occurs during a transition, use the "No Video" option.	

Special Cases:
Driving in Reverse/Backing up: This instance applies when the driver's face is completely facing the rear window with the intention of driving in reverse. These instances are to be coded as Forward (not as Over-The-Shoulder). This is the only instance in which the directions will be reversed. For glance purposes, the rear window will become the forward windshield and the forward windshield will become the rear window. Glances back towards the forward windshield while driving in reverse will be coded over-the-shoulder-left.

Drive-Throughs and Toll Booths: All glances to the teller, menu, teller speaker, etc. will be coded as Left Window. If the teller is handing back the driver a receipt or money or credit card and the driver is looking at the object being handed to them, start coding the glance as Interior Object when the object makes contact with the driver's hand.

Dark Sunglasses: If the eyes are not visible for the entire event due to dark or opaque shades, most studies will ask reductionists to code glance as well as possible using head movements. However, some studies may require that these events be coded as No Eyes Visible. In all cases, these events should be clearly noted in the reduction log spreadsheet.

"Lazy" Eyes and Uneven Pupils: When a driver has eyes that appear to be looking different directions, reductionists should try to figure out which eye is the driver's dominant eye and which is the "lazy" eye. Once it has been determined which eye is dominant, only code based on that eye's glance location for the whole event.

Grainy/Poor Videos: If the video image is extremely grainy or poor such that it is very difficult to determine see where the eyes are looking for the majority of the event, reductionists should treat this similarly to the Dark Sunglasses case described above. Most studies will ask reductionists to code glance as well as possible using head movements. However, some studies may require that these events be coded as No Eyes Visible. In all cases, these events should be clearly noted in the reduction log spreadsheet.

Skewed Camera Angles: Sometimes a camera is misaligned during an entire event, or is bumped during at event. Reductionists should still code the event as usual provided that at least one eye is visible.

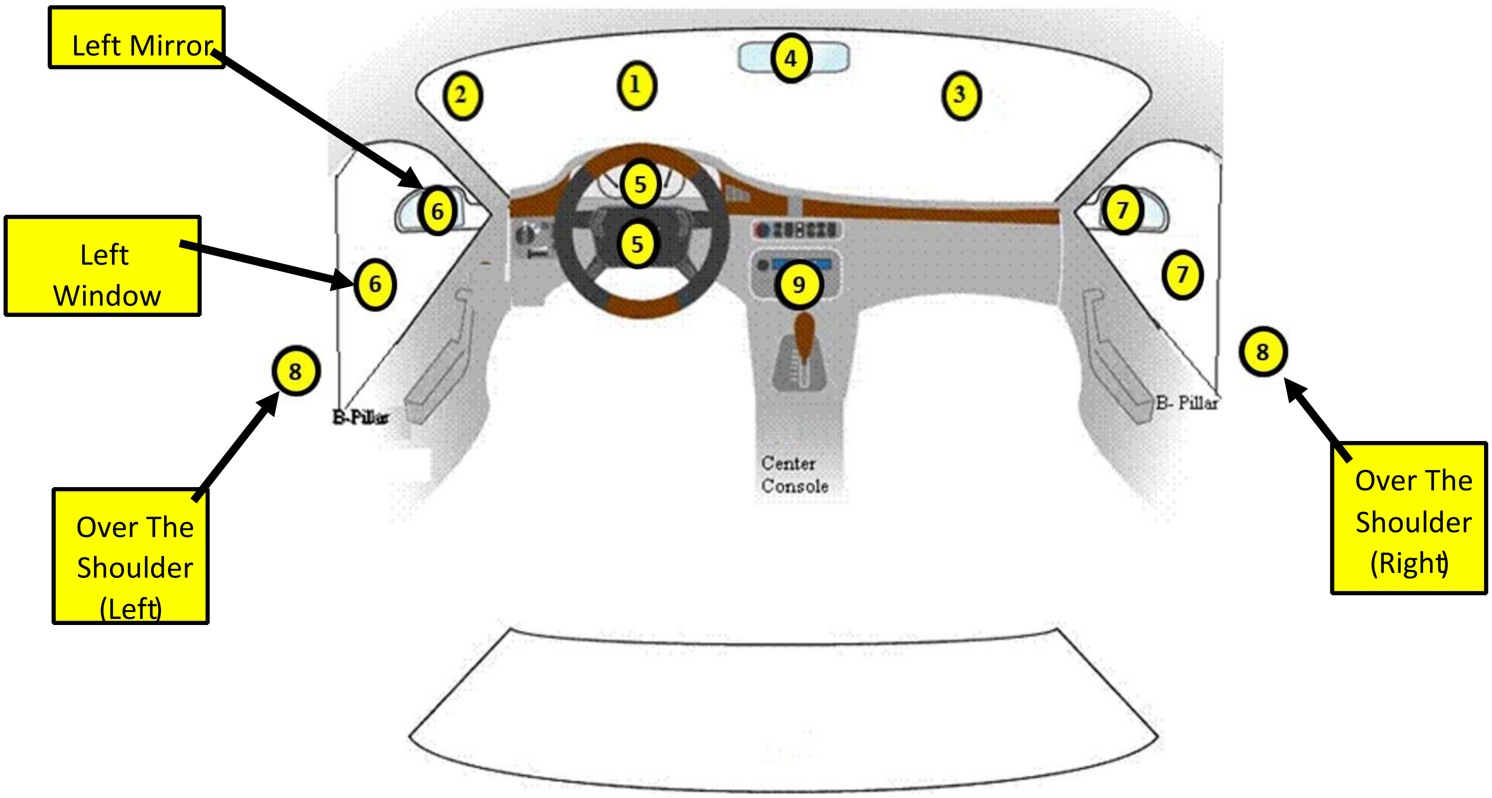
Sensitive Content: Reductionists should always refer to and abide by the Handling of Sensitive Video Content procedures listed in VTTI's DR Lab Policies.

Typical Glance Behaviors:

- Transitions and Blinks: Drivers will often blink just before, during, or at the end of a transition between glances. Blinks can be a good indicator of a transition or glance location change.
- Hard Braking: Drivers also typically check the Rear View Mirror immediately after slamming on the brakes to see if the following vehicle is stopping as well.
- Crashing: During the impact portion of a crash, the driver's eyes will often move around randomly for several frames without fixating on anything as their body is bounced around, this can be coded as "No Eyes Visible – Glance Location Unknown".
- Changing Lanes: Drivers almost always check behind them before merging or changing lanes. Glances will often include Rear View Mirror, Left Mirror, Left or Right Window, and/or Over-the-Shoulder (Left) or Over-the Shoulder (Right).
- Traffic Signals: When stopped at a traffic signal drivers will sometime glance from Forward, to the traffic signal (coded as "Other"), and then to an "Interior Object" like their hands or to a device like a "Cell Phone".
- Making a Turn: Before initiating the turn the driver will often glance to the "Right/Left Windshield" and/or the "Right/Left Window" to see that there path is clear. Once the turning begins (indicated by steering wheel rotation) those Left/Right glances are considered "Forward" provided that they are in the direction of the turn.
- Cell Phones: It's sometimes helpful to check outside the event window to determine if an object is a cell phone or a different kind of electronic device. Drivers using their phones will usually interact with them frequently especially when sitting at stop lights.
- Passengers: It can also be helpful to look outside the event window for the presence of legs or hands in the passenger seat. Drivers will typically glance at a passenger more frequently when they are engaged in conversation. Drivers also tend to turn their head towards the passenger, to indicate they are listening, while keeping their eyes forward

Glance Diagram

(Changes from the normal standard are shown in yellow boxes below)



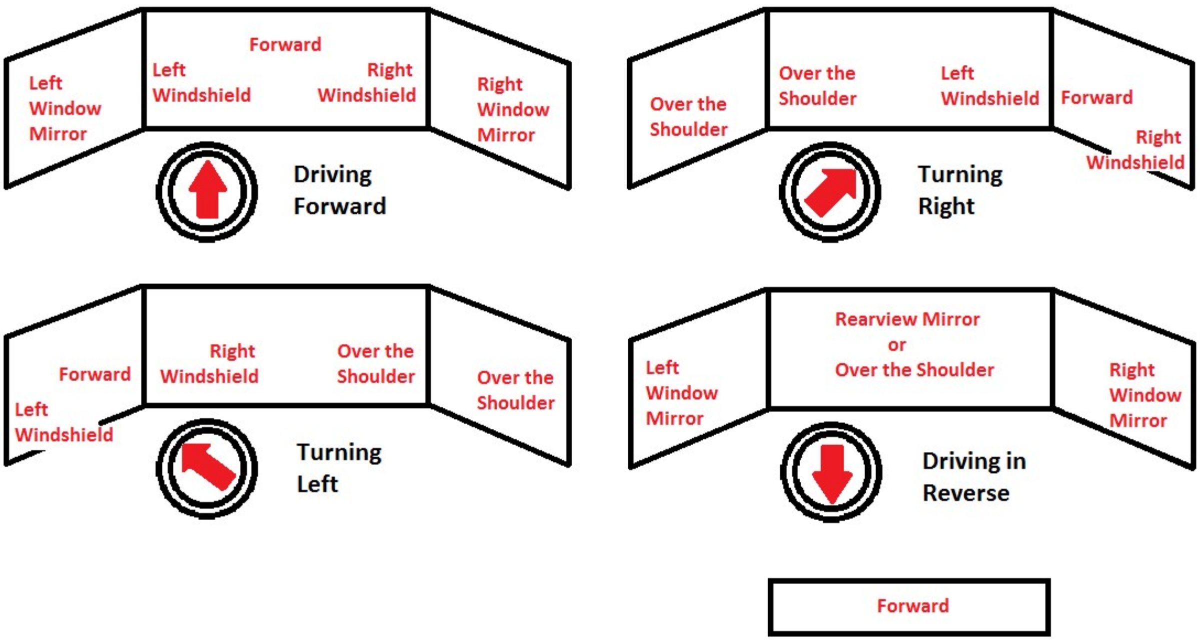
<u>Number From Image Above</u>	<u>Corresponding Key</u>	<u>Glance Location</u>
1	F	Forward
2	D	Left Forward / Left Windshield
3	G	Right Forward / Right Windshield
4	M	Rearview Mirror
5	I	Instrument Cluster
6	L	Left Mirror / Left Window
7	R	Right Mirror / Right Window
8	S	Over the Shoulder (Left or Right)
9	C	Center Stack
Not Shown	Q	Transition
Not Shown	V	No Video
Not Shown	A	Passenger
Not Shown	P	Cell Phone

Not Shown	H	Portable Media Device
Not Shown	W	Interior Object
Not Shown	O	Other
Not Shown	E	No Eyes Visible – Glance Location Unknown
Not Shown	T	No Eyes Visible – Eyes are Off-Road
Not Shown	Z	Eyes Closed

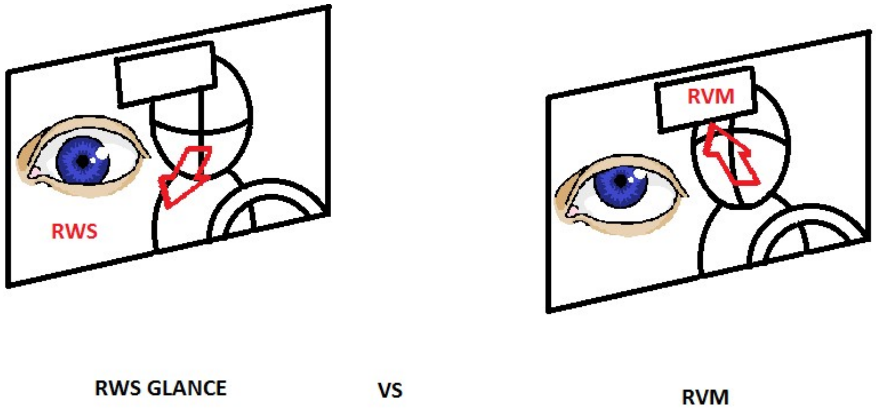
Helpful Images

Glance Turns

While the vehicle is turning the continuum of glances moving from left to right is shifted in the direction of the turn. This shift is illustrated in the diagram below.



Glance Right Windshield (RWS) vs. Rear View Mirror (RVM)



Examples of VTTI Standard glance locations. (Examples show a VTTI Employee)

FORWARD: (ROAD AHEAD) Note this is coded in direction of travel, which shifts as the driver negotiates curves and turns.

Image 1:

Image 2:

LEFT WINDSHIELD: Note that this is usually more of an eye movement with little or no head movement, which can be distinguished from forward provided that sunglasses, glare, etc. do not obstruct.

Image 1: (looking at vehicle overtaking on the left)

Image 2: (looking at left adjacent vehicle ahead)

LEFT WINDOW/MIRROR:

Image 1: (at intersection)

Image 2:(approaching intersection

RIGHT WINDSHIELD: Notice that glance is slightly to the right and level with Forward.

Image 1: (at intersection)

Image 2: (at intersection)

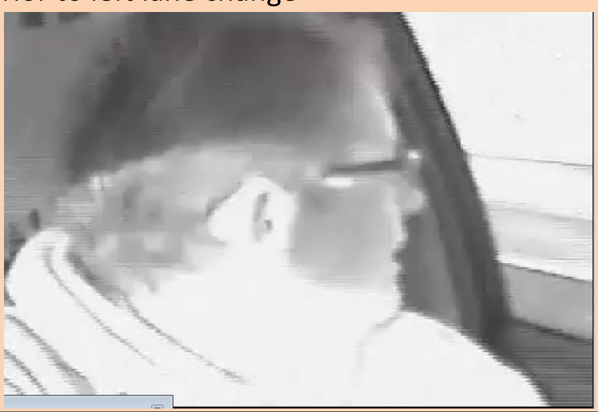
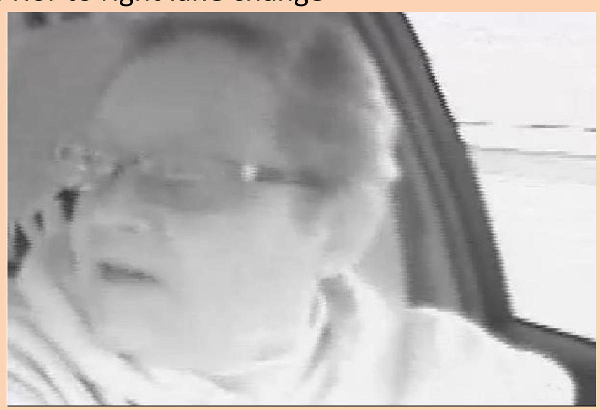
RIGHT WINDOW/MIRROR:

Image 1: (approaching intersection)

Image2: (at intersection)

REAR-VIEW MIRROR:

(Notice glance is to the right and up; looking directly at the camera.)

CELL PHONE:  NOTE: the phone could be located in many places. This option is used regaerdless of where phone is located.	**INSTRUMENT CLUSTER:** Press button on steering wheel 	**INSTRUMENT CLUSTER:** Speed check 
OVER-THE-SHOULDER: Prior to left lane change 	**OVER-THE-SHOULDER:** Prior to right lane change 	**CENTER STACK:** Radio/HVAC 

INTERIOR OBJECT: Looking down at jacket or arm rest	**INTERIOR OBJECT:** Looking for/at object in purse or wallet	**ADDITIONAL CATEGORIES:**
		• Look at Passenger (Use Passenger) • Look seatbelt/window controls (Use Interior Object) • Look at center console/glove box (Use Interior Object) We use a combination of the face and hands video to determine context and code to appropriate category.

APPENDIX C. FULL RESULTS

UNINTERRUPTED LANE CHANGES

Glance Characteristics

Percentage of Time

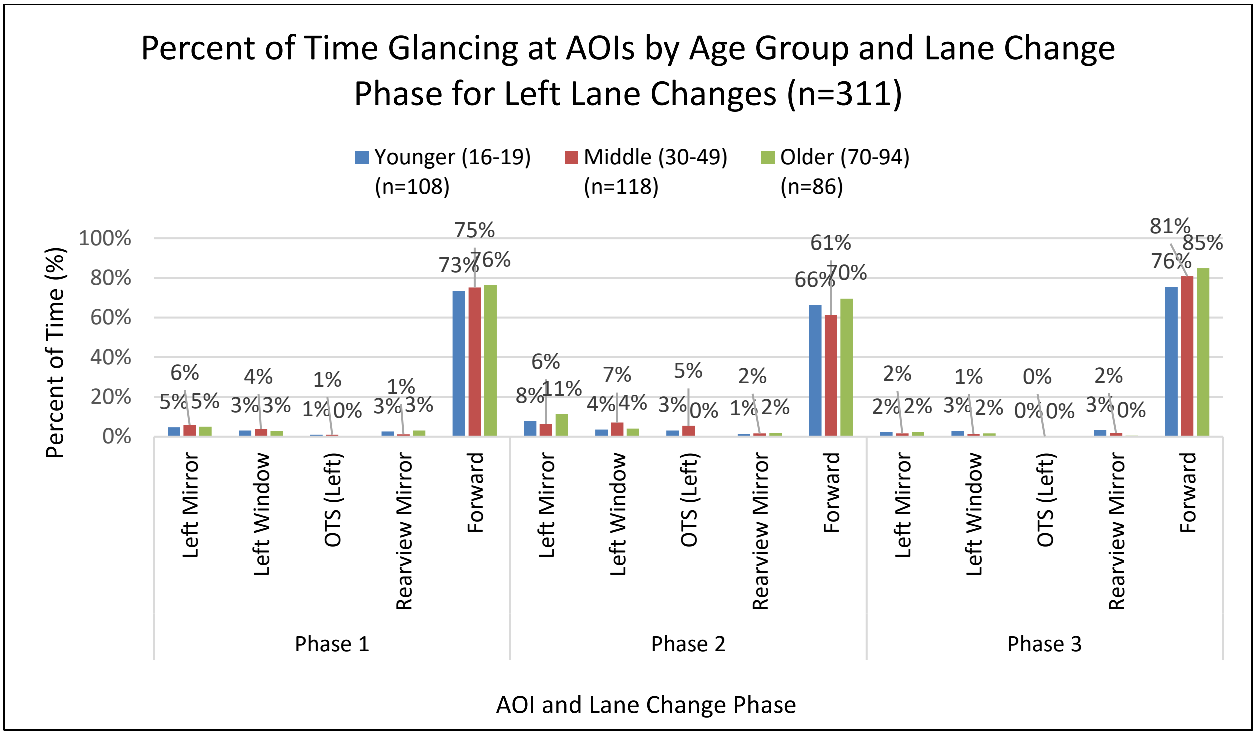


Figure 70. Chart. Percentage of time glancing to AOIs by age group and lane change phase for uninterrupted left lane changes.

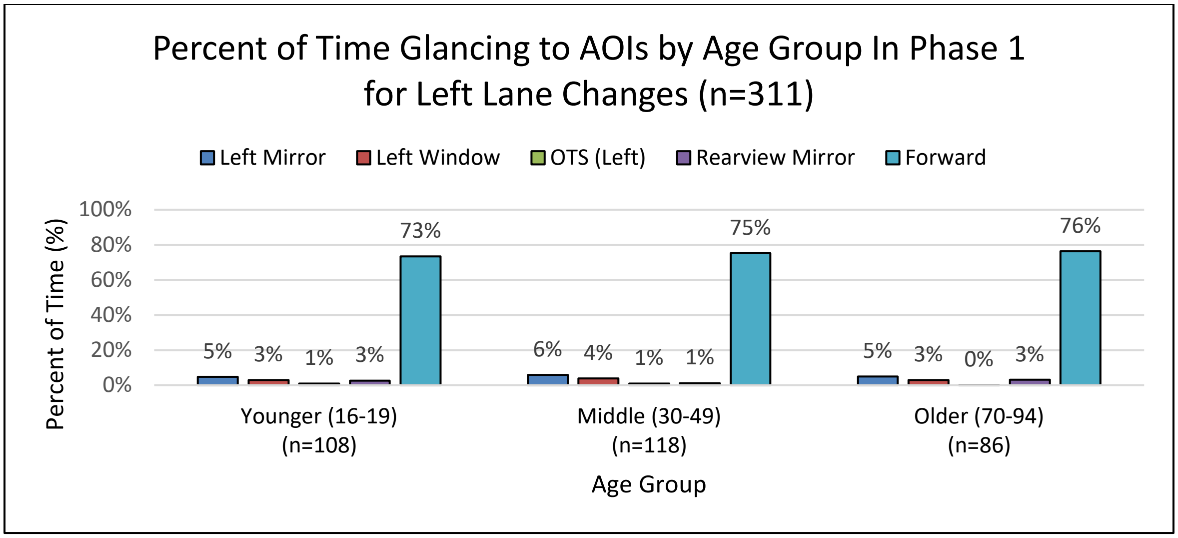


Figure 71. Chart. Percentage of time glancing to AOIs by age group for Phase 1 of uninterrupted left lane changes.

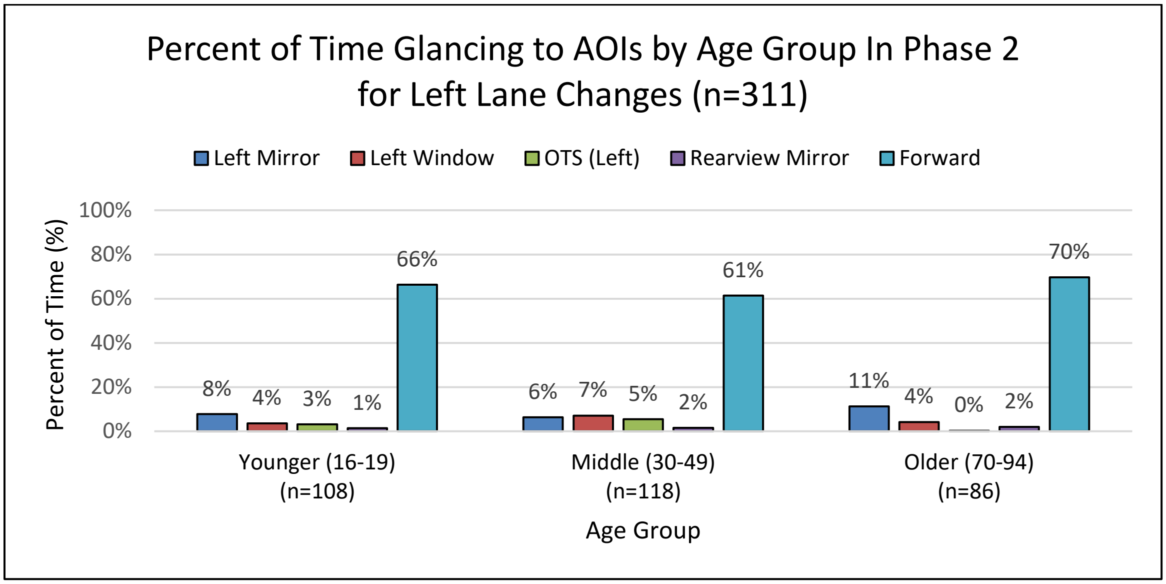


Figure 72. Chart. Percentage of time glancing to AOIs by age group for Phase 2 of uninterrupted left lane changes.

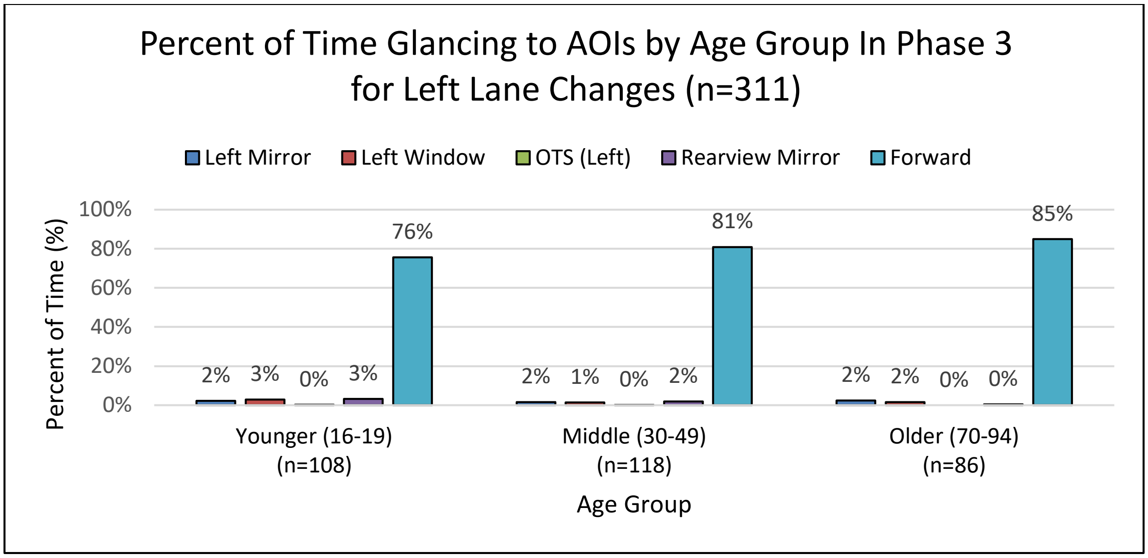


Figure 73. Chart. Percentage of time glancing to AOIs by age group for Phase 3 of uninterrupted left lane changes.

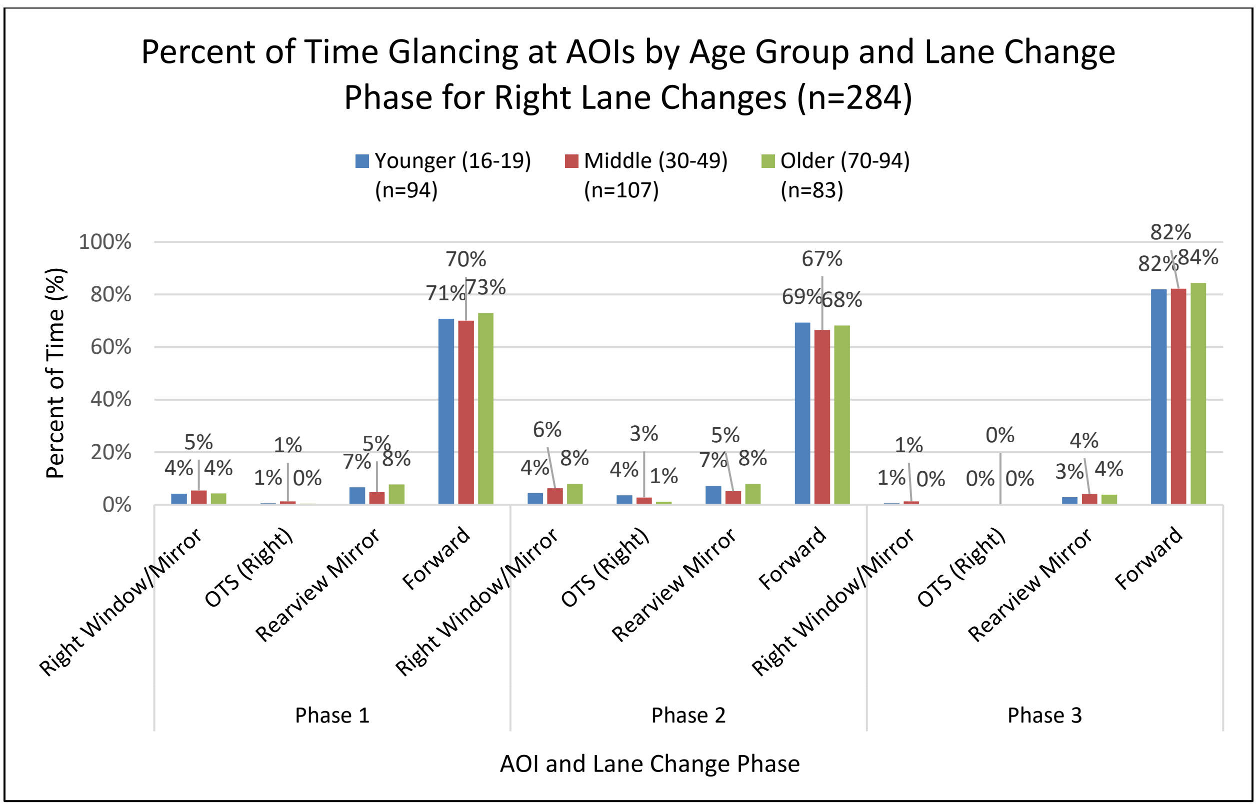


Figure 74. Chart. Percentage of time glancing to AOIs by age group and lane change phase for uninterrupted right lane changes.

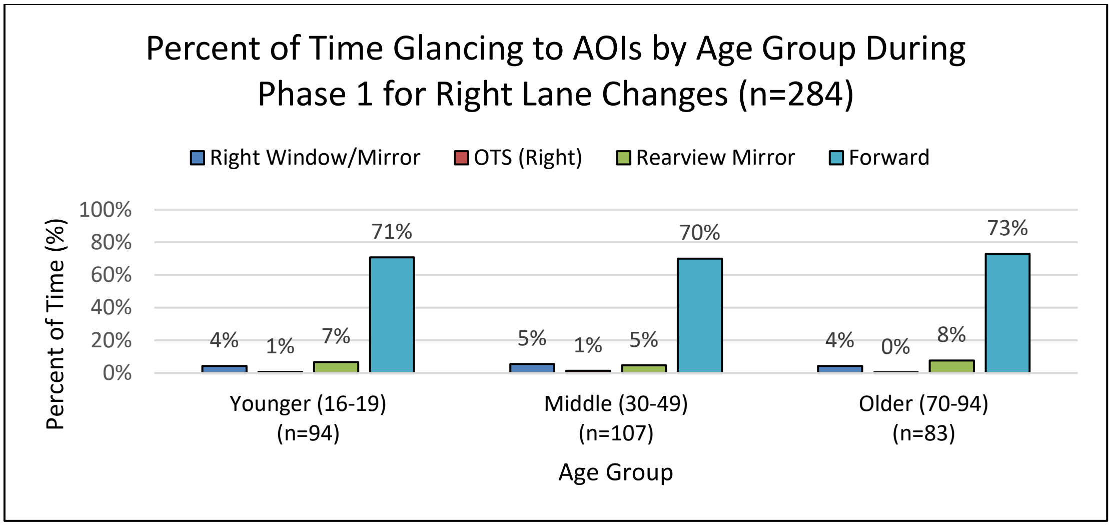


Figure 75. Chart. Percentage of time glancing to AOIs by age group for Phase 1 of uninterrupted right lane changes.

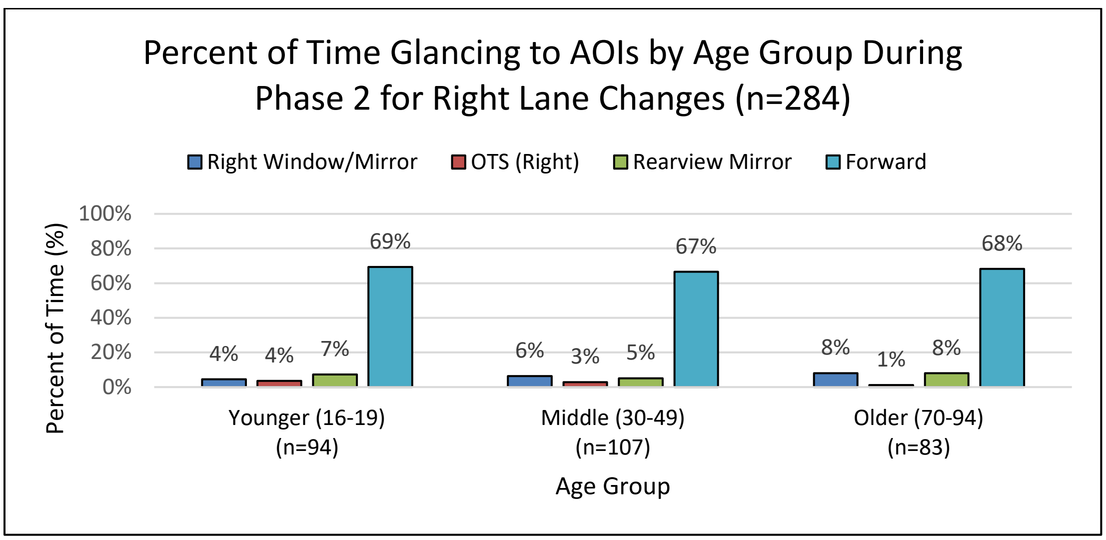


Figure 76. Chart. Percentage of time glancing to AOIs by age group for Phase 2 of uninterrupted right lane changes.

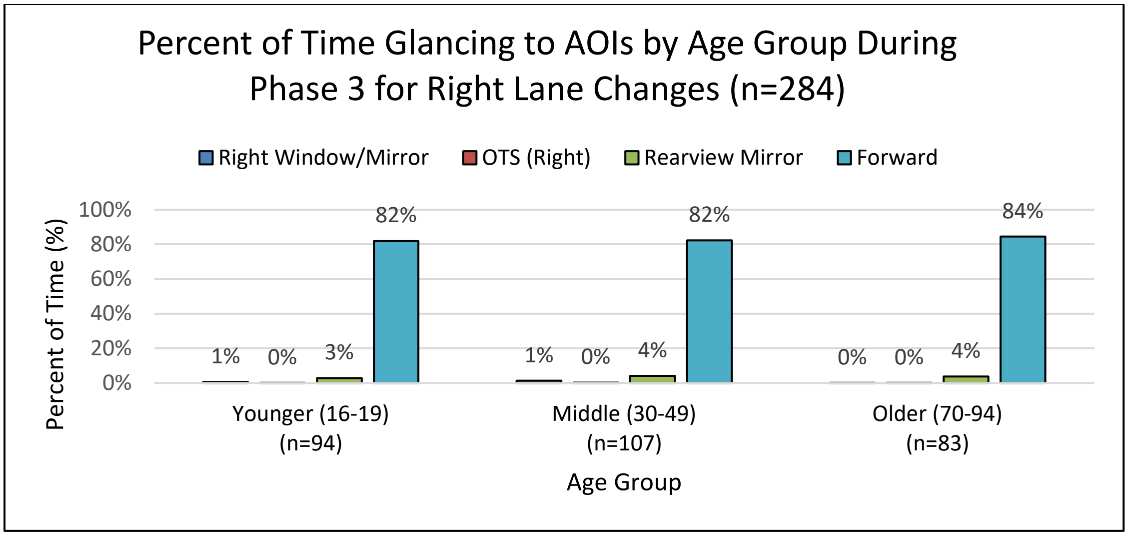


Figure 77. Chart. Percentage of time glancing to AOIs by age group for Phase 3 of uninterrupted right lane changes.

Percentage of Glances

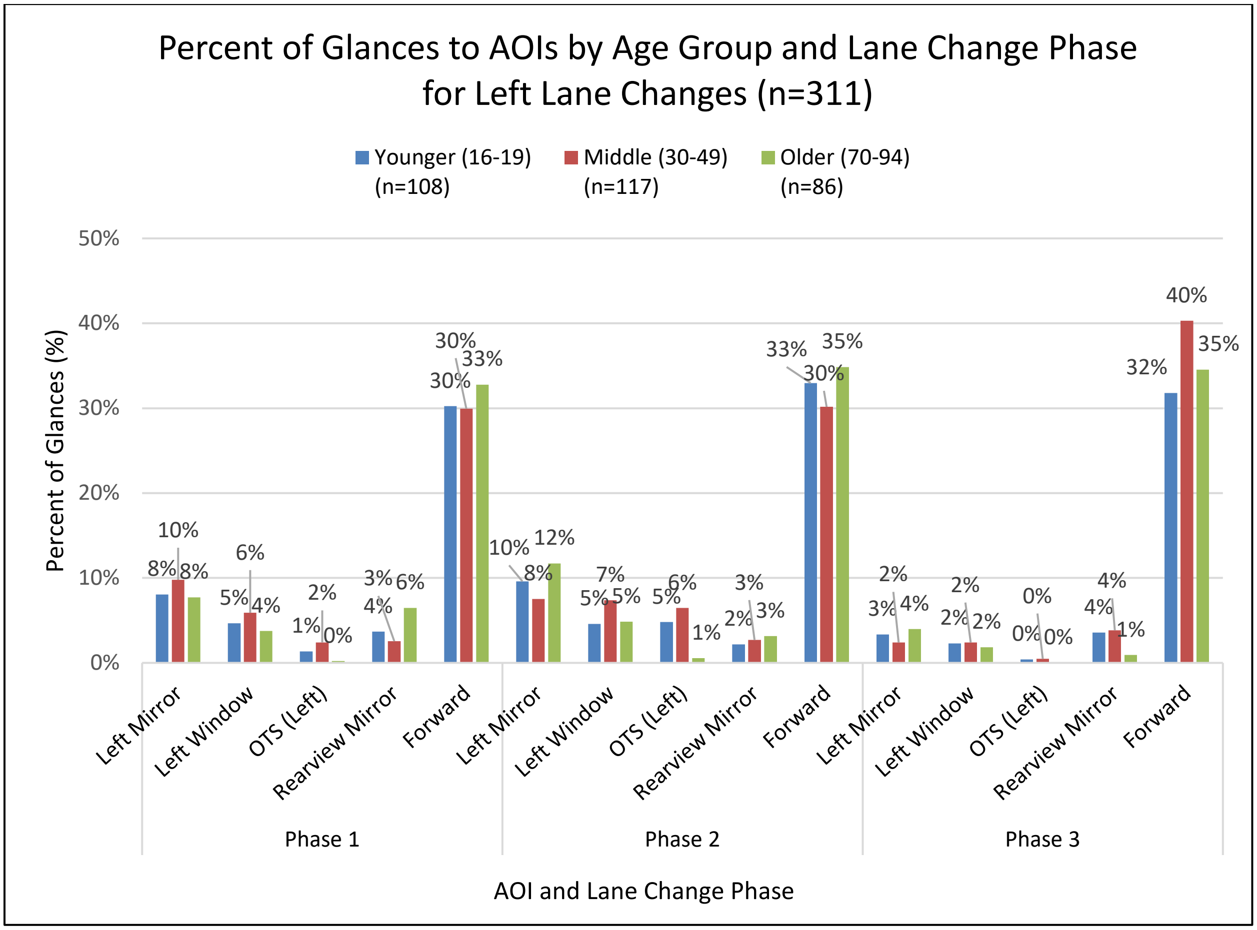


Figure 78. Chart. Percentage of glances to AOIs by age group and lane change phase for uninterrupted left lane changes.

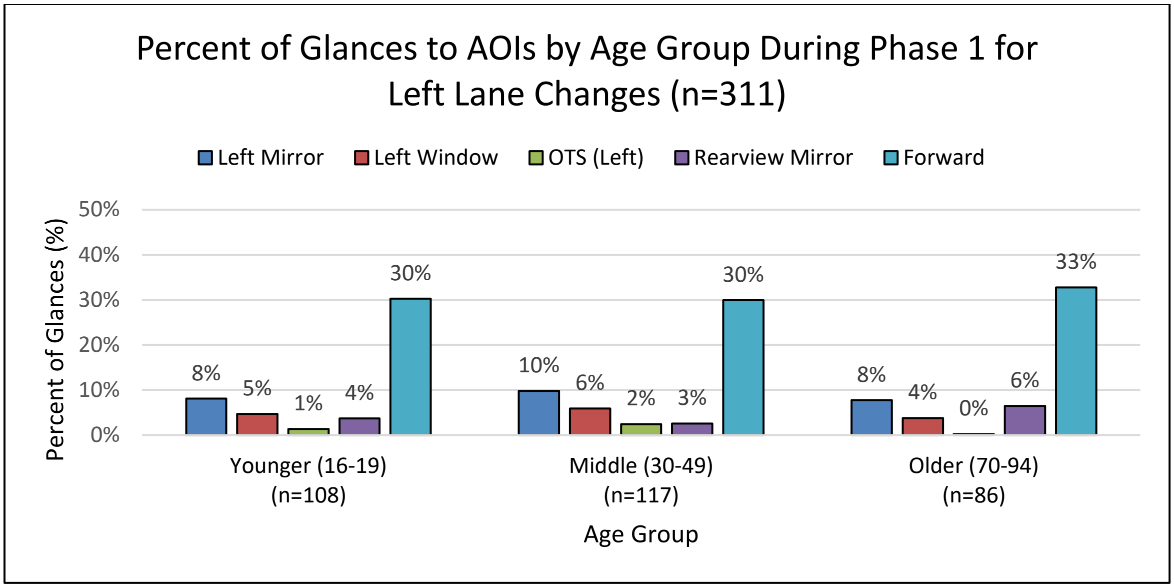


Figure 79. Chart. Percentage of glances to AOIs by age group for Phase 1 of uninterrupted left lane changes.

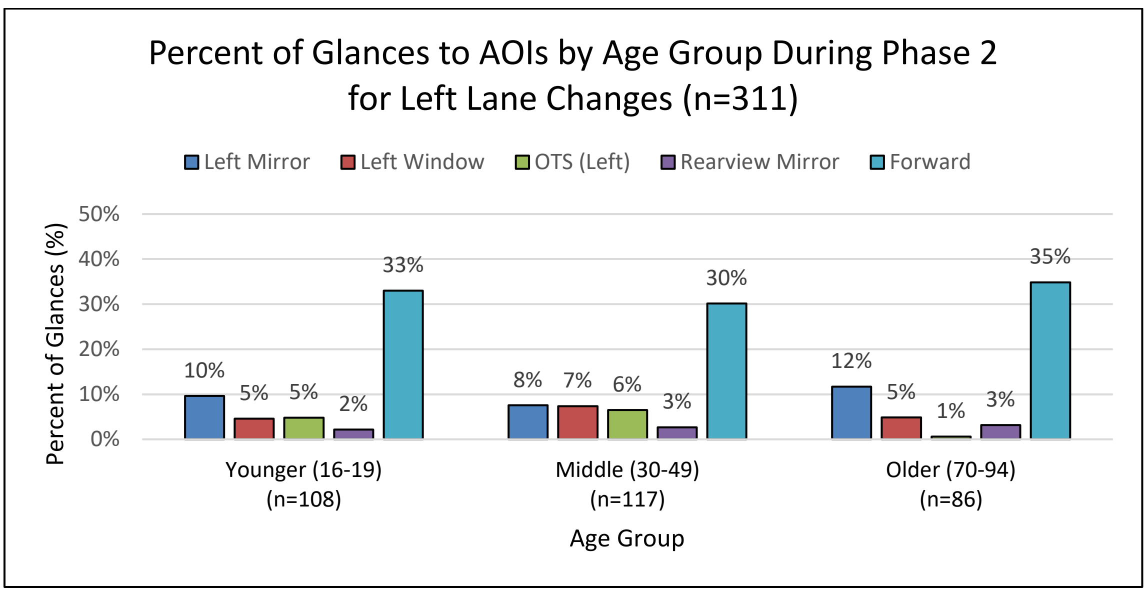


Figure 80. Chart. Percentage of glances to AOIs by age group for Phase 2 of uninterrupted left lane changes.

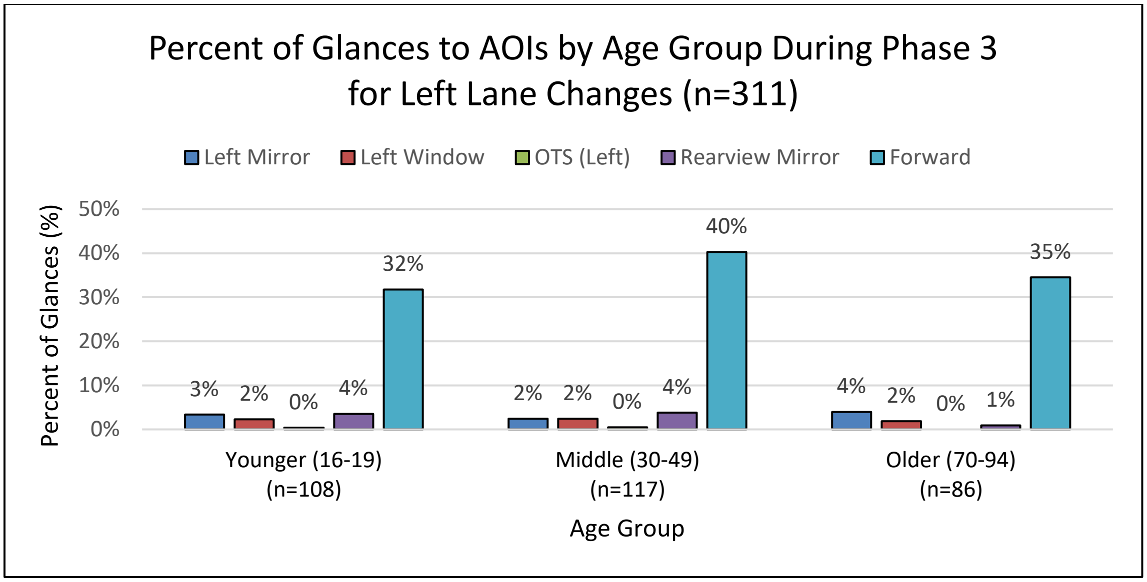


Figure 81. Chart. Percentage of glances to AOIs by age group for Phase 3 of uninterrupted left lane changes.

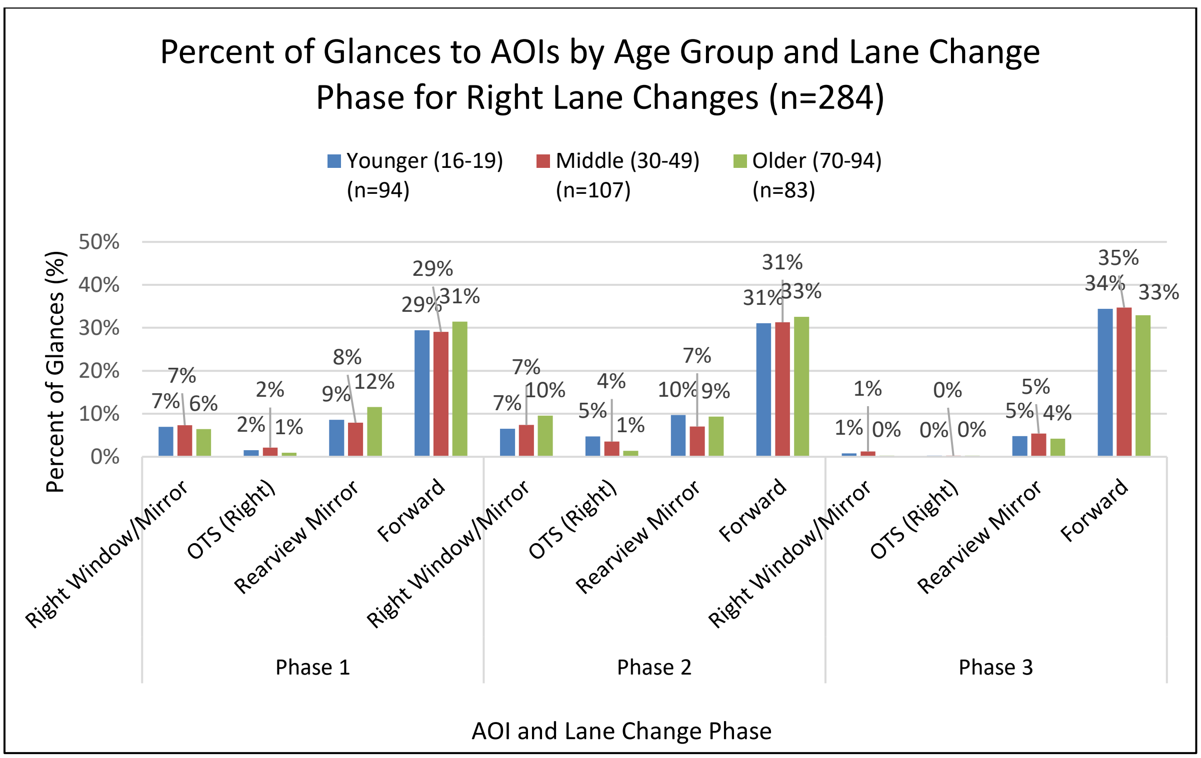


Figure 82. Chart. Percentage of glances to AOIs by age group and lane change phase for uninterrupted right lane changes.

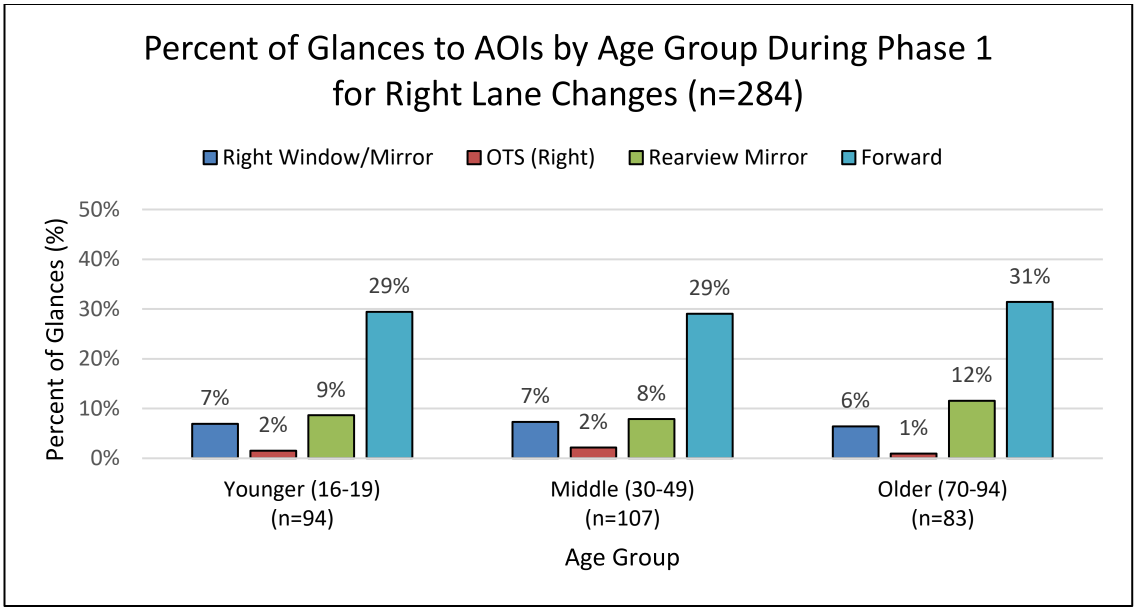


Figure 83. Chart. Percentage of glances to AOIs by age group for Phase 1 of uninterrupted right lane changes.

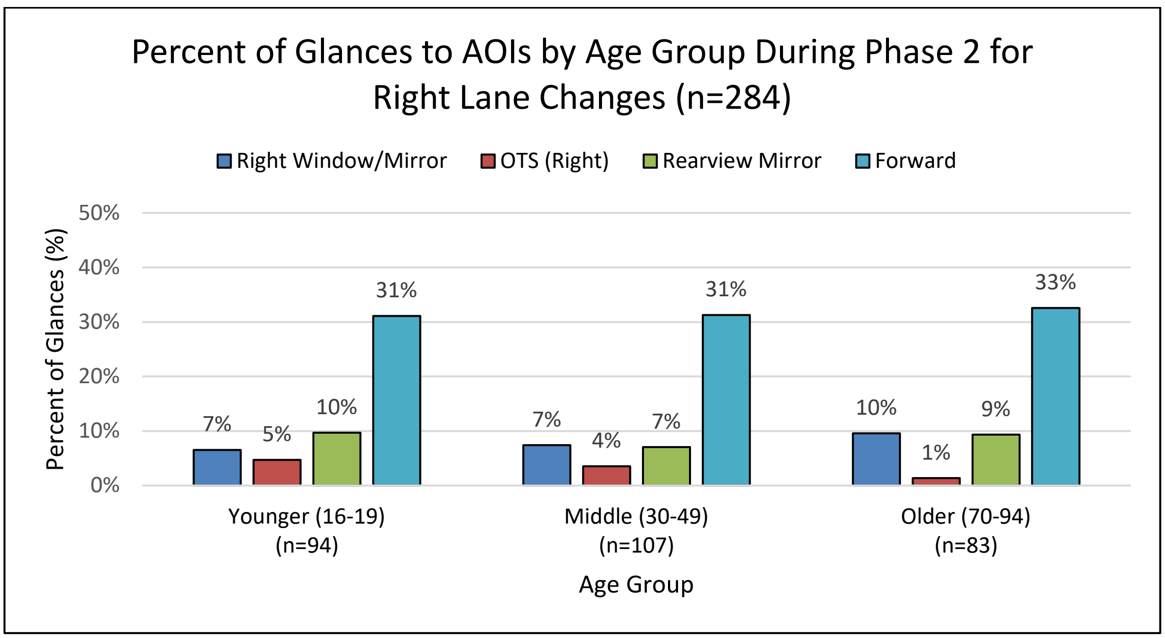


Figure 84. Chart. Percentage of glances to AOIs by age group for Phase 2 of uninterrupted right lane changes.

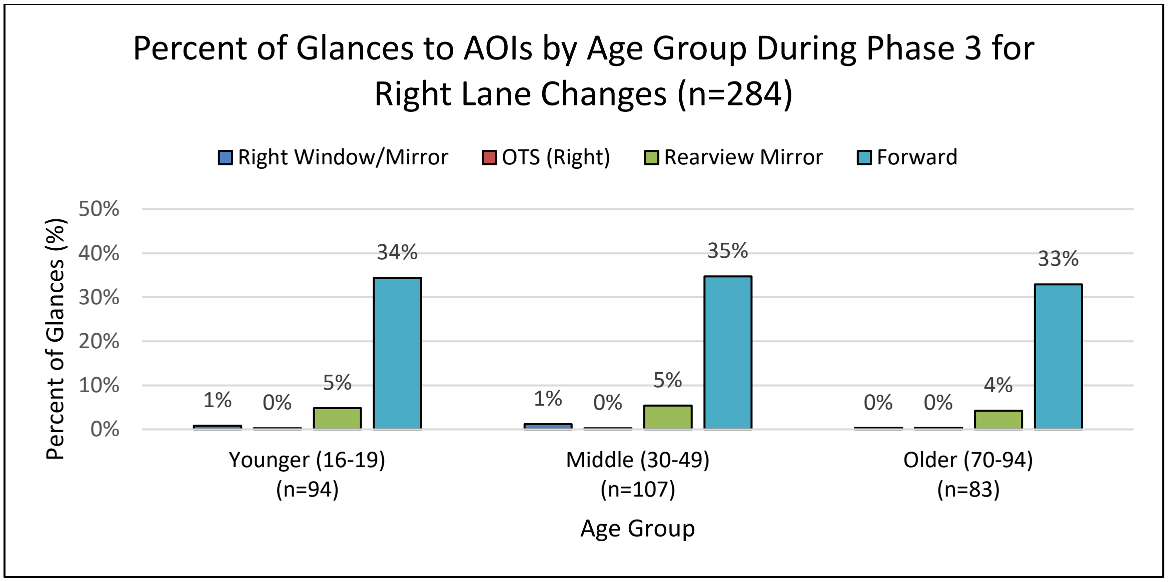


Figure 85. Chart. Percentage of glances to AOIs by age group for Phase 3 of uninterrupted right lane changes.

Glance Duration

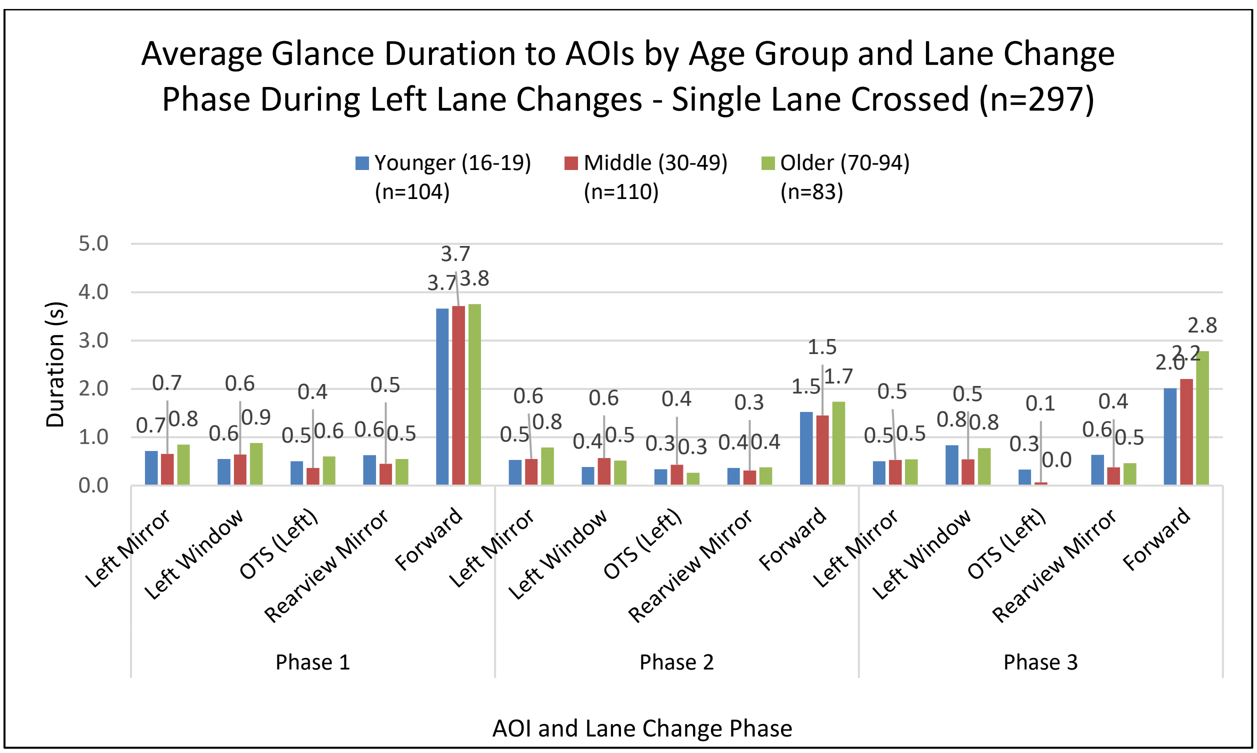


Figure 86. Chart. Average glance duration to AOIs by age group and lane change phase for uninterrupted left lane changes.

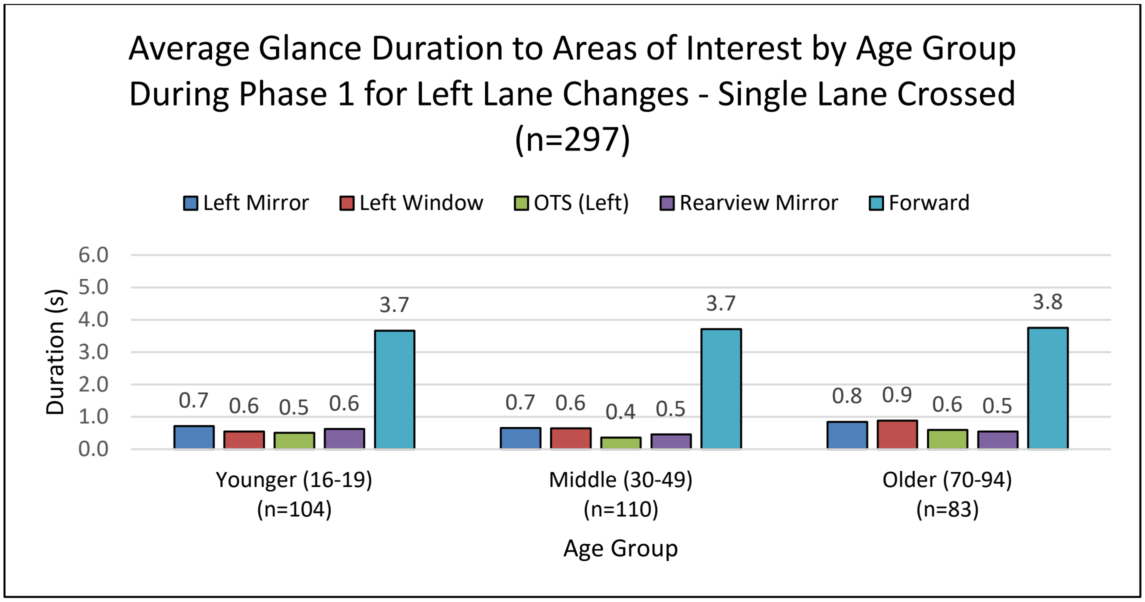


Figure 87. Chart. Average glance duration to AOIs for Phase 1 of uninterrupted left lane changes.

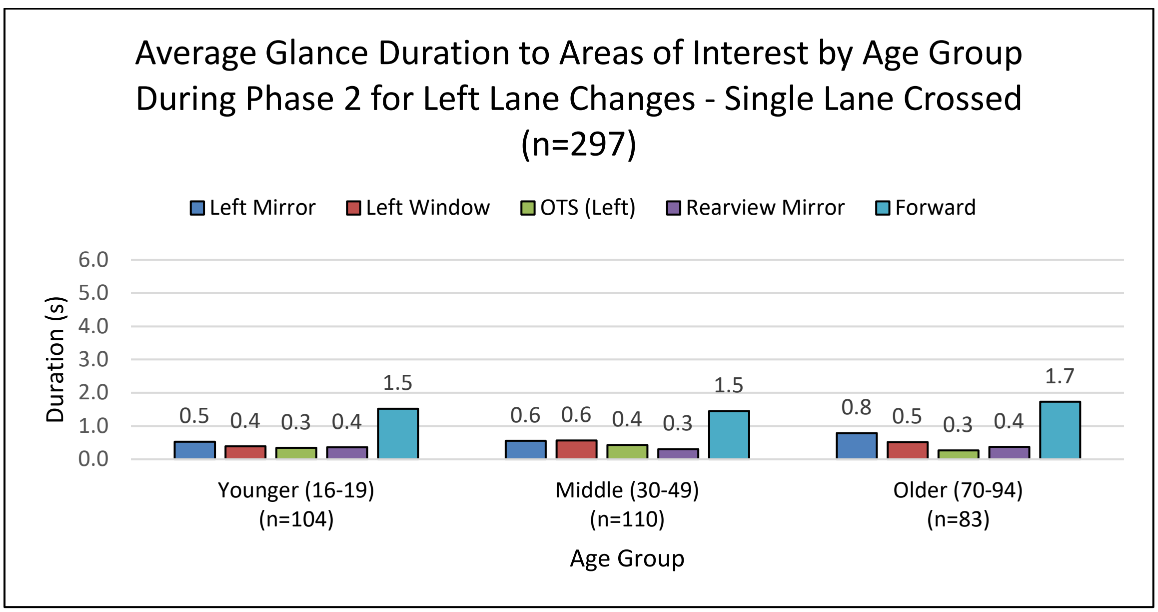


Figure 88. Chart. Average glance duration to AOIs for Phase 2 of uninterrupted left lane changes.

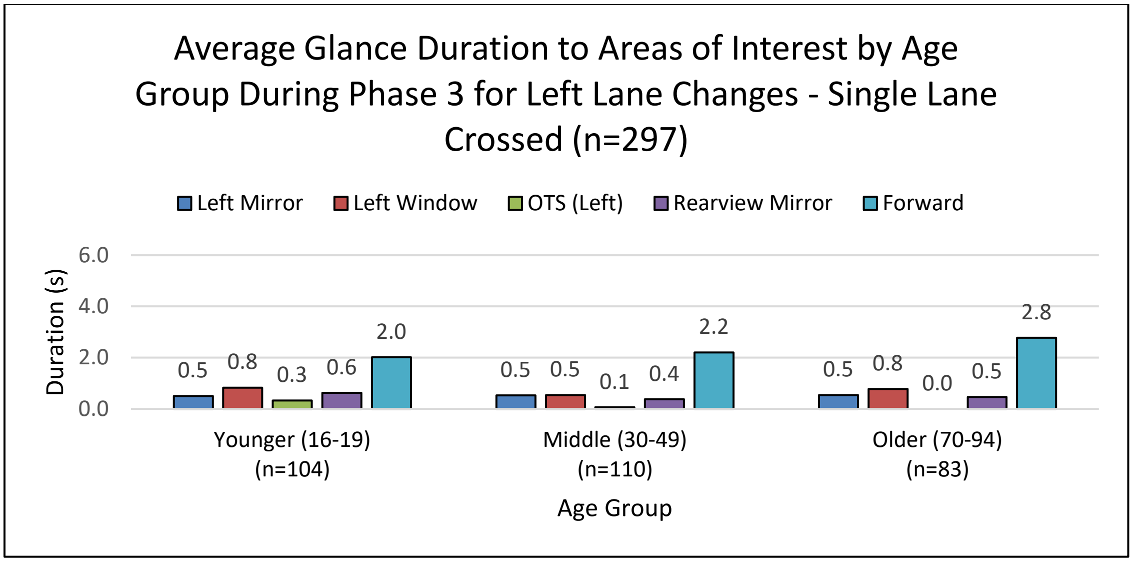


Figure 89. Chart. Average glance duration to AOIs for Phase 3 of uninterrupted left lane changes.

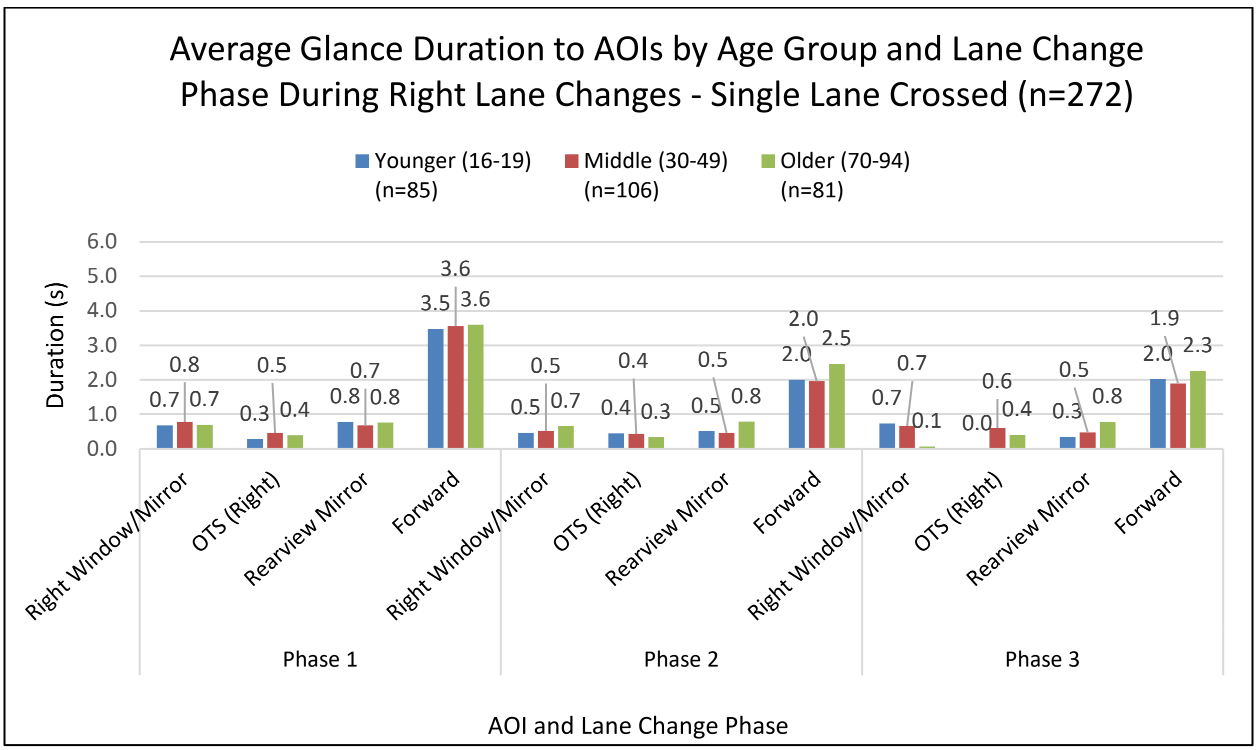


Figure 90. Chart. Average glance duration to AOIs by age group and lane change phase for uninterrupted right lane changes.

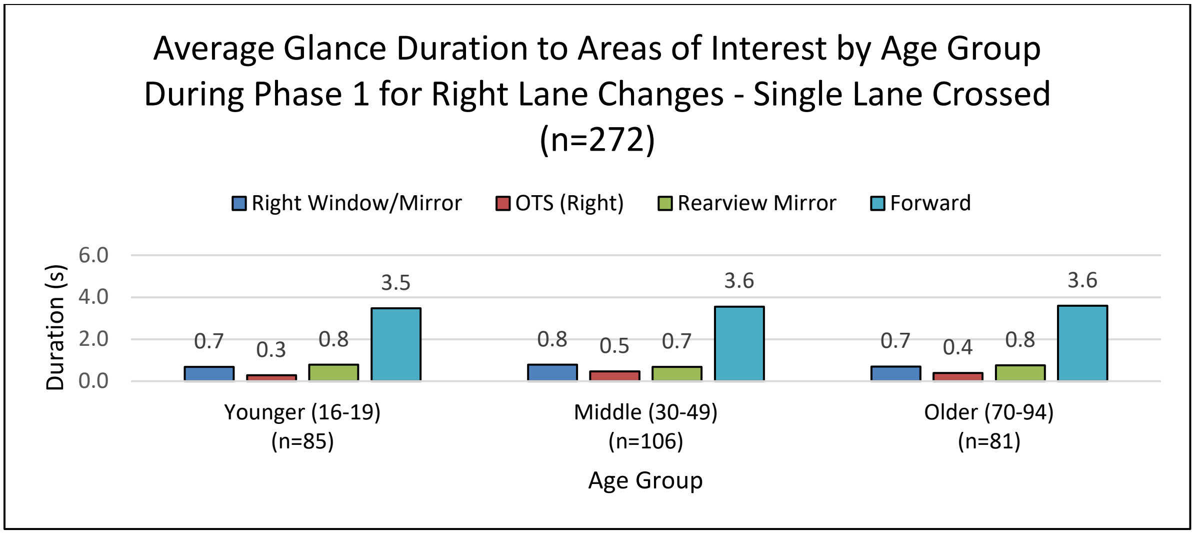


Figure 91. Chart. Average glance duration to AOIs for Phase 1 of uninterrupted right lane changes.

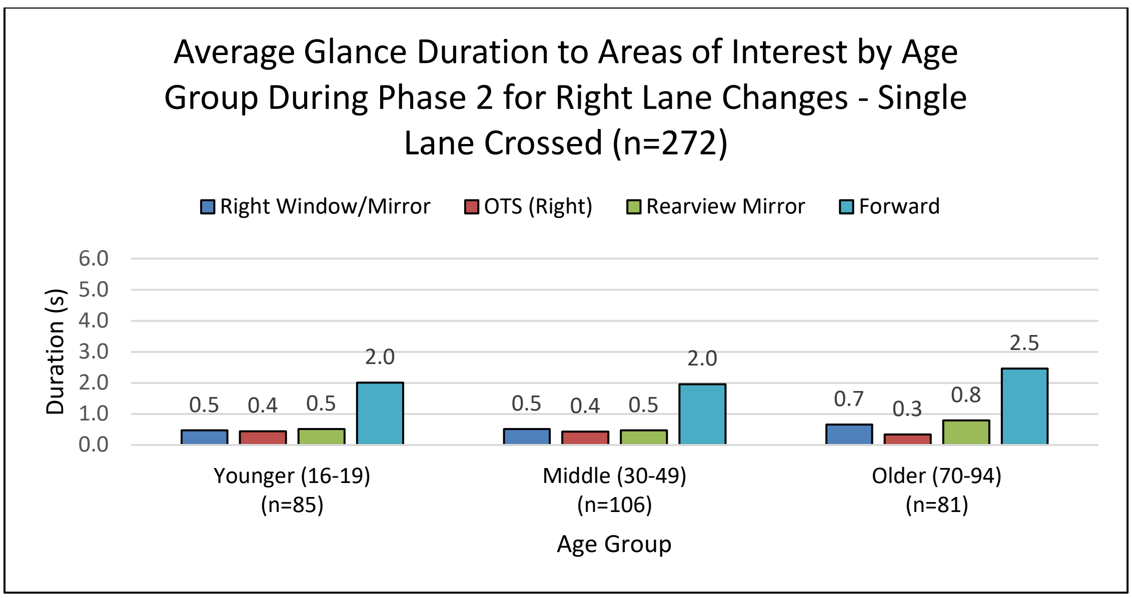


Figure 92. Chart. Average glance duration to AOIs for Phase 2 of uninterrupted right lane changes.

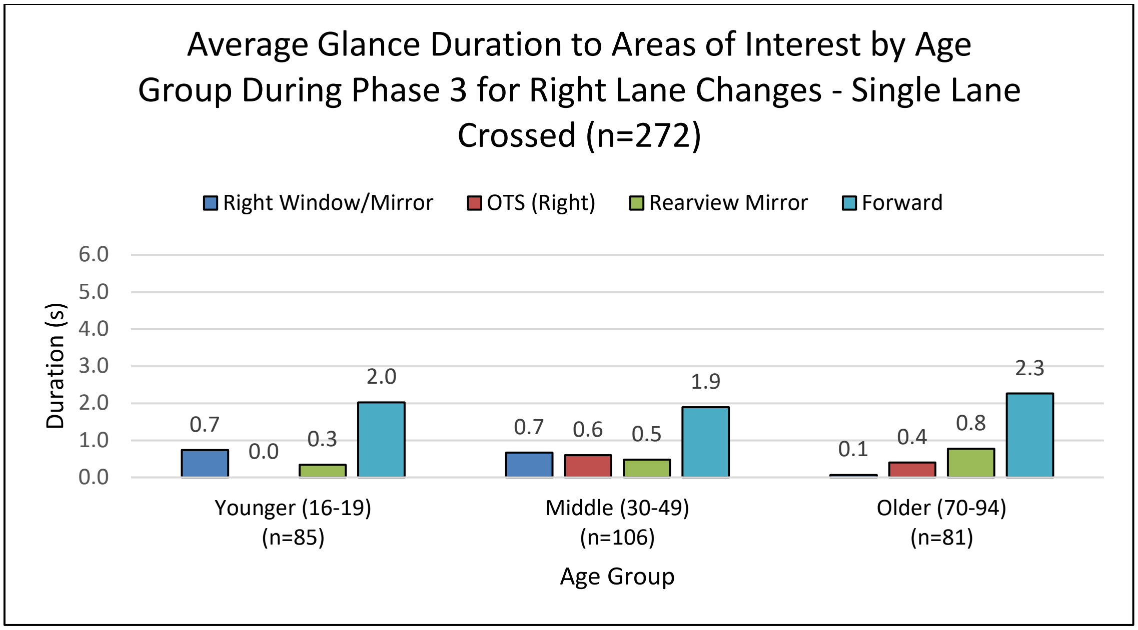


Figure 93. Chart. Average glance duration to AOIs for Phase 3 of uninterrupted right lane changes.

Glance Counts

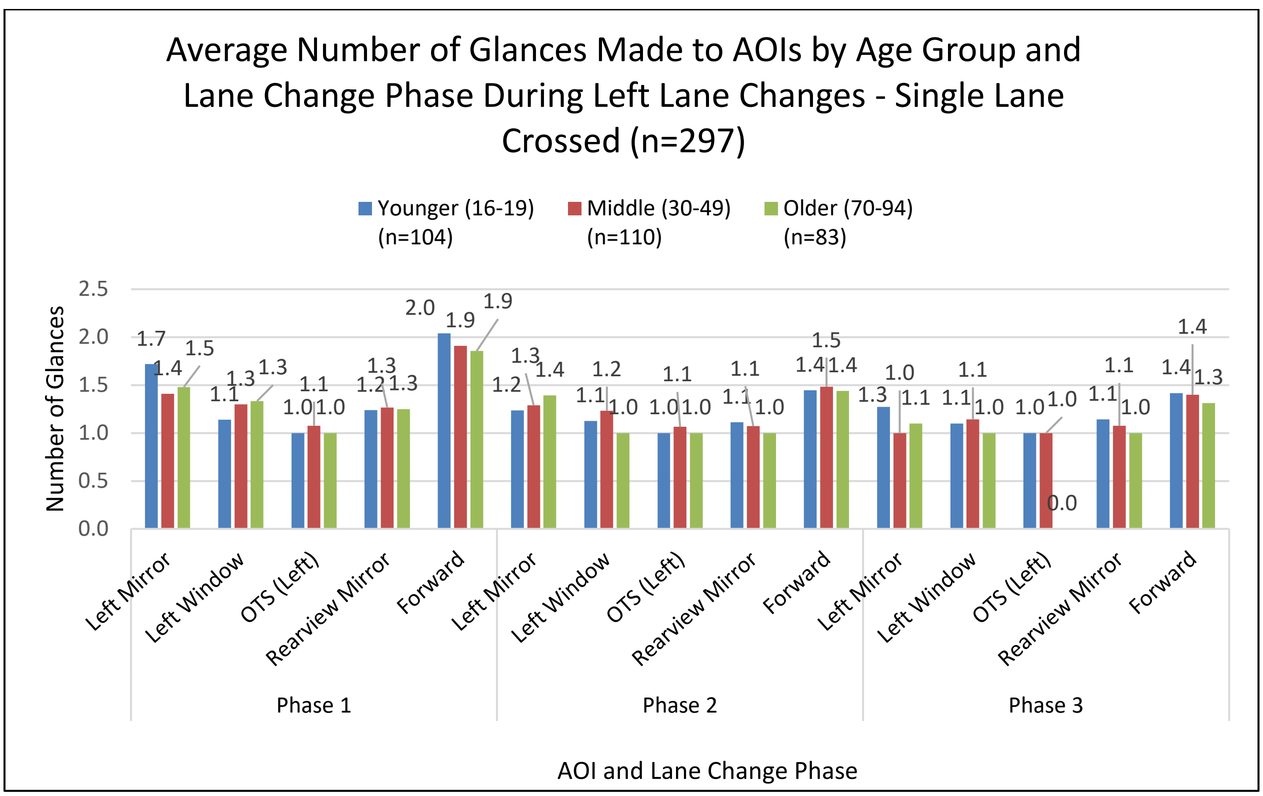


Figure 94. Chart. Average number of glances to AOIs by age group and lane change phase for uninterrupted left lane changes.

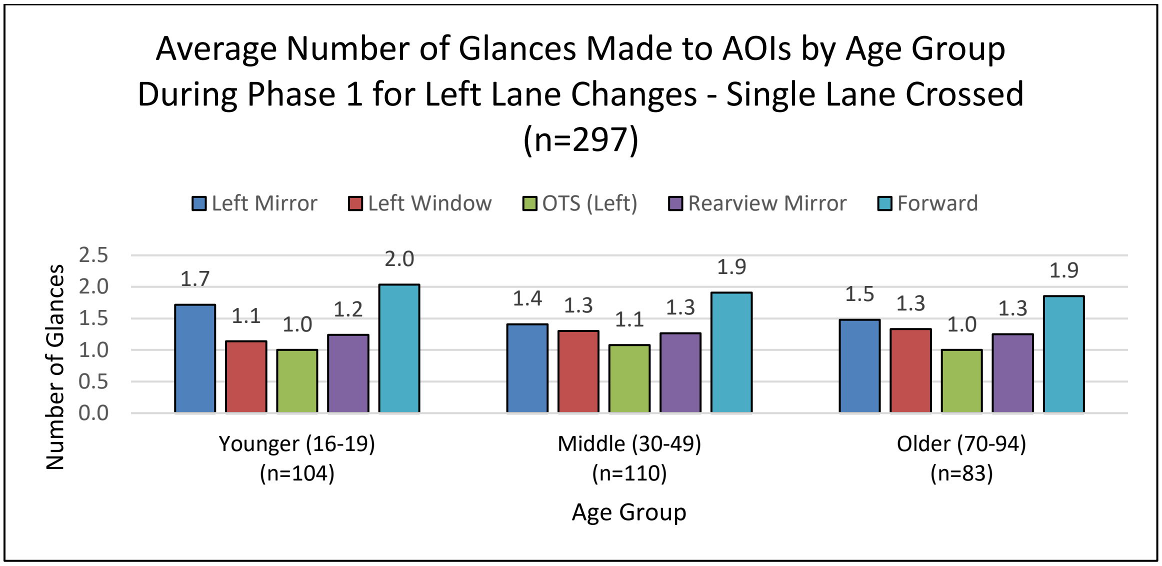


Figure 95. Chart. Average glance count made during Phase 1 of uninterrupted left lane changes.

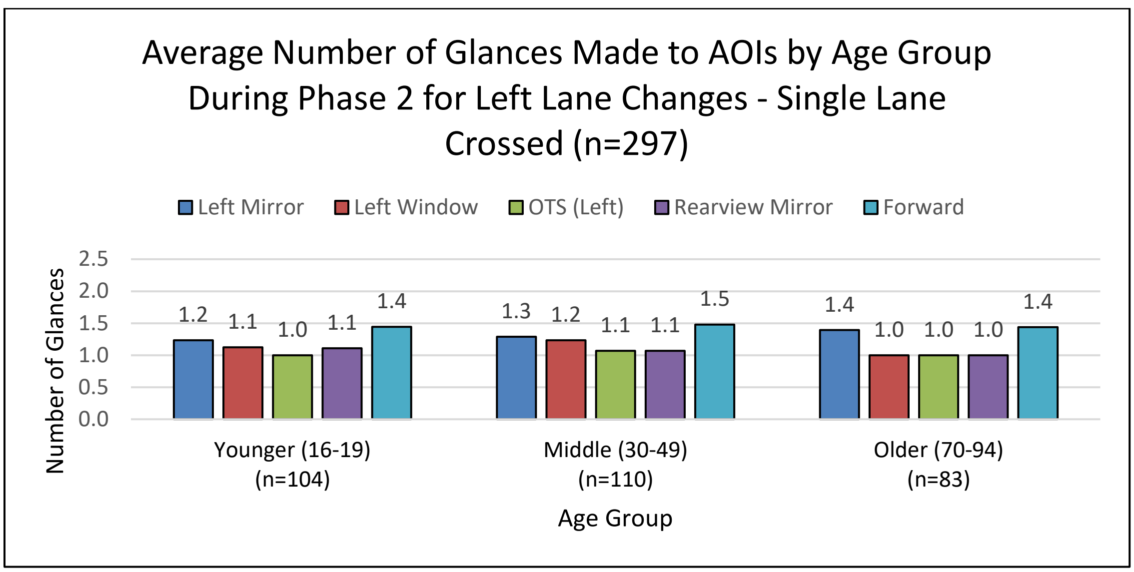


Figure 96. Chart. Average glance count made during Phase 2 of uninterrupted left lane changes.

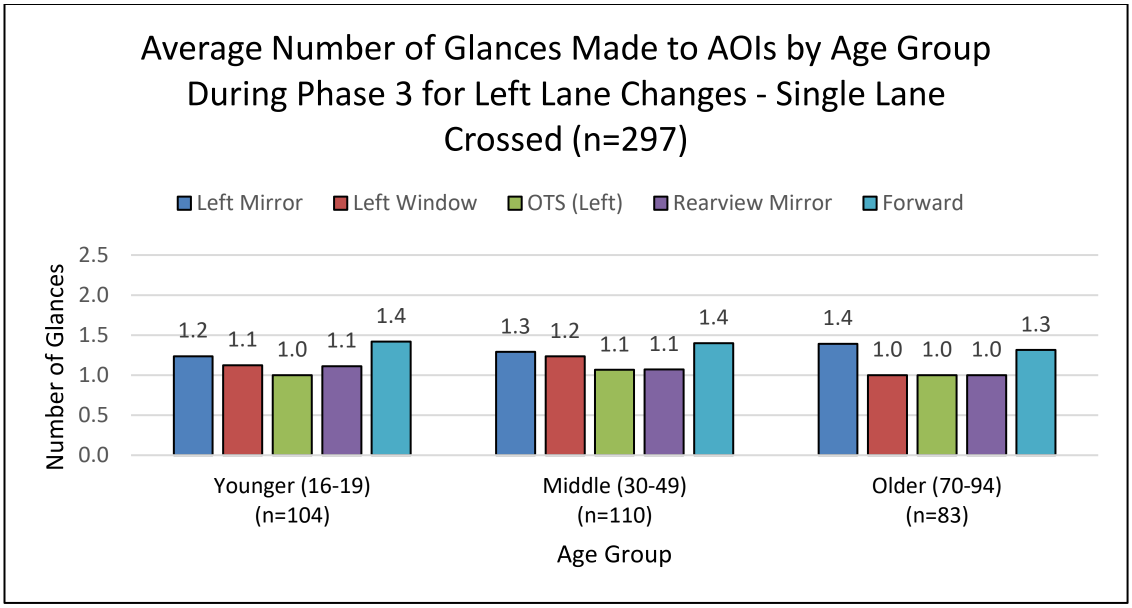


Figure 97. Chart. Average glance count made during Phase 3 of uninterrupted left lane changes.

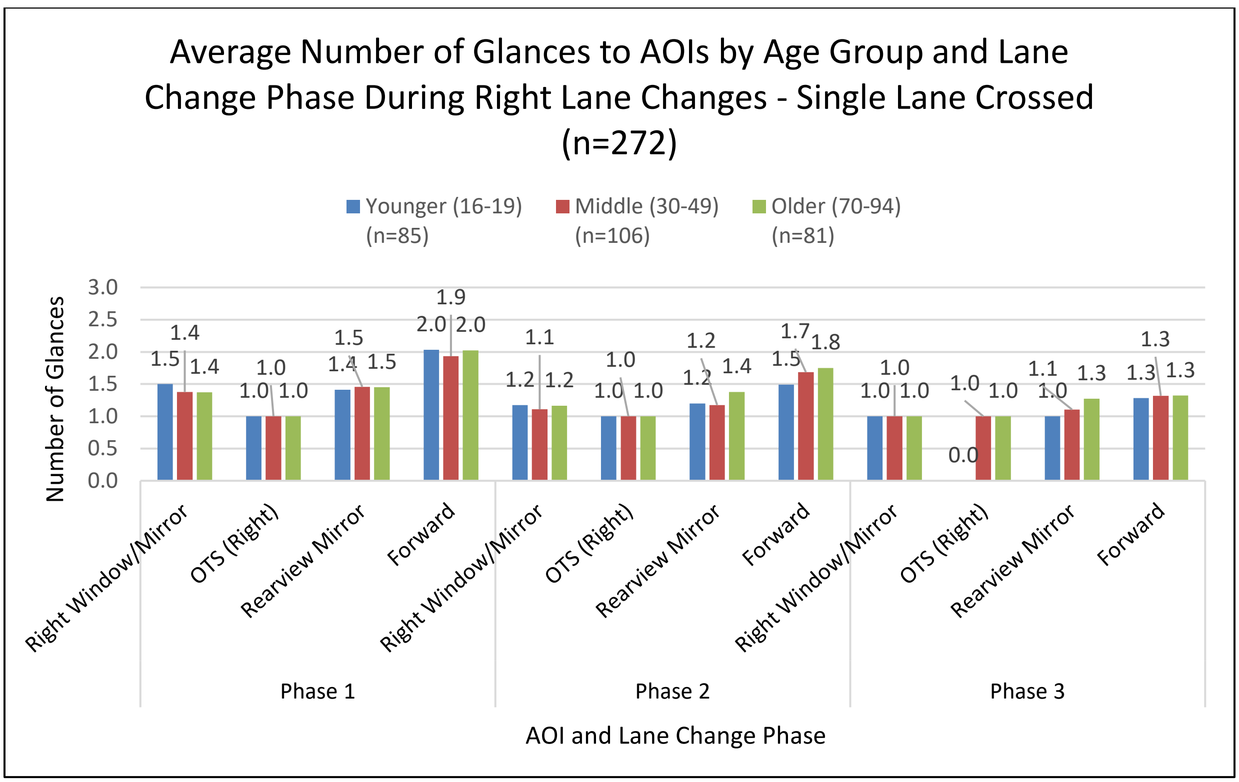


Figure 98. Chart. Average glance count by age group and lane change phase for uninterrupted right lane changes.

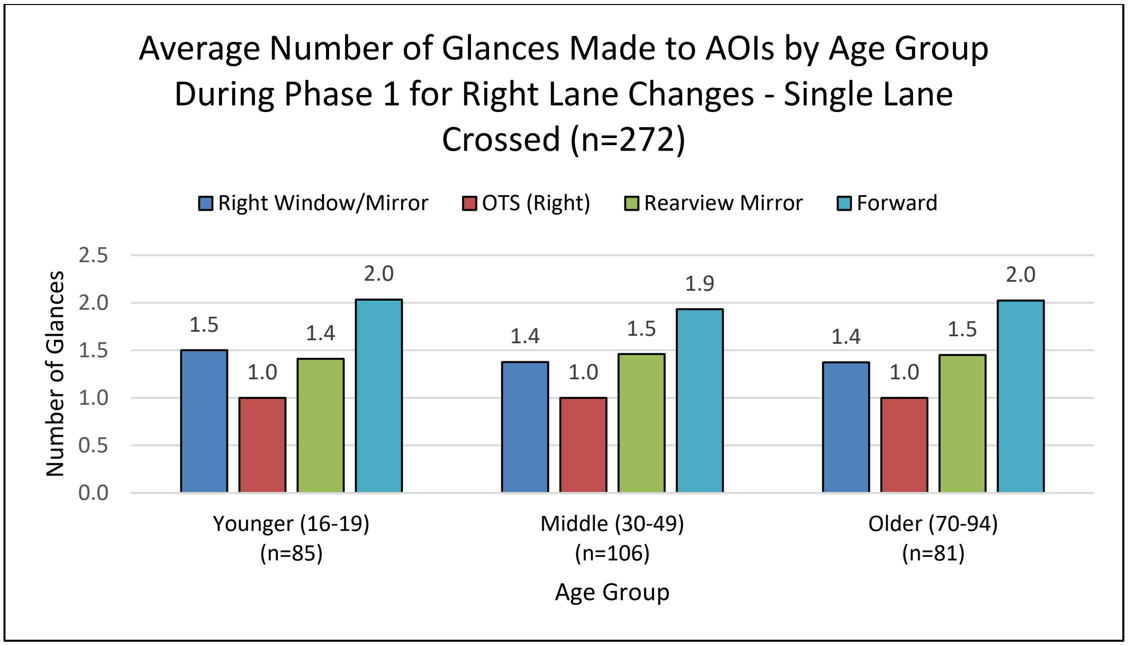


Figure 99. Chart. Average glance count made during Phase 1 of uninterrupted right lane changes.

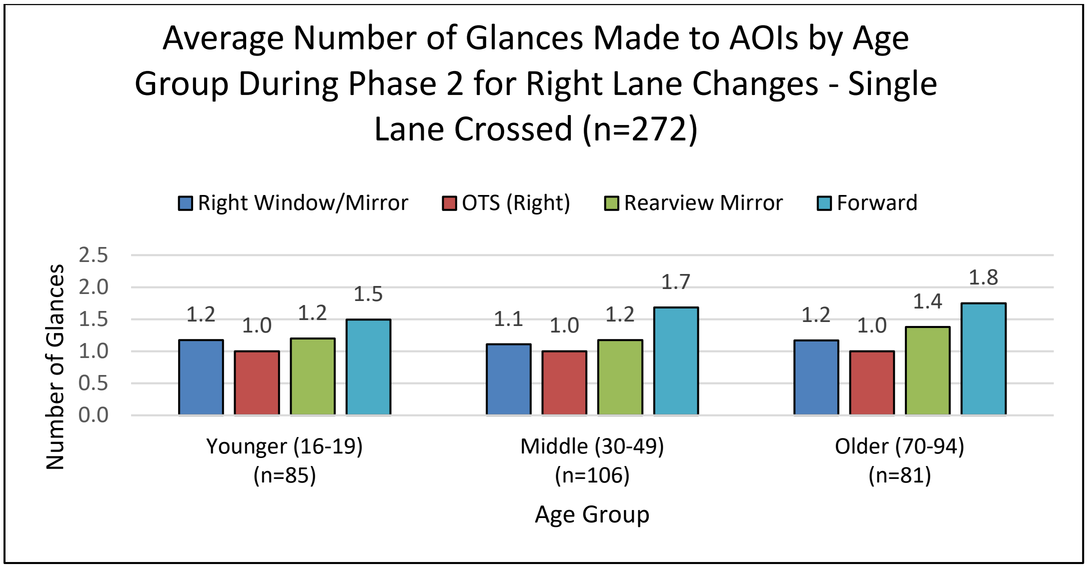


Figure 100. Chart. Average glance count made during Phase 2 of uninterrupted right lane changes.

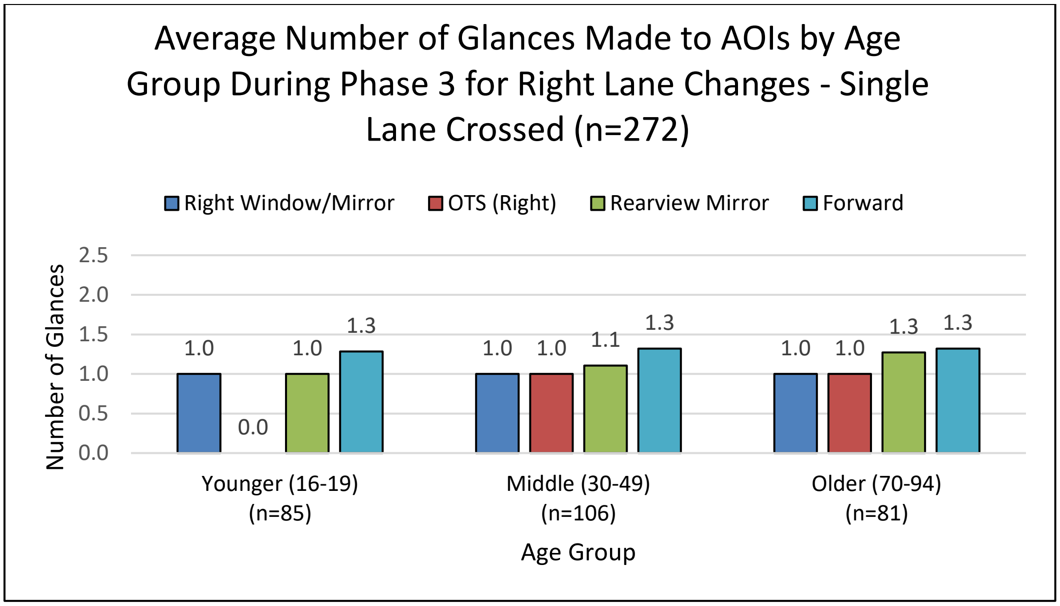


Figure 101. Chart. Average glance count made during Phase 3 of uninterrupted right lane changes.

Probability

Glance Probability

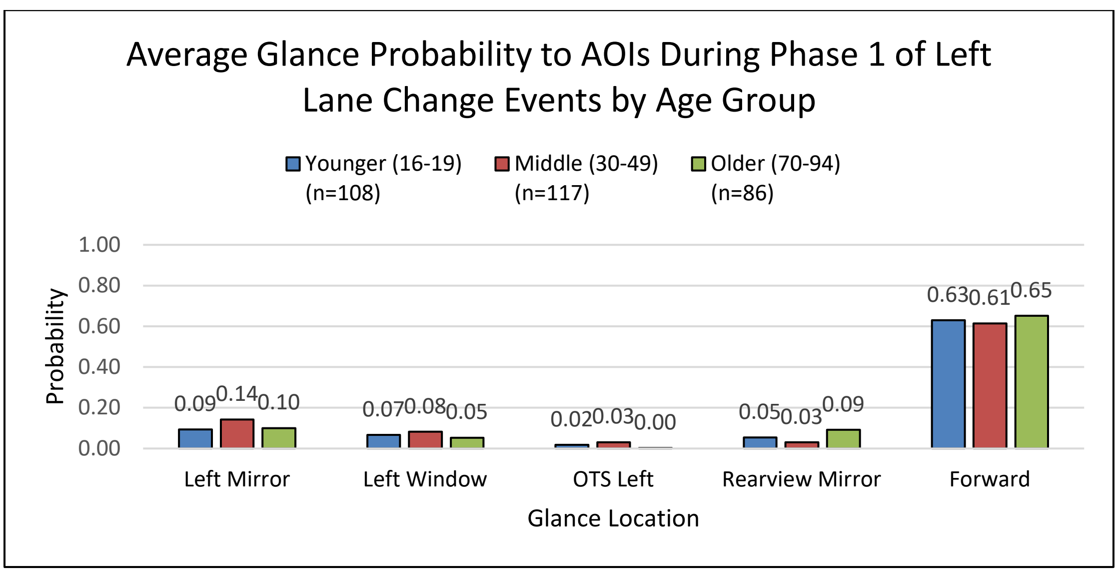


Figure 102. Chart. Average glance probability during Phase 1 of uninterrupted left lane changes.

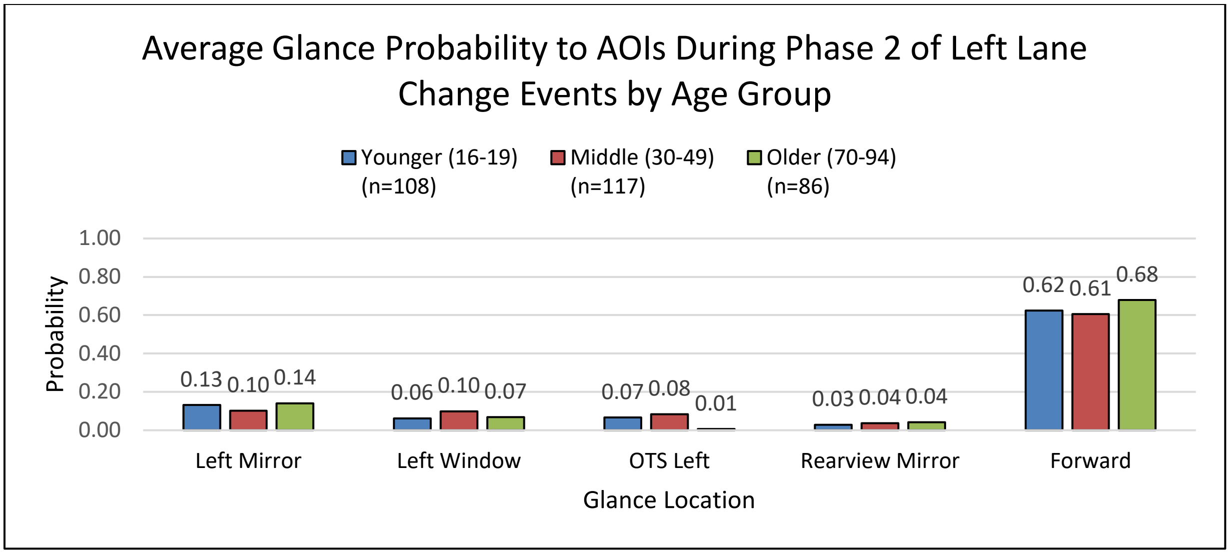


Figure 103. Chart. Average glance probability during Phase 2 of uninterrupted left lane changes.

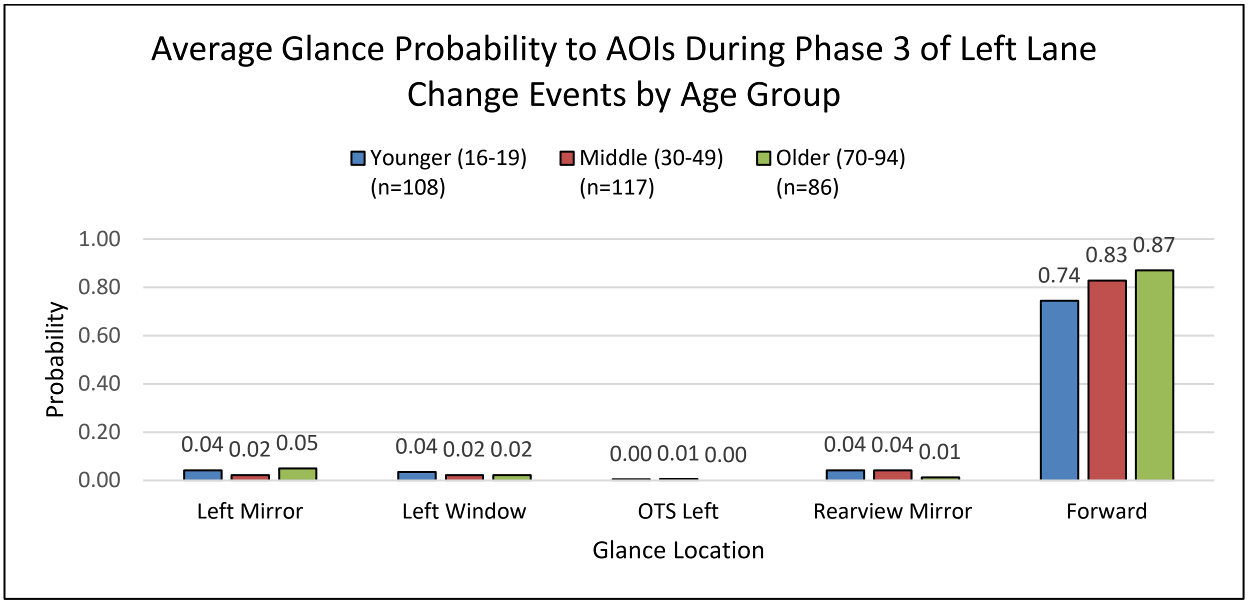


Figure 104. Chart. Average glance probability during Phase 3 of uninterrupted left lane changes.

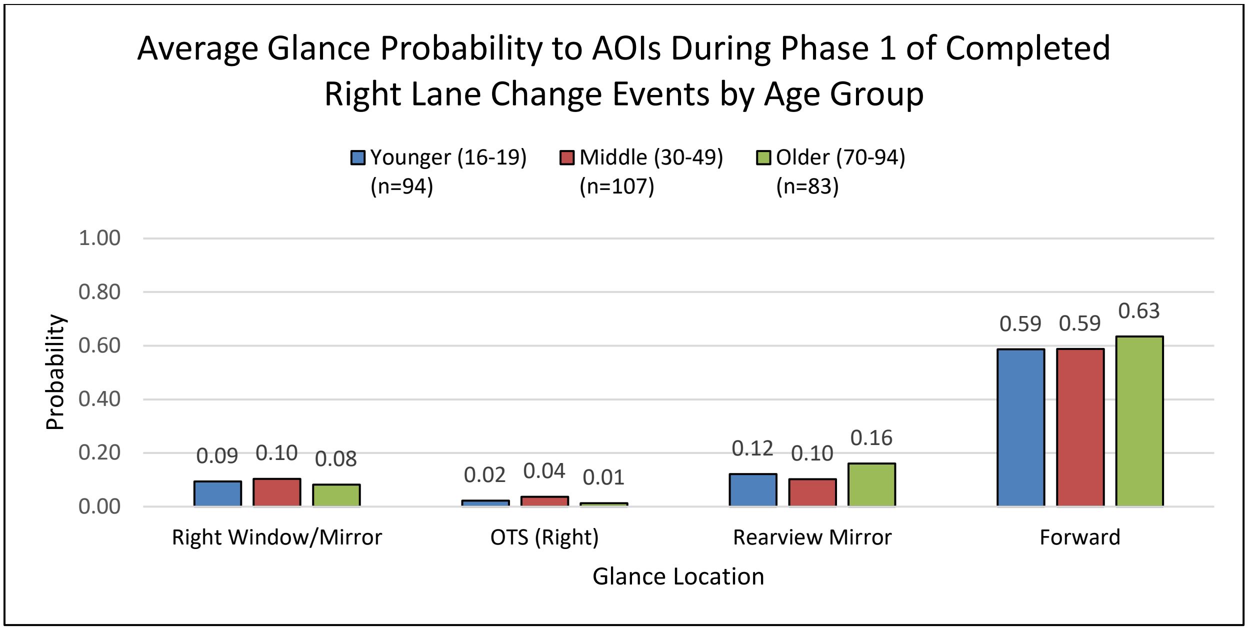


Figure 105. Chart. Average glance probability during Phase 1 of uninterrupted right lane changes.

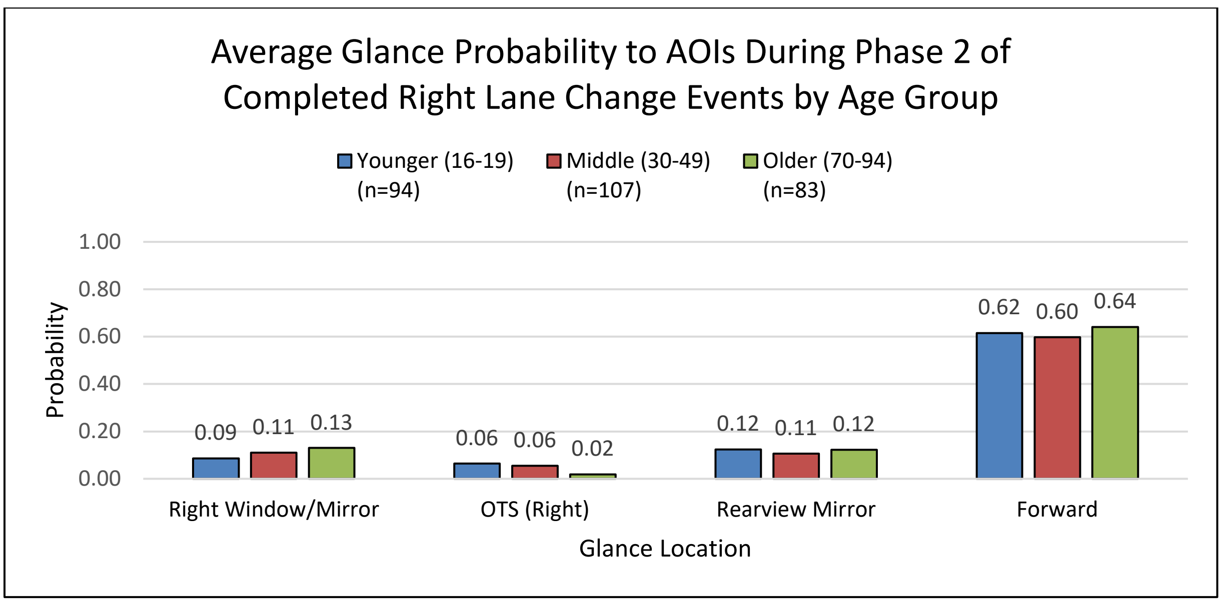


Figure 106. Chart. Average glance probability during Phase 2 of uninterrupted right lane changes.

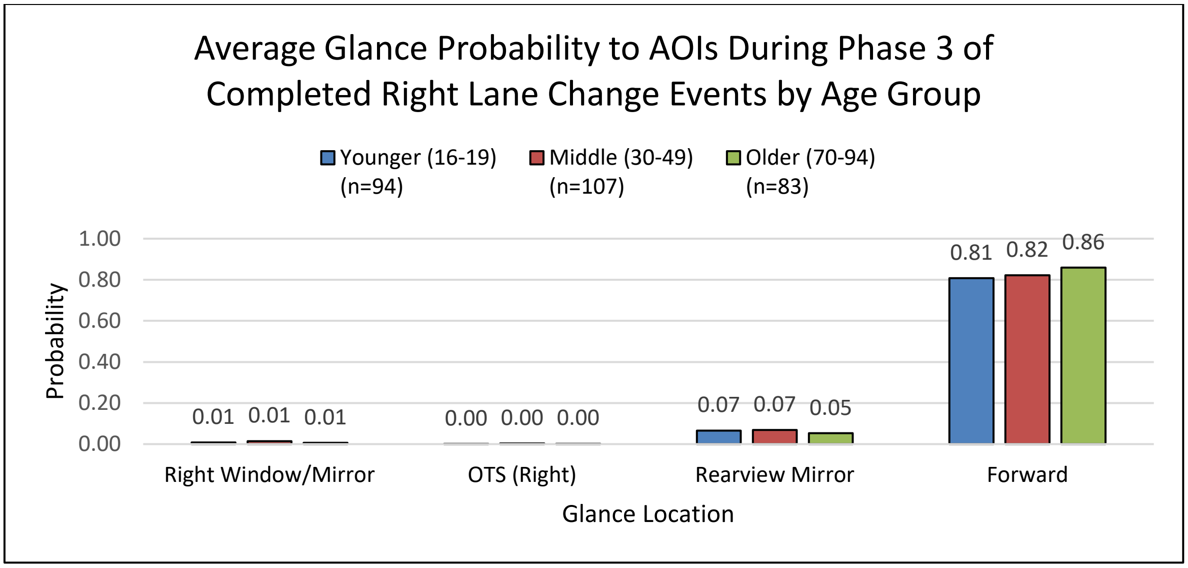


Figure 107. Chart. Average glance probability during Phase 3 of uninterrupted right lane changes.

Entropy

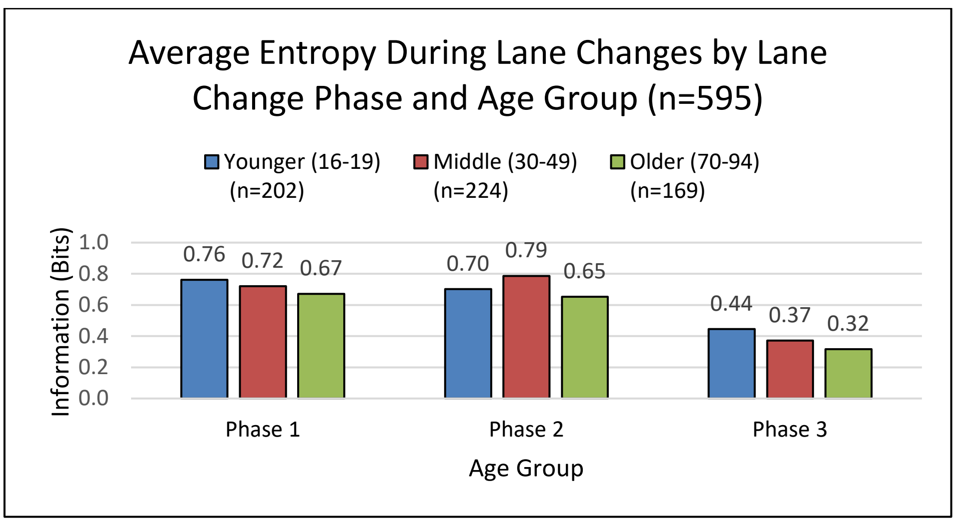


Figure 108. Chart. Average entropy during uninterrupted lane changes.

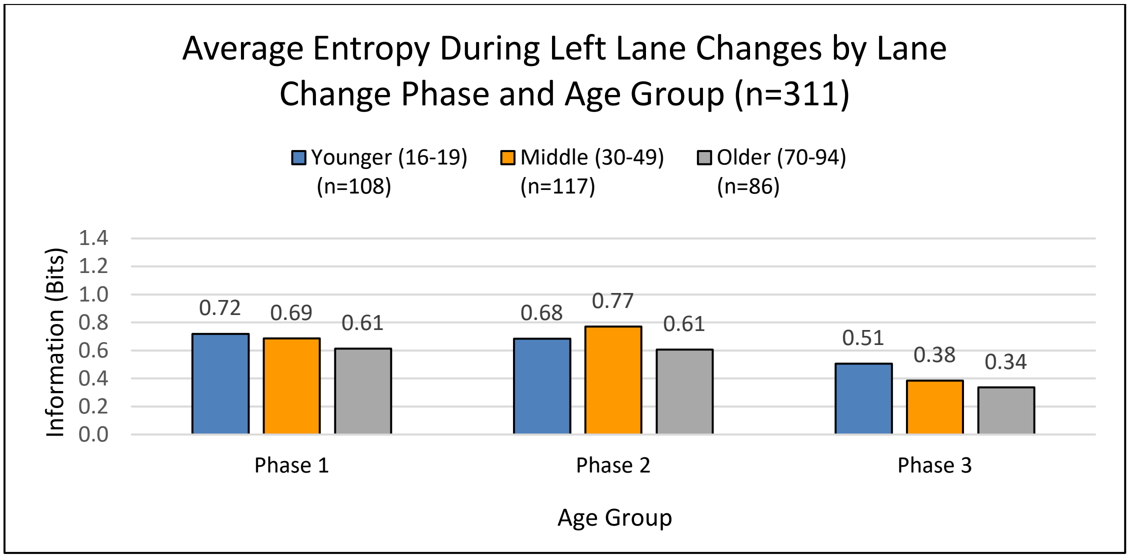


Figure 109. Chart. Average entropy during uninterrupted left lane changes.

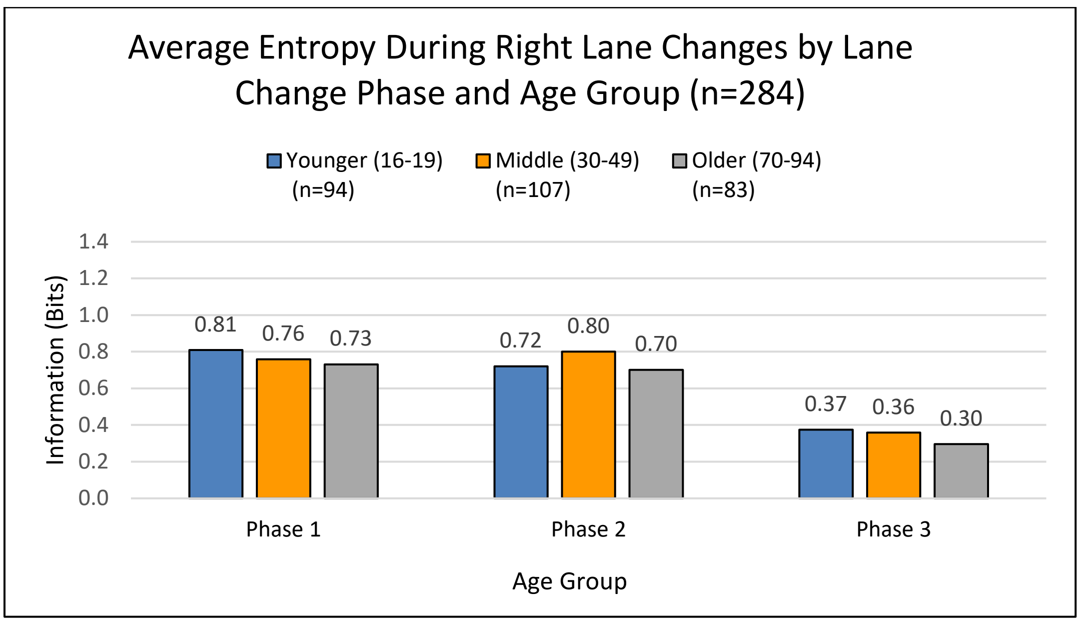


Figure 110. Chart. Average entropy during uninterrupted right lane changes.

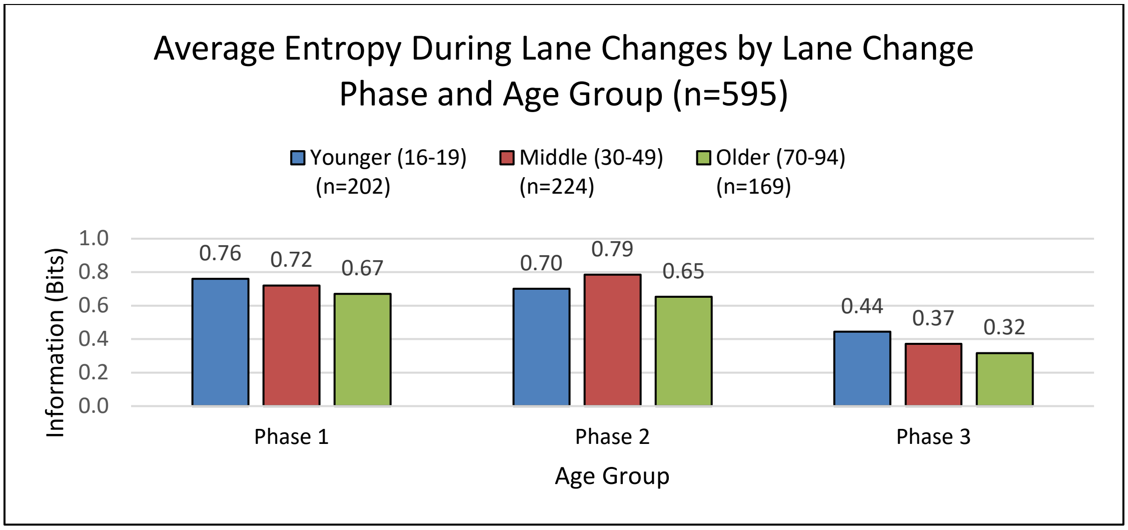


Figure 111. Chart. Average entropy during uninterrupted lane changes – driving-related glances only.

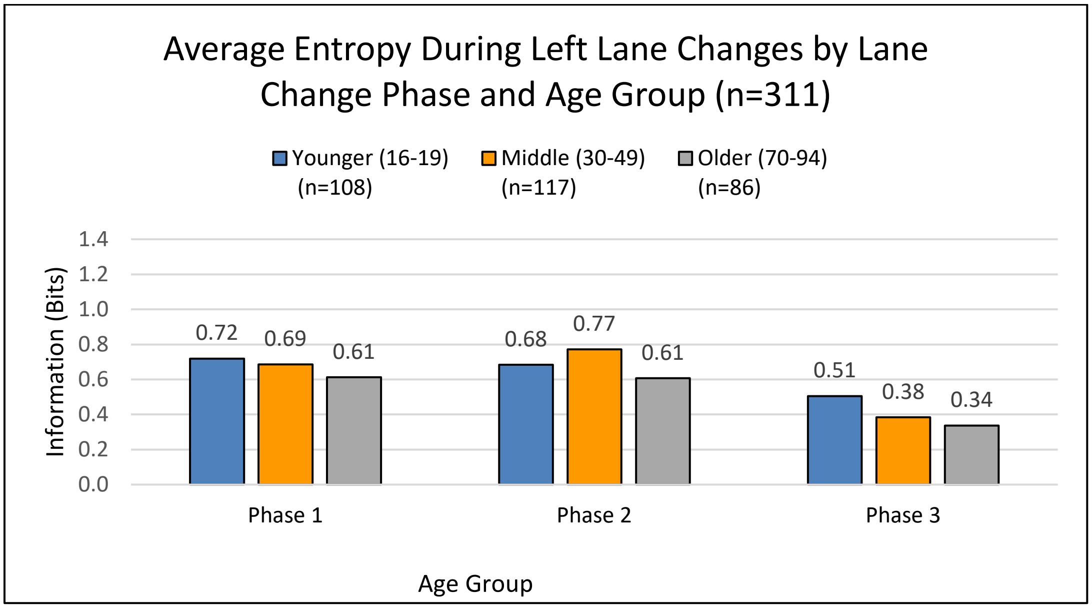


Figure 112. Chart. Average entropy during uninterrupted left lane changes – driving-related glances only.

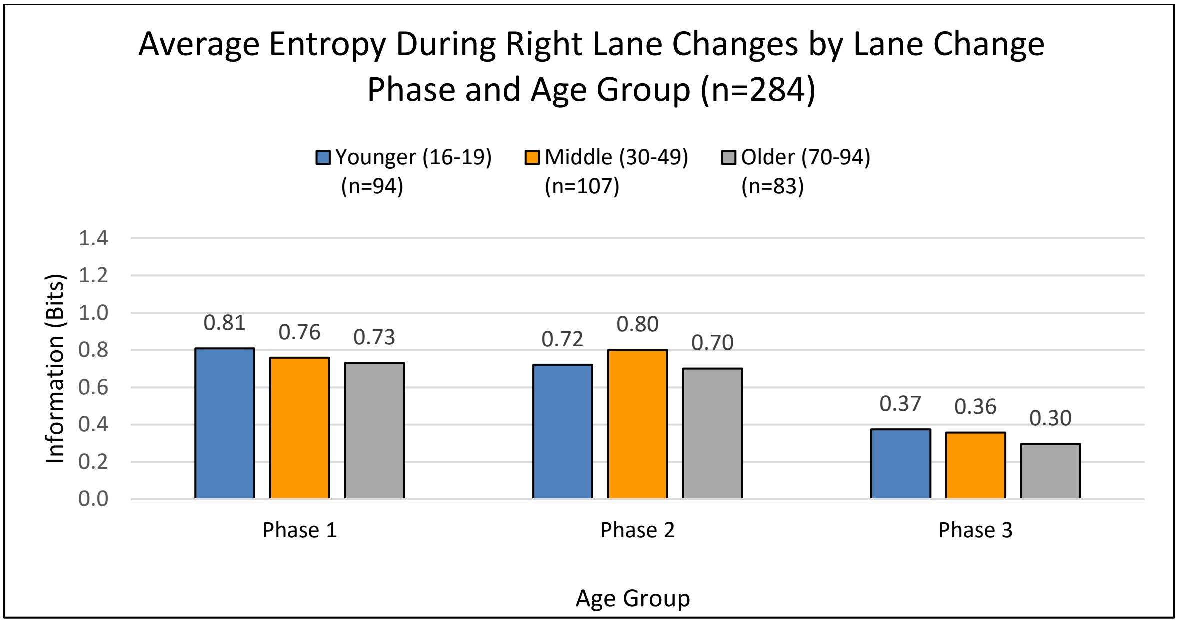


Figure 113. Chart. Average entropy during uninterrupted right lane changes – driving-related glances only.

Errors

Glance Errors

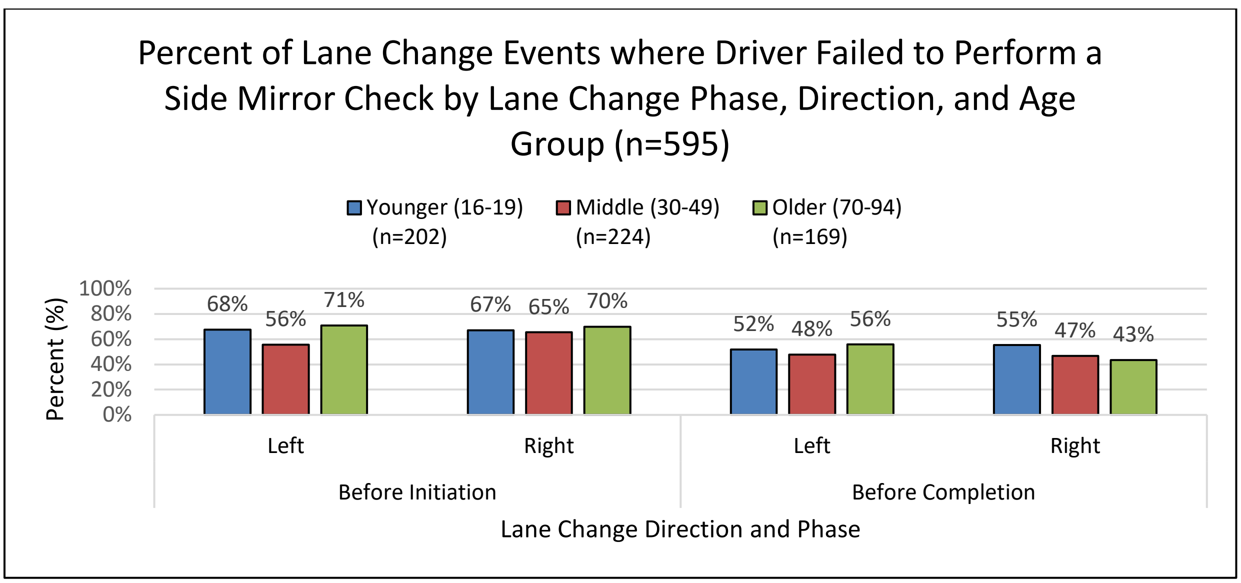


Figure 114. Chart. Failure to perform side mirror check for uninterrupted lane changes.

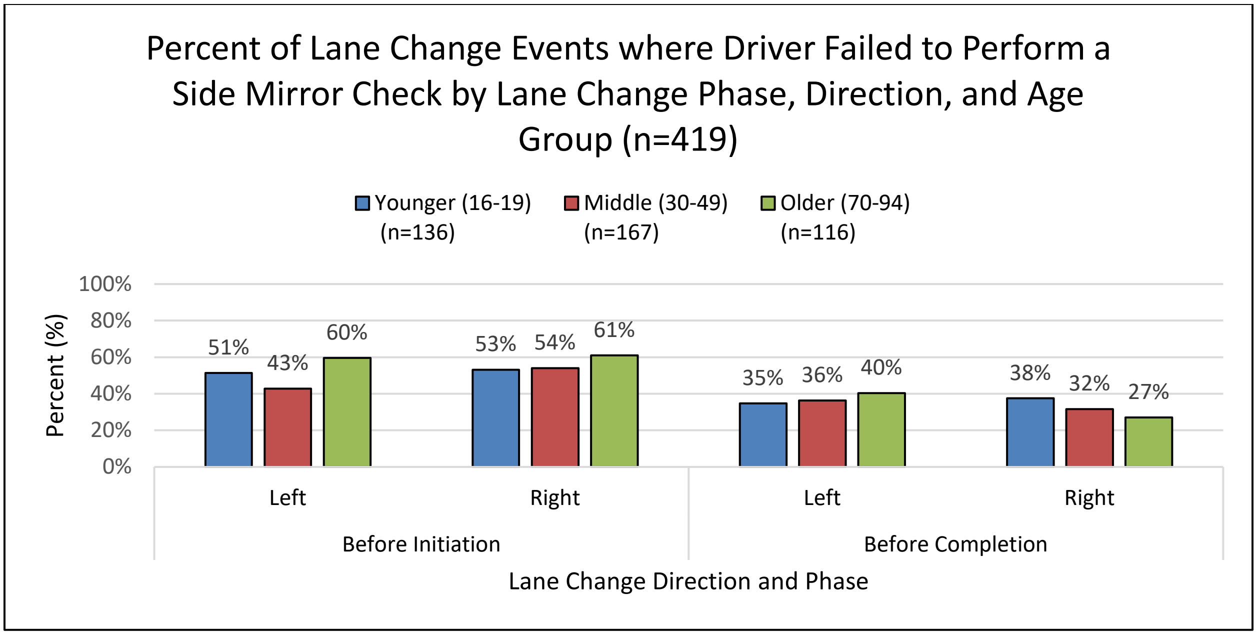


Figure 115. Chart. Failure to perform a side mirror check prior to initiation for uninterrupted lane change events – events removed.

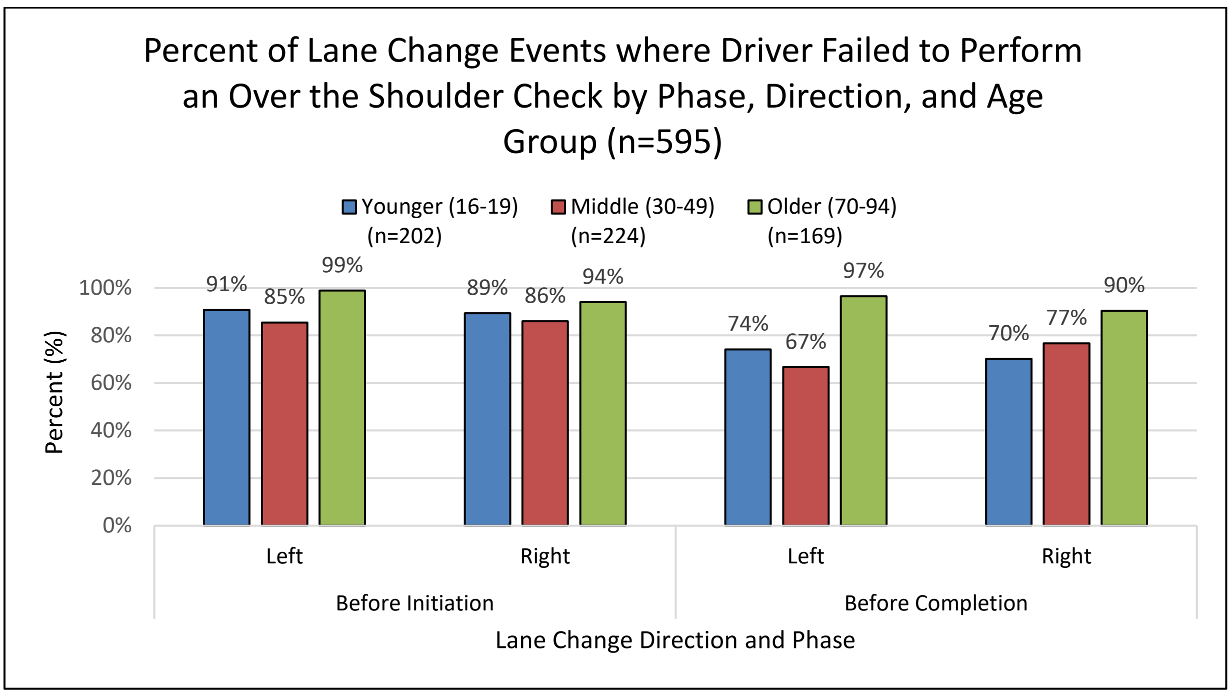


Figure 116. Chart. Failure to perform an OTS glance prior to initiation for uninterrupted lane change events.

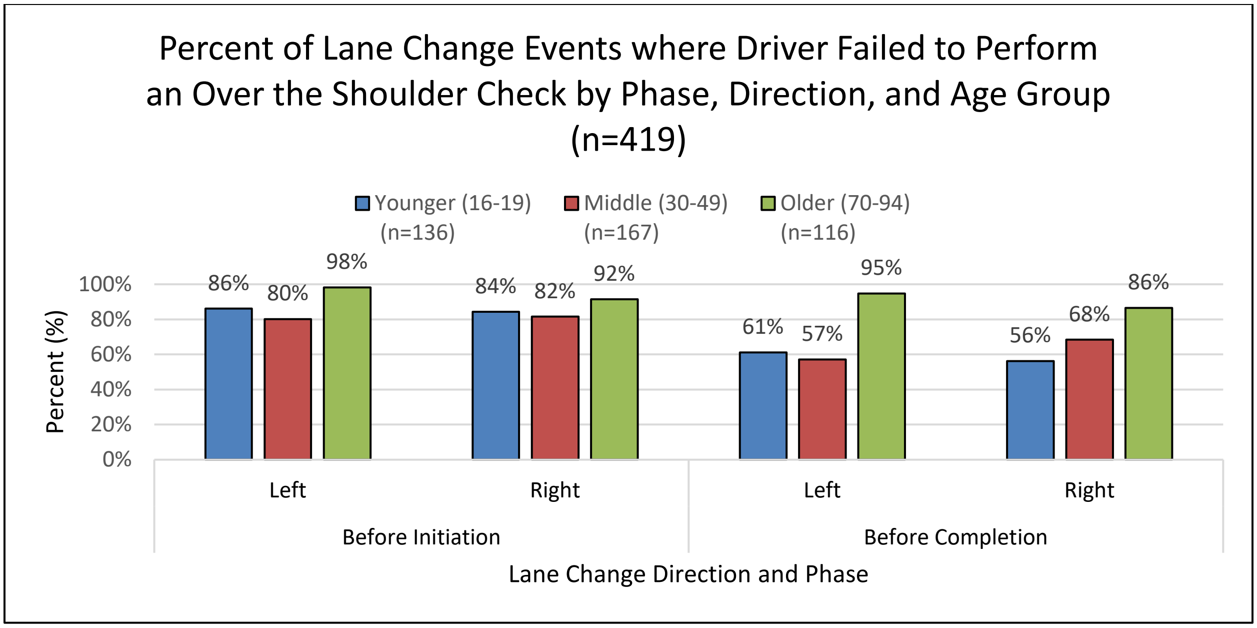


Figure 117. Chart. Failure to perform OTS glance prior to lane change initiation for uninterrupted lane change events – events removed.

Turn Signal Errors

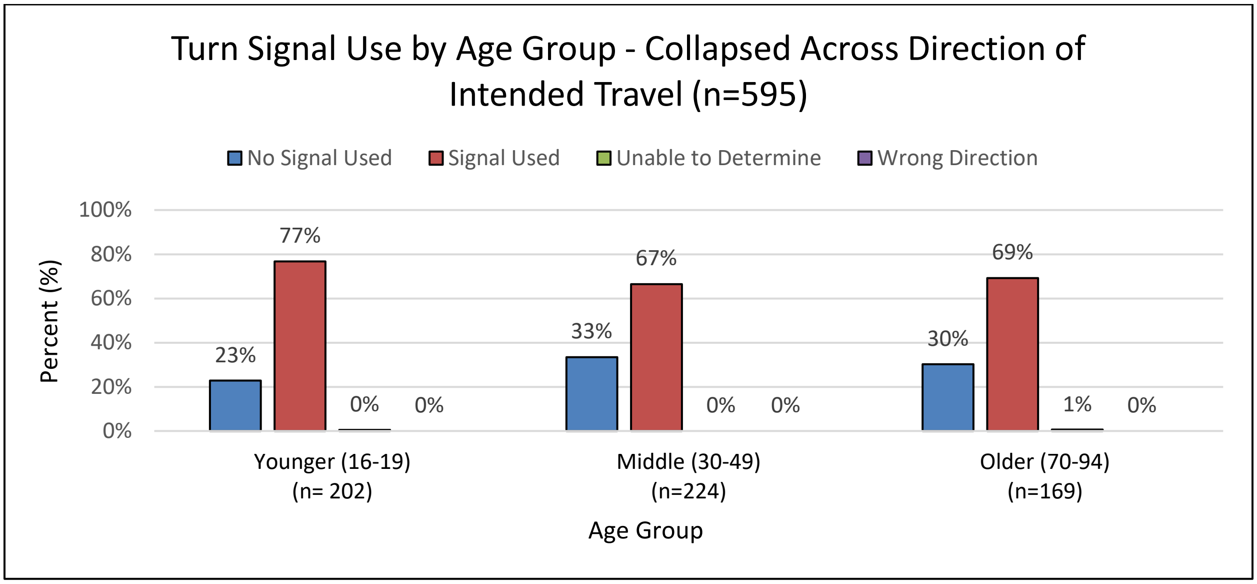


Figure 118. Chart. Turn signal use by age group for uninterrupted lane changes.

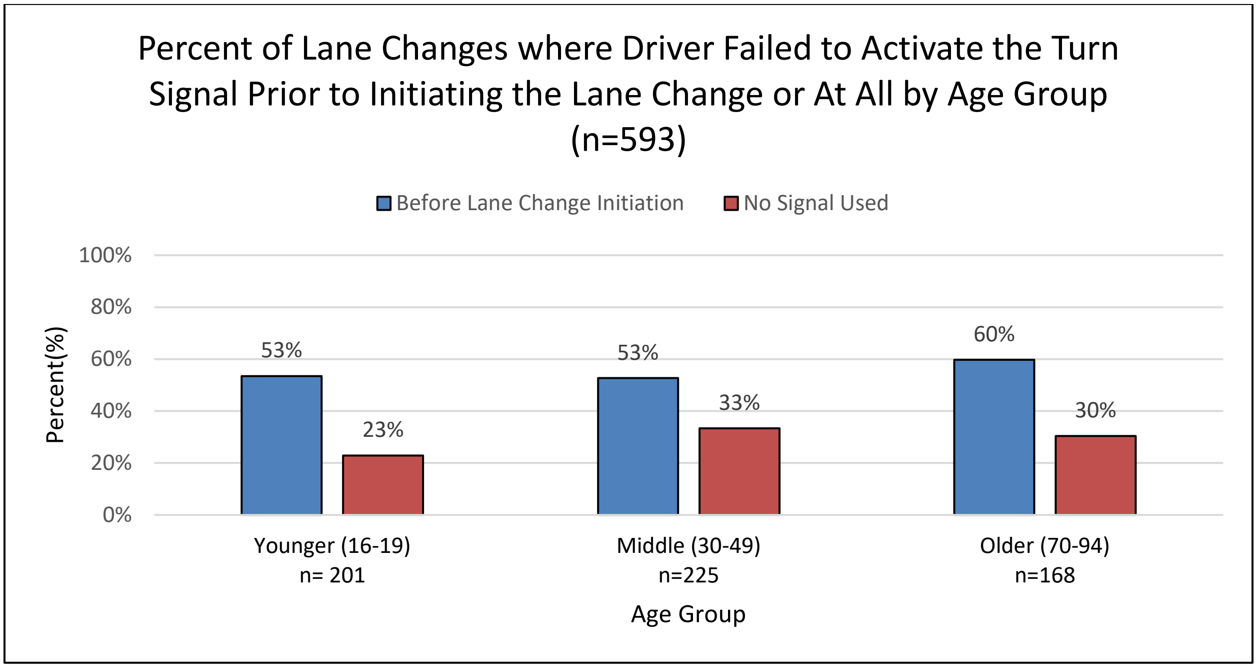


Figure 119. Chart. Turn signal activation prior to initiation of lane change for uninterrupted lane changes.

Cut-Off Errors

Table 6. Percentage of uninterrupted lane change events where driver cut off a trailing vehicle in the destination lane.

Age Group	Did Not Cut Off	Cut Off	Unable to Determine
Younger (16–19)	87%	2%	12%
Middle-Aged (30–49)	88%	1%	11%
Older (70–94)	90%	0%	10%

Environmental Factors

Level of Service

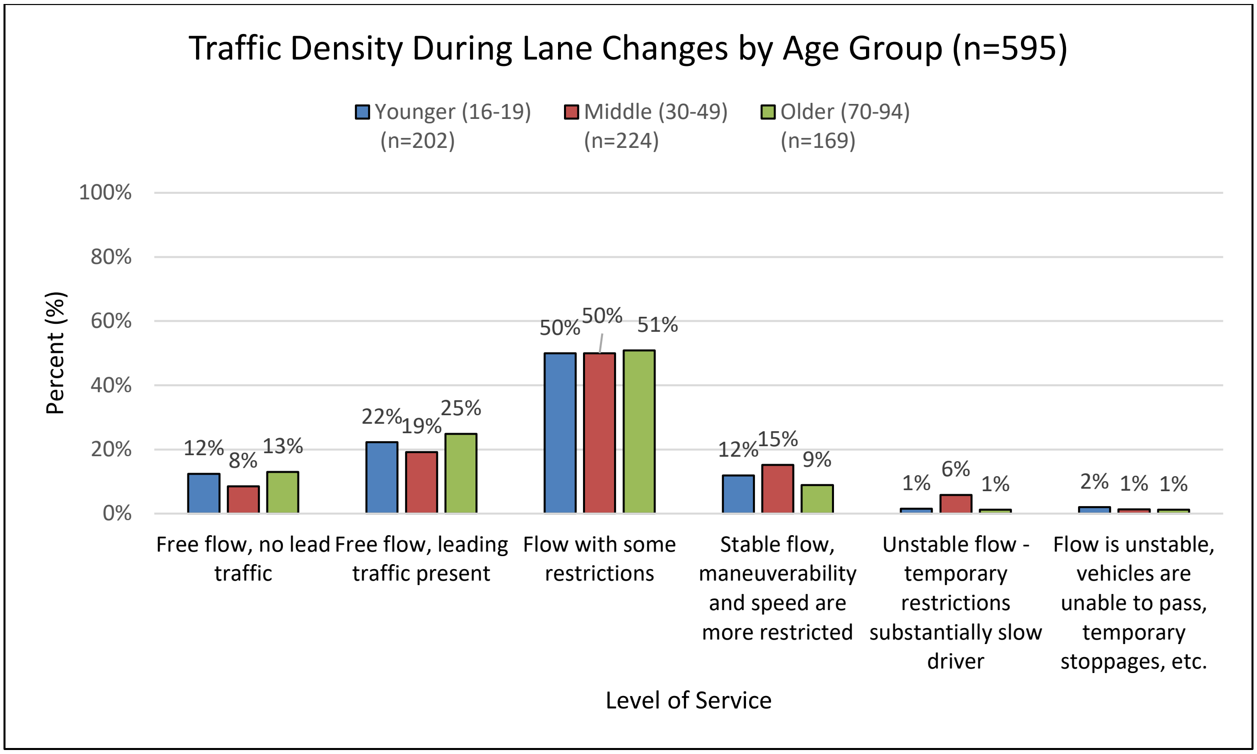


Figure 120. Chart. Traffic density by age group for uninterrupted lane changes.

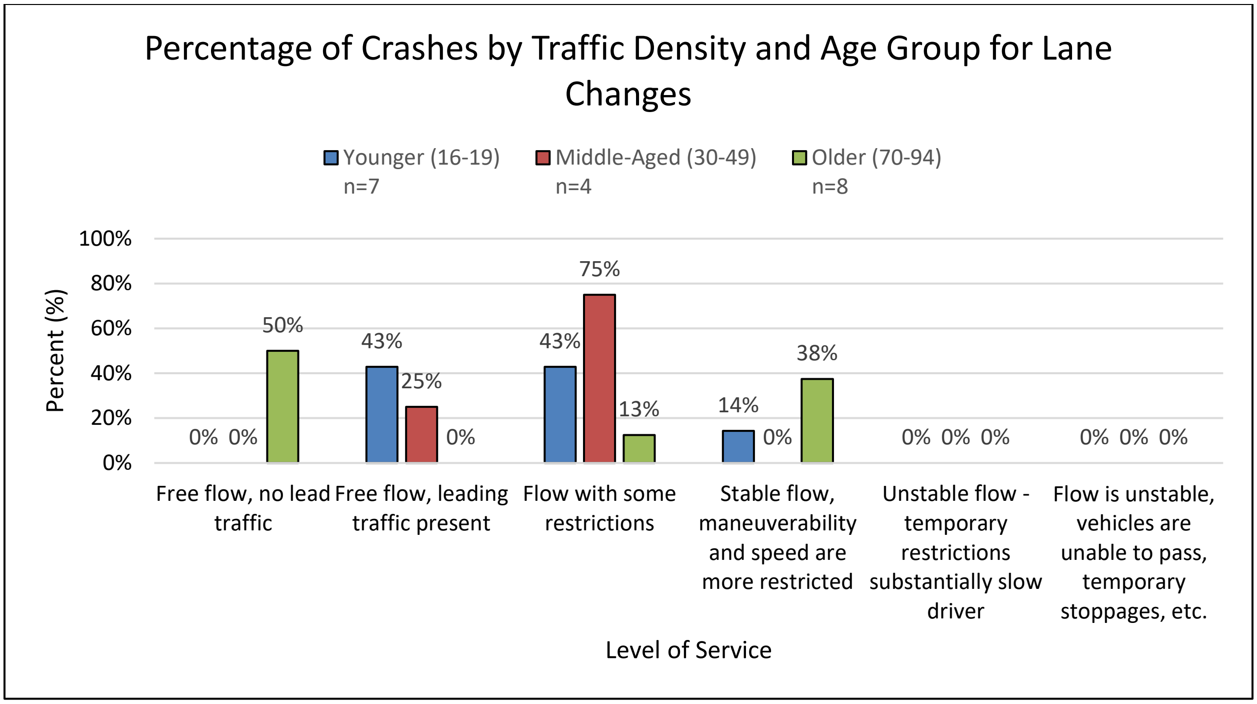


Figure 121. Chart. Percentage of crashes by traffic density for uninterrupted lane changes.

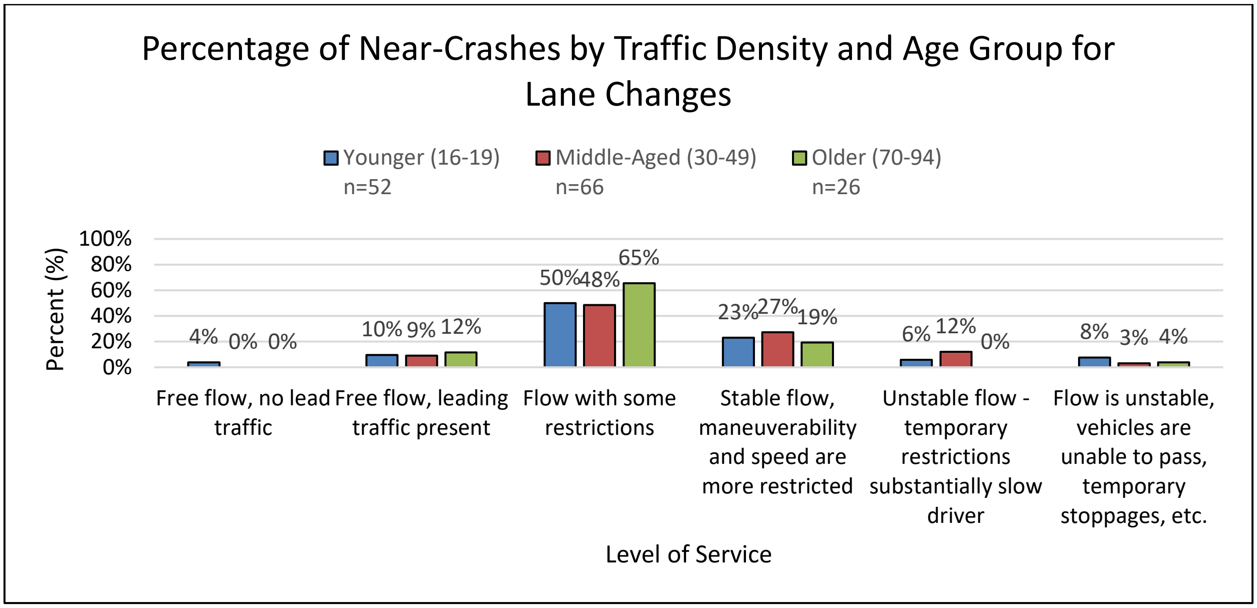


Figure 122. Chart. Percentage of near-crashes by traffic density for uninterrupted lane changes.

Passengers

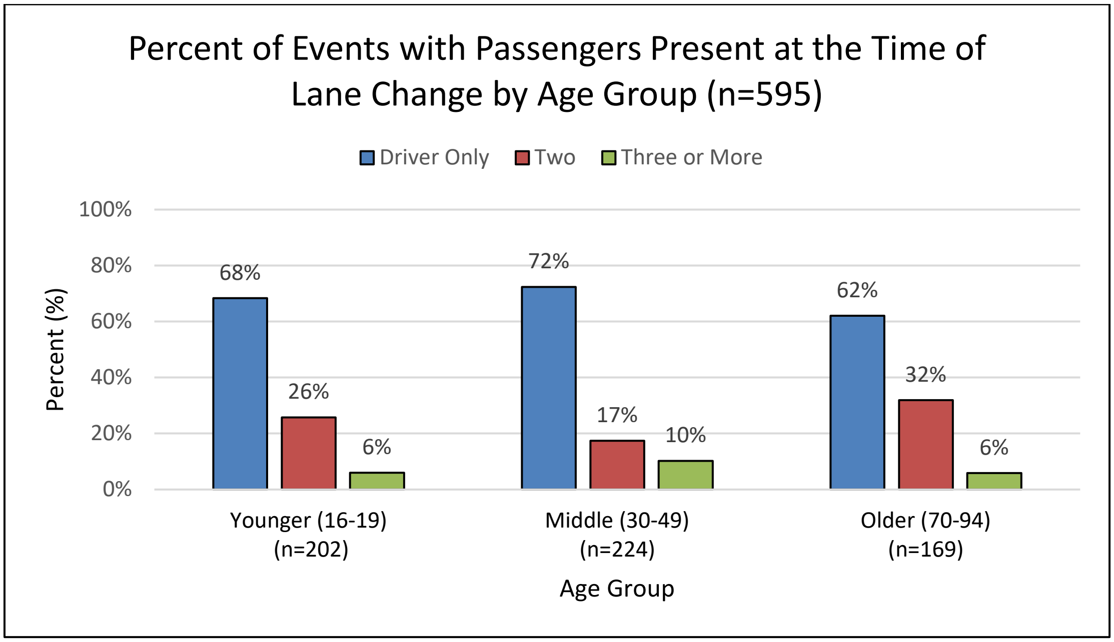


Figure 123. Chart. Passengers present by age group for uninterrupted lane changes.

Day of Week

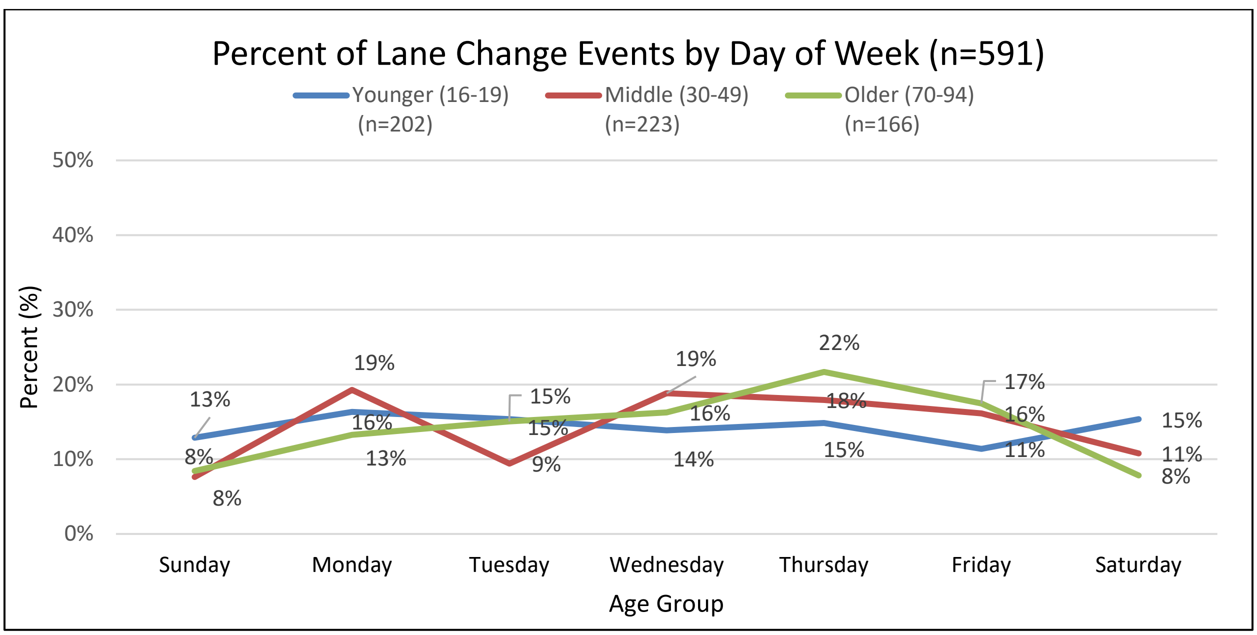


Figure 124. Chart. Percentage of lane changes by day of week for uninterrupted lane changes.

Time of Day

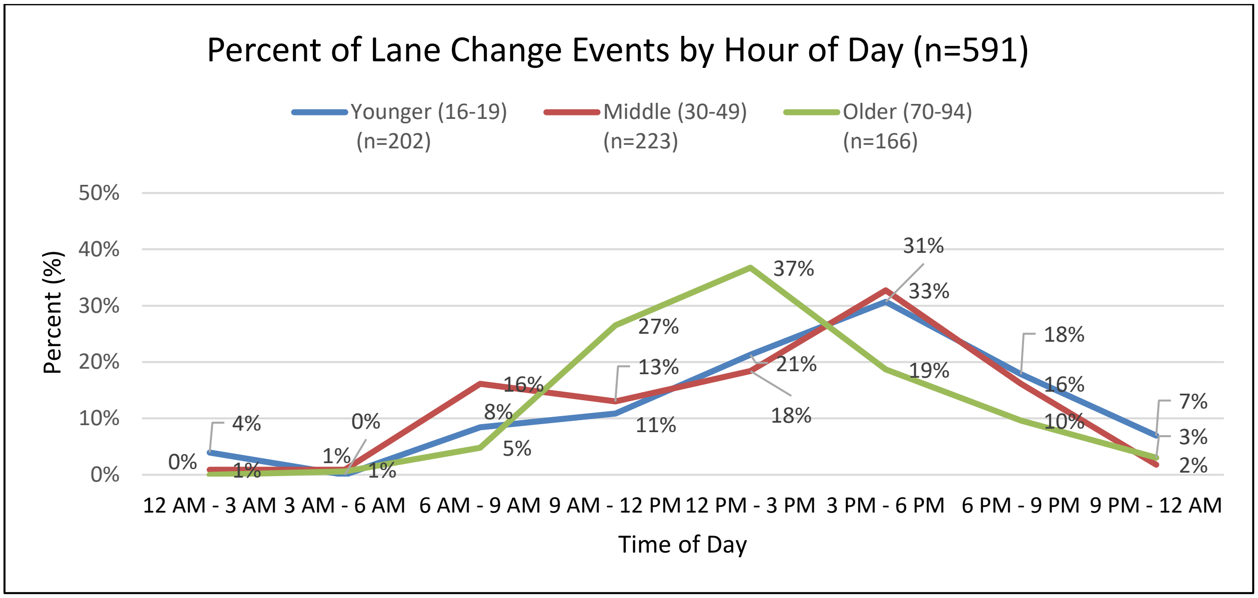


Figure 125. Chart. Percentage of lane changes by hour of day for uninterrupted lane changes.

Conflict Type

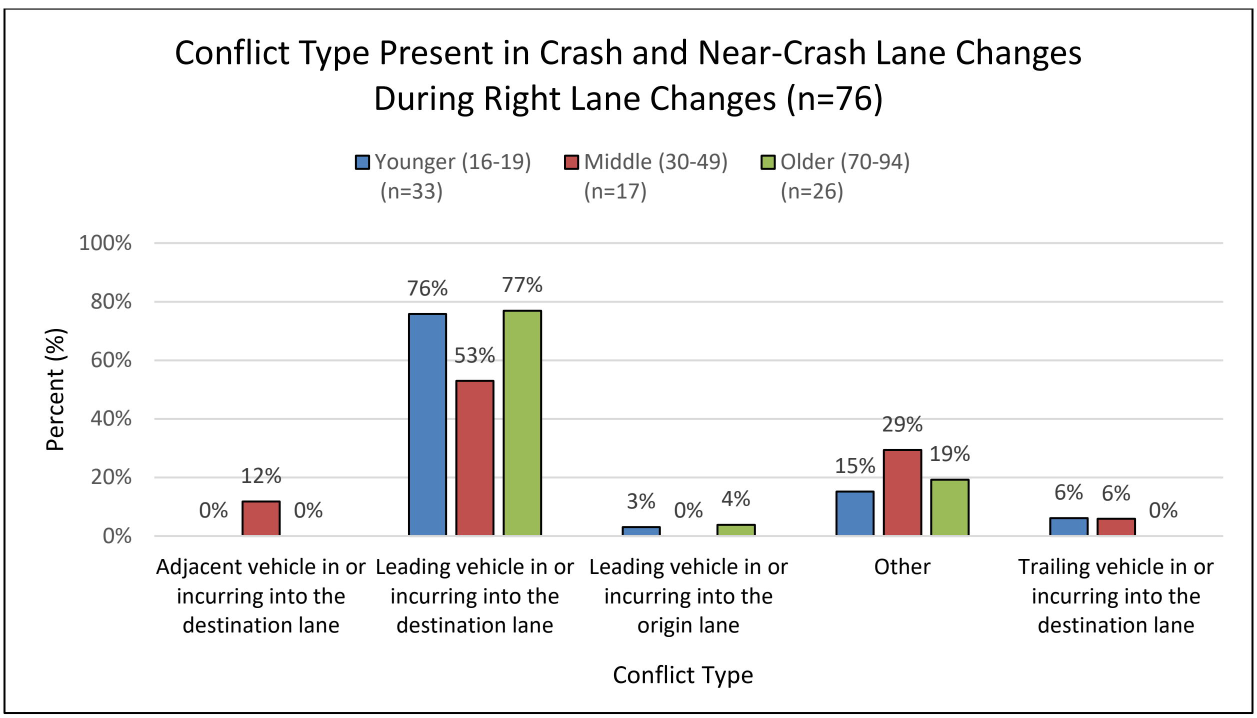


Figure 126. Chart. Conflict type by age group for uninterrupted right lane changes.

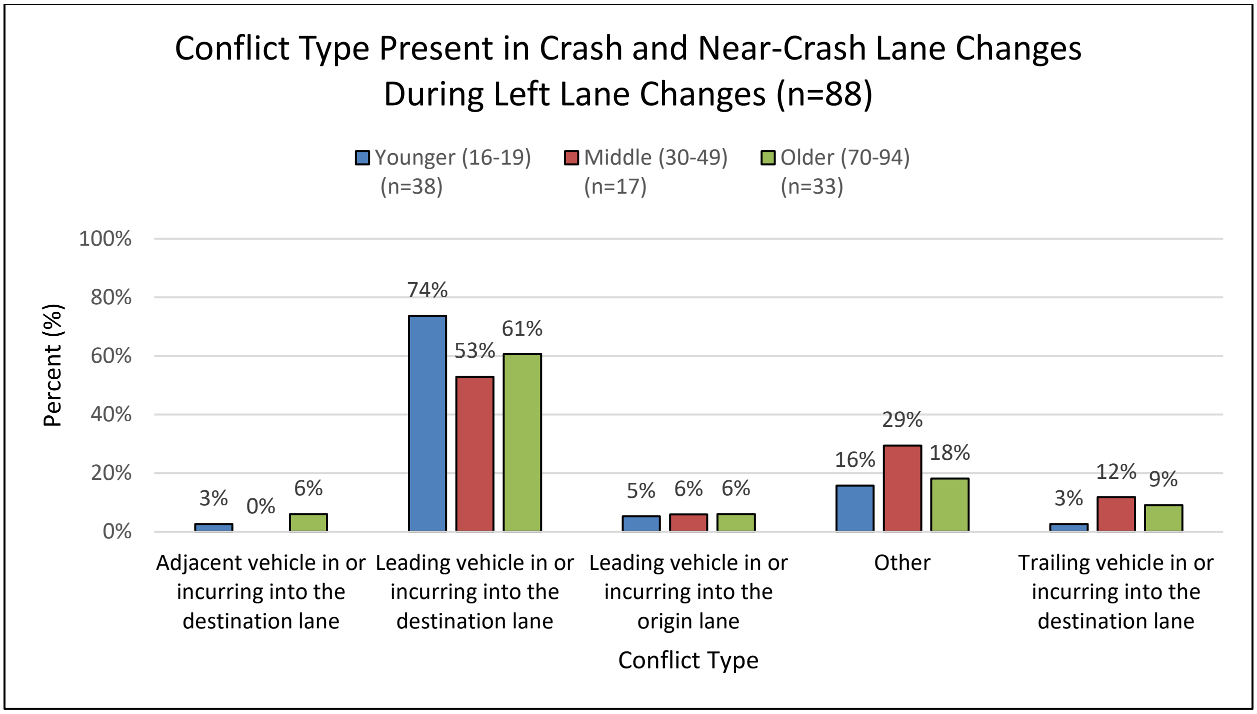


Figure 127. Chart. Conflict type by age group for uninterrupted left lane changes.

Behavioral

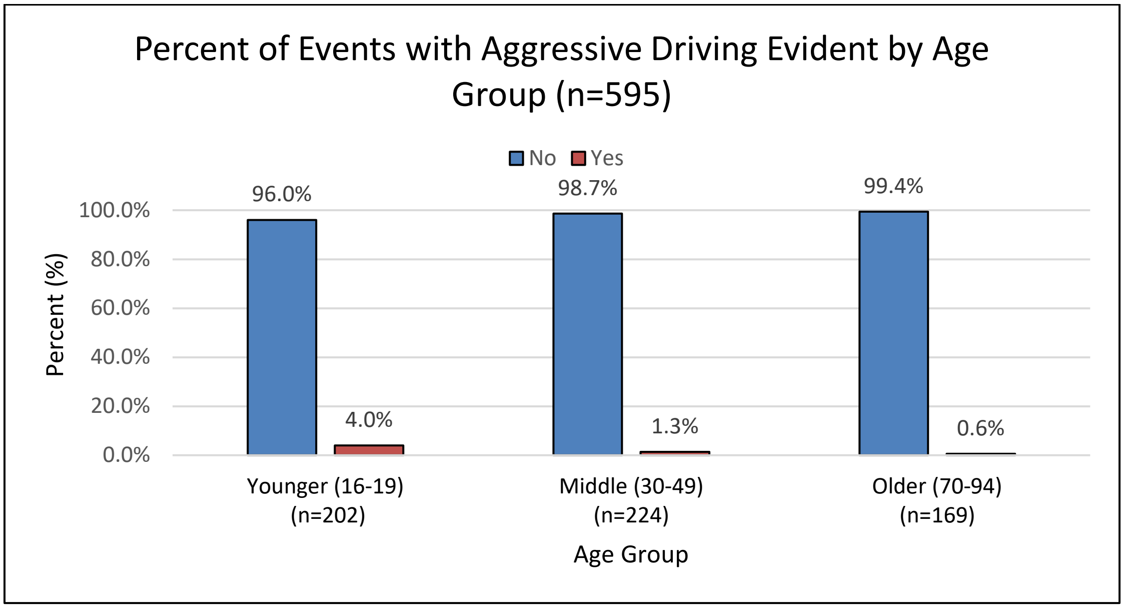


Figure 128. Chart. Aggressive driving presence during uninterrupted lane changes.

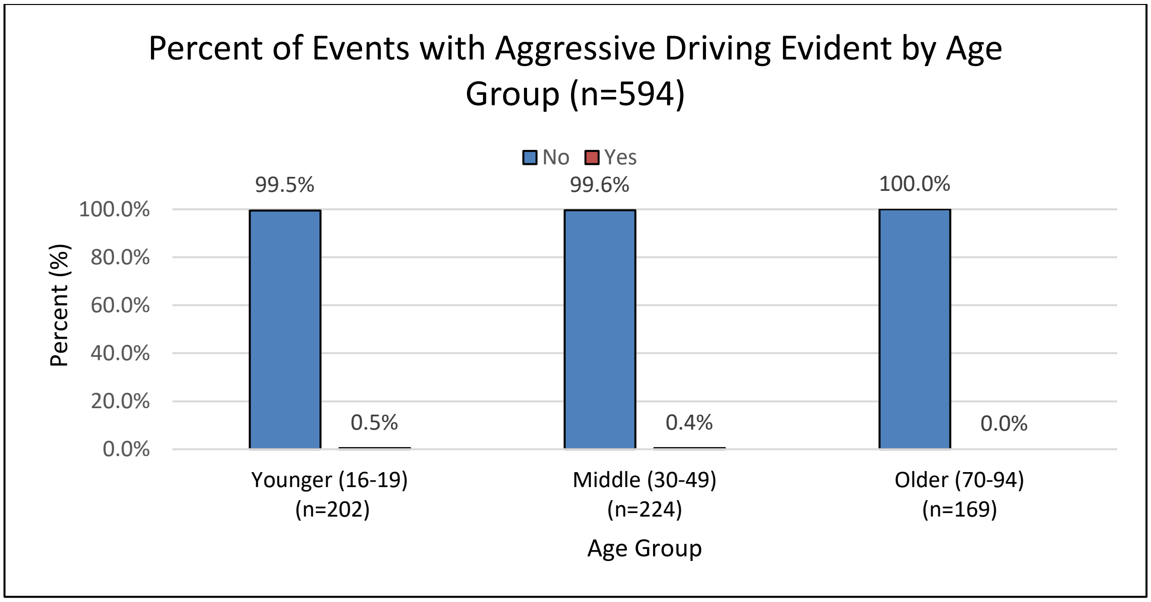


Figure 129. Chart. Sporty driving presence during uninterrupted lane changes.

Secondary Task Engagement

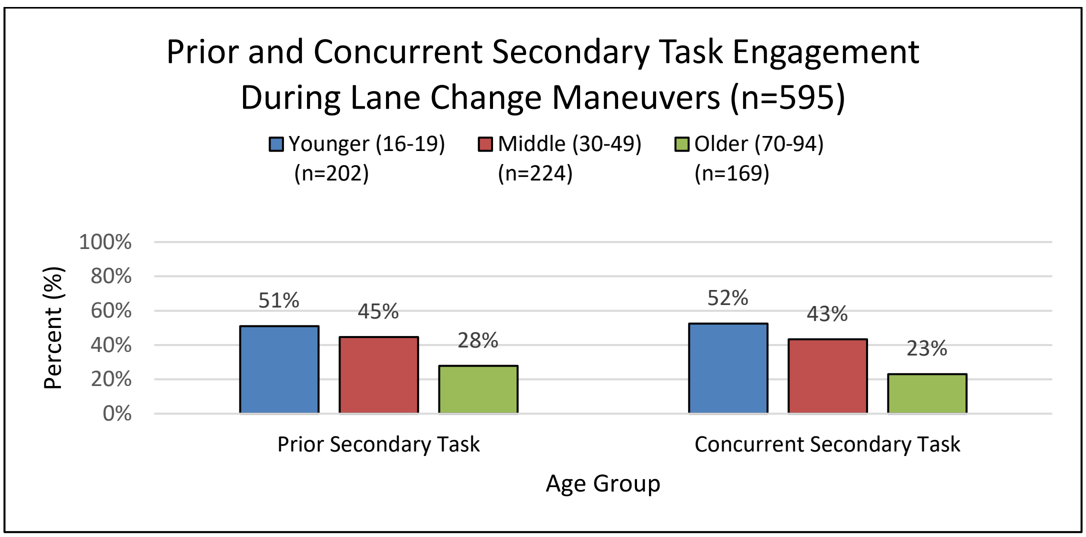


Figure 130. Chart. Secondary task engagement both prior to and during the uninterrupted lane change maneuver.

Direction

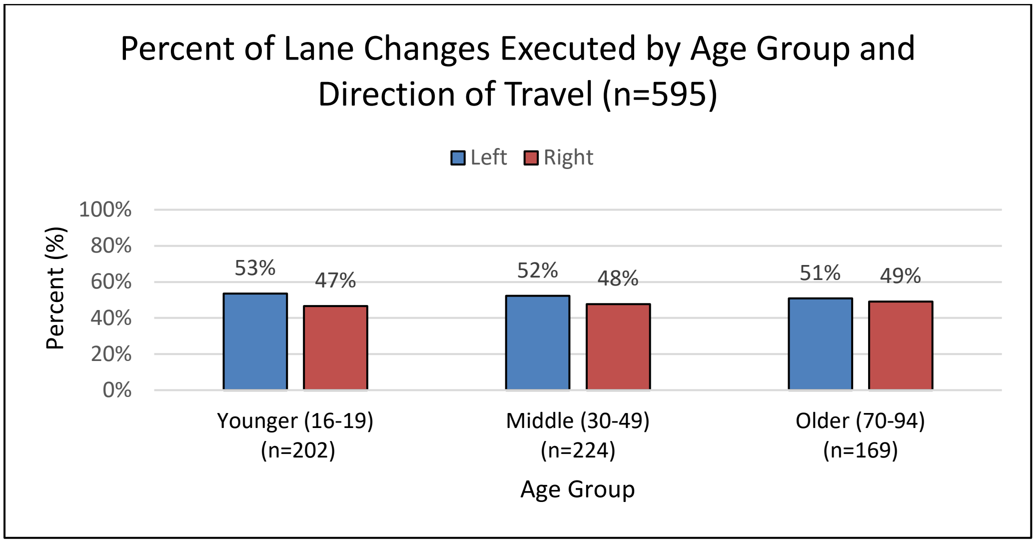


Figure 131. Chart. Percentage of uninterrupted lane changes directed by age group and direction.

FULL RESULTS FOR INTERRUPTED LANE CHANGES

Glance Characteristics

Percentage of Time

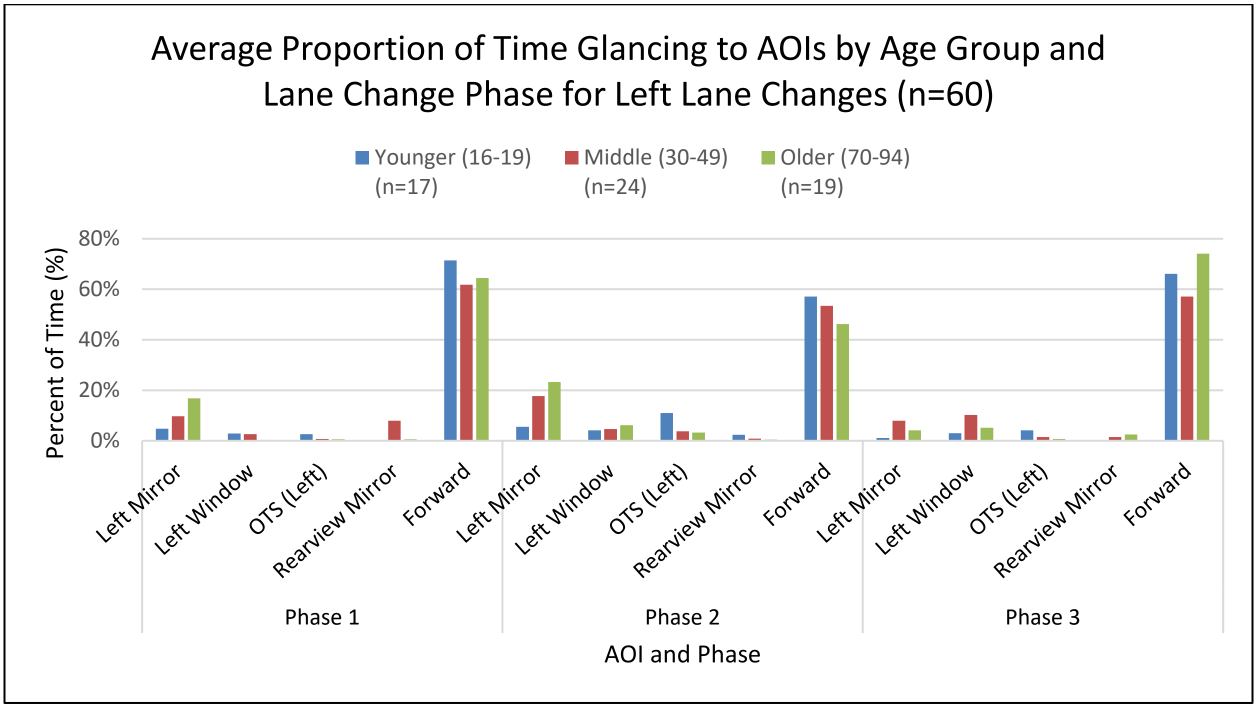


Figure 132. Chart. Percentage of time glancing to AOIs by age group and lane change phase for interrupted left lane changes.

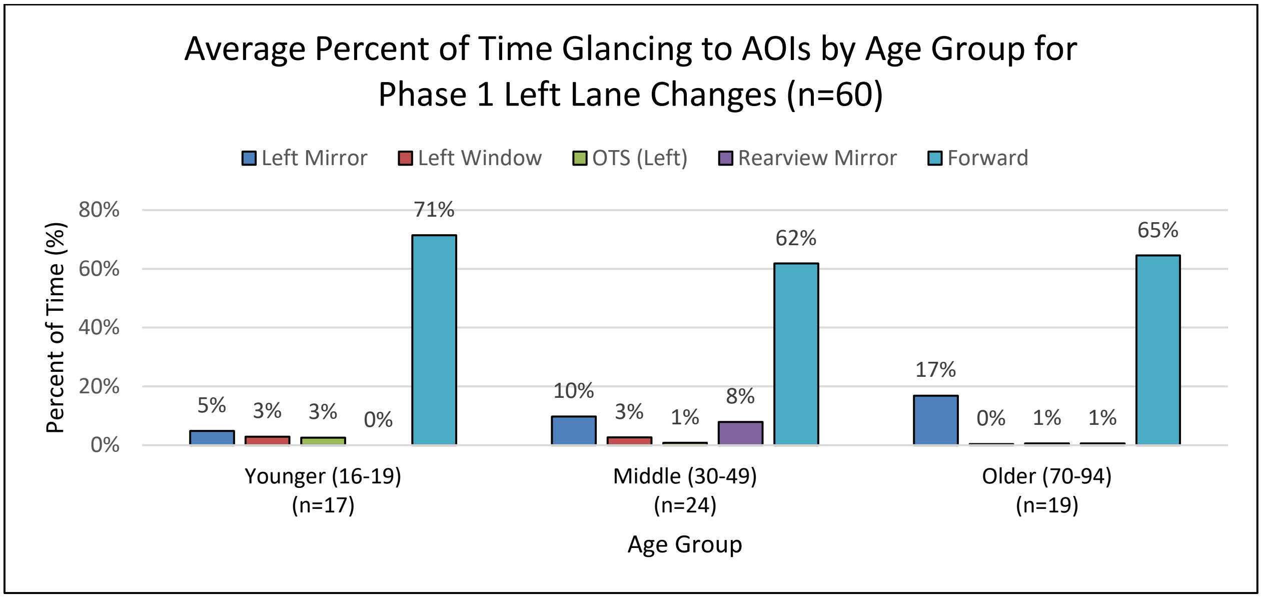


Figure 133. Chart. Percentage of time glancing to AOIs by age group for Phase 1 of interrupted left lane changes.

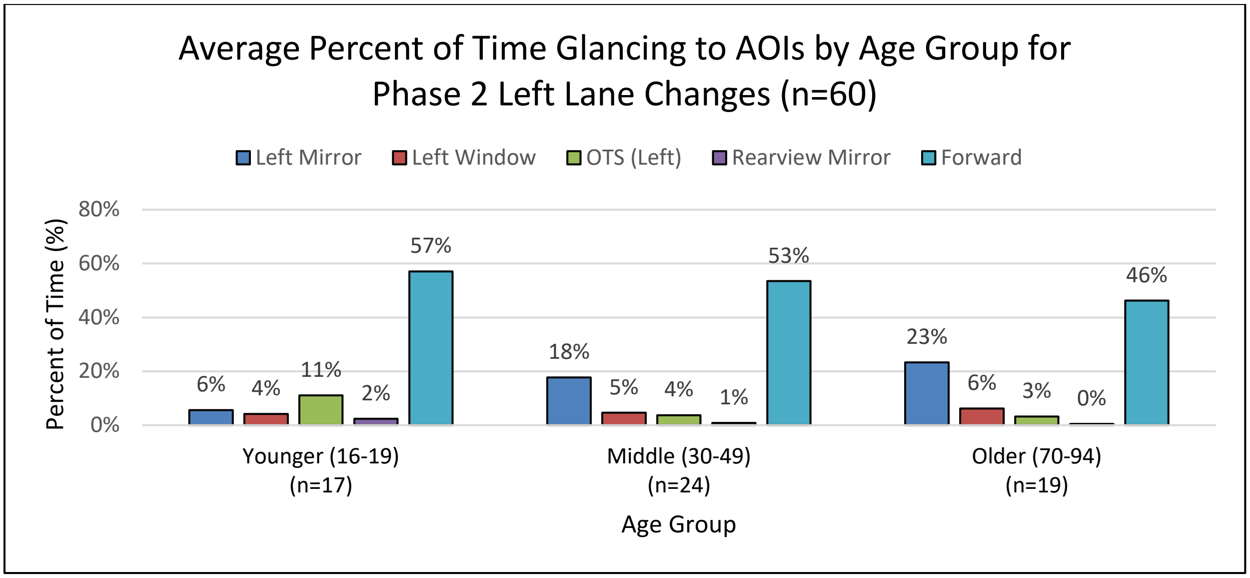


Figure 134. Chart. Percentage of time glancing to AOIs by age group for Phase 2 of interrupted left lane changes.

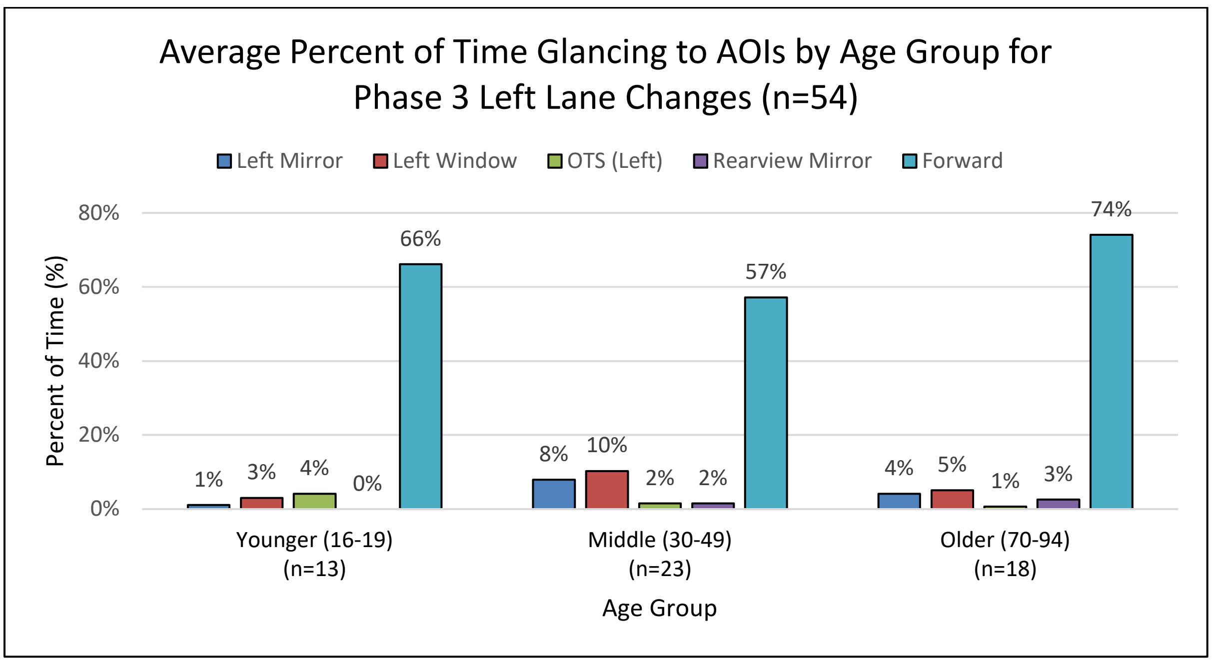


Figure 135. Chart. Percentage of time glancing to AOIs by age group for Phase 3 of interrupted left lane changes.

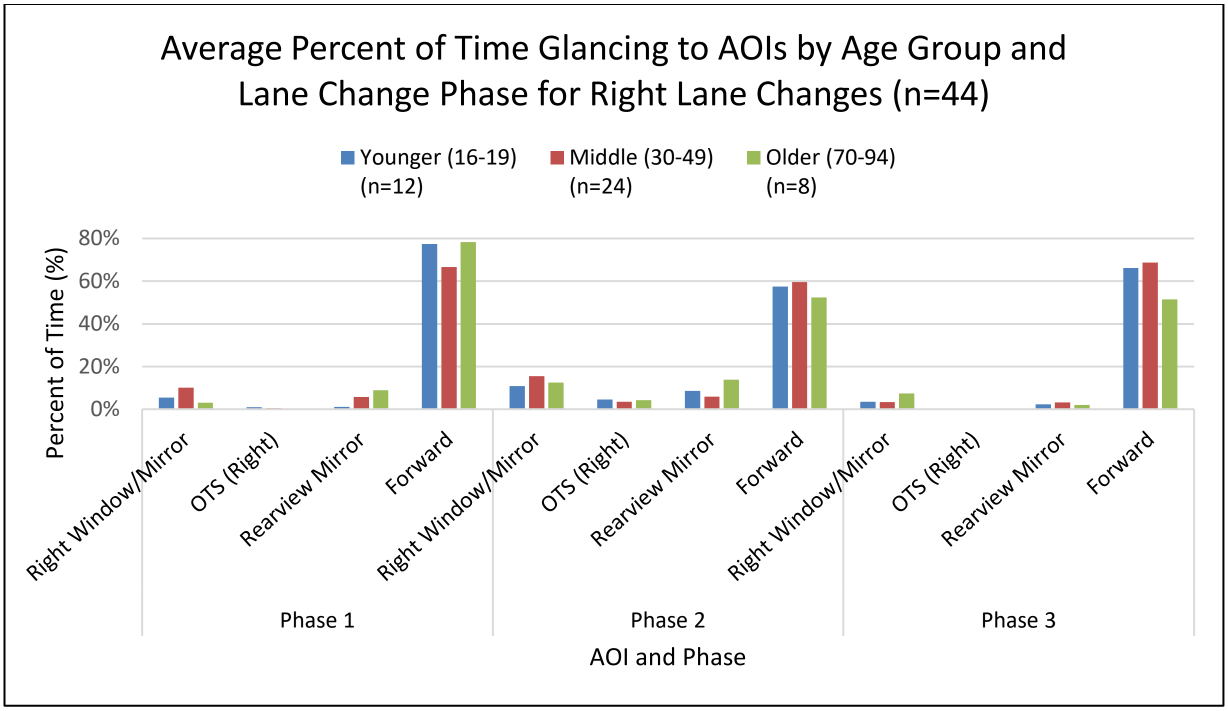


Figure 136. Chart. Average percentage of time glancing to AOIs by lane change phase and age group for interrupted right lane changes

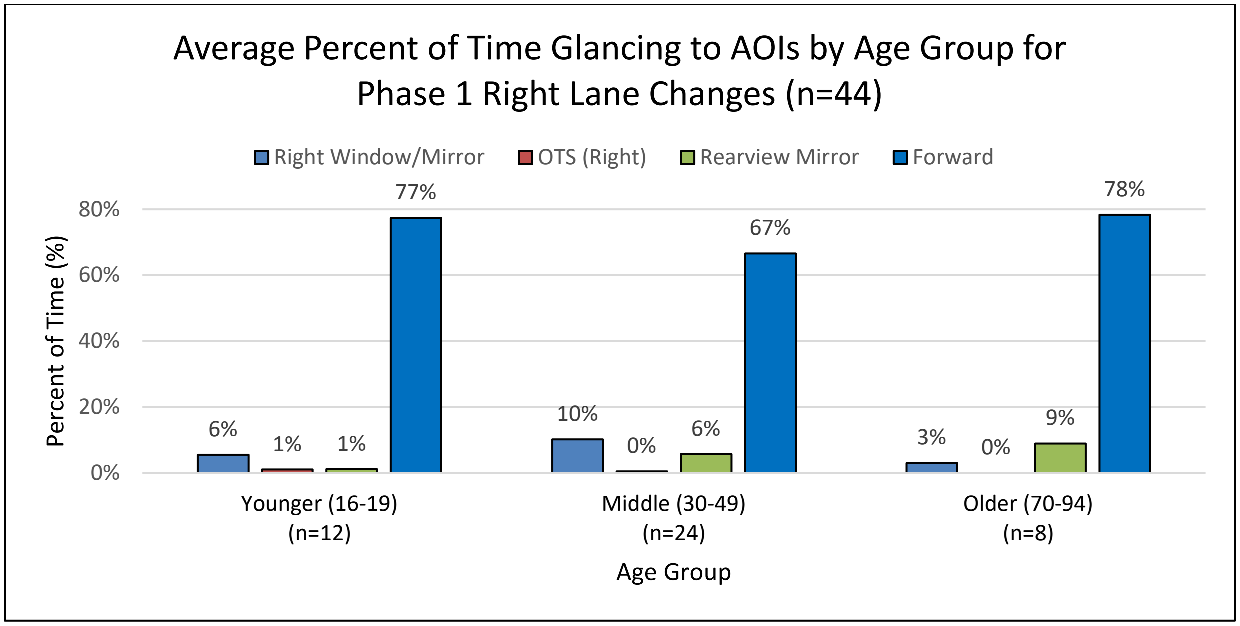


Figure 137. Chart. Percentage of time glancing to AOIs by age group for Phase 1 of interrupted right lane changes.

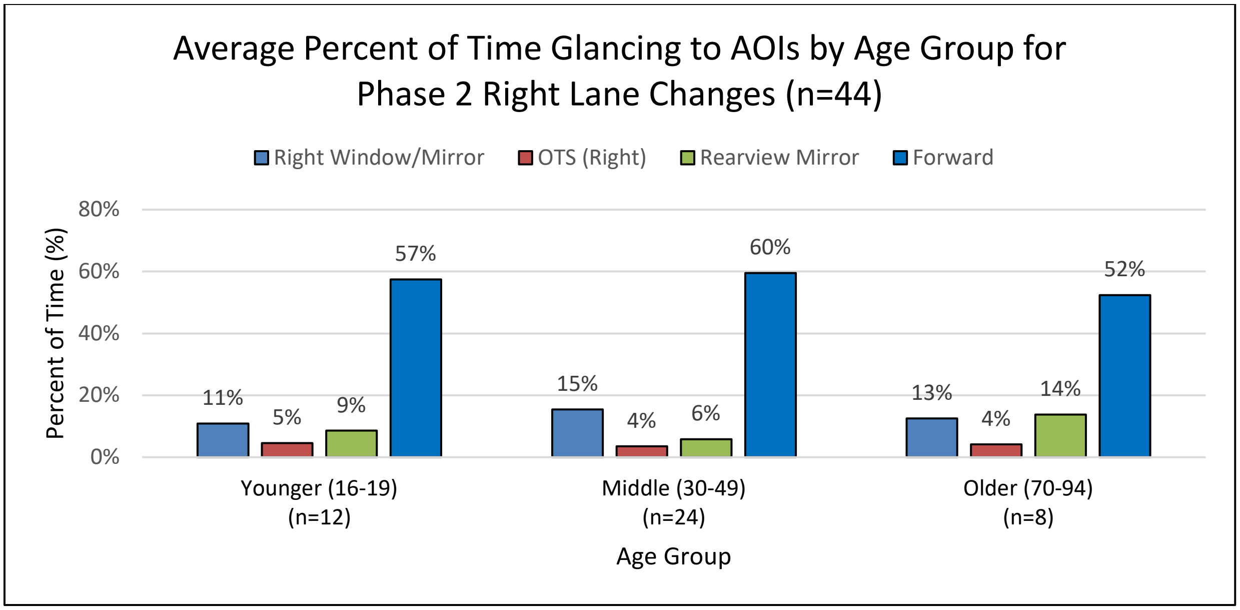


Figure 138. Chart. Percentage of time glancing to AOIs by age group for Phase 2 of interrupted right lane changes.

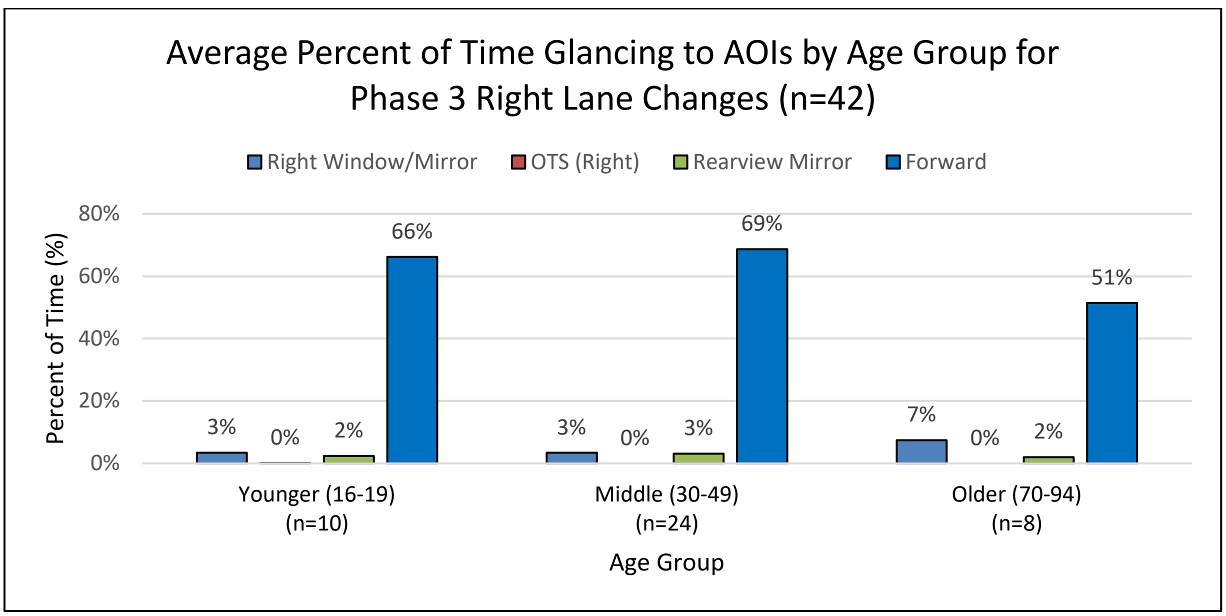


Figure 139. Chart. Percentage of time glancing to AOIs by age group for Phase 3 of interrupted right lane changes.

Percentage of Glances

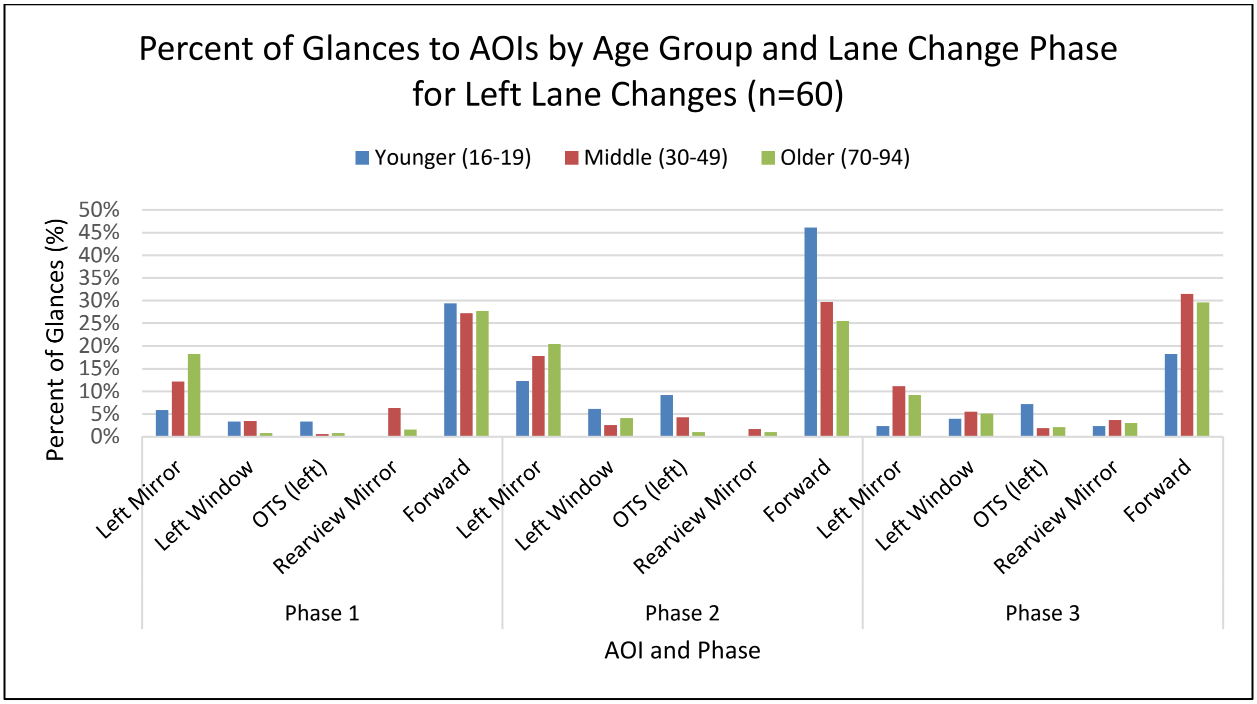


Figure 140. Chart. Percentage of glances to AOIs by age group and lane change phase for interrupted left lane changes.

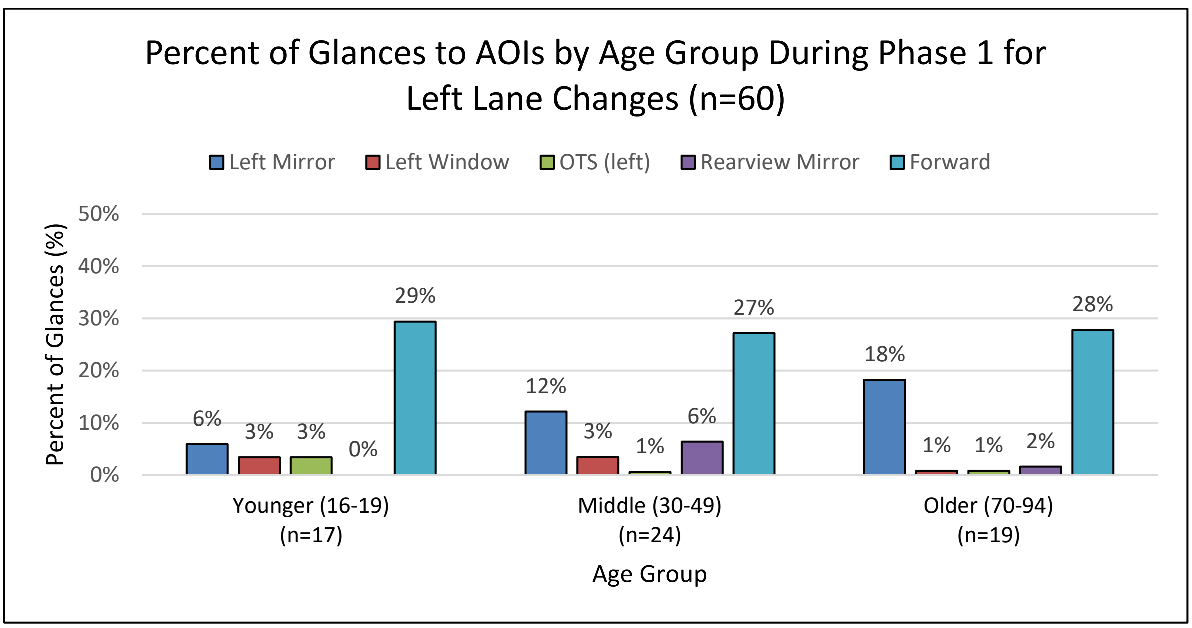


Figure 141. Chart. Percentage of glances to AOIs by age group for Phase 1 of interrupted left lane changes.

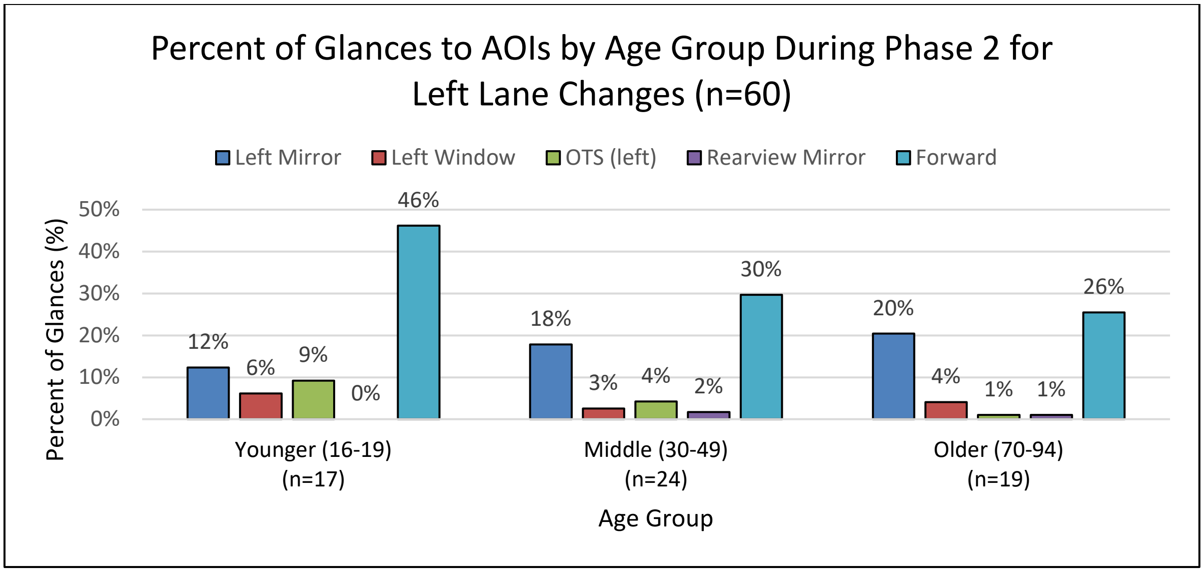


Figure 142. Chart. Percentage of glances to AOIs by age group for Phase 2 of interrupted left lane changes.

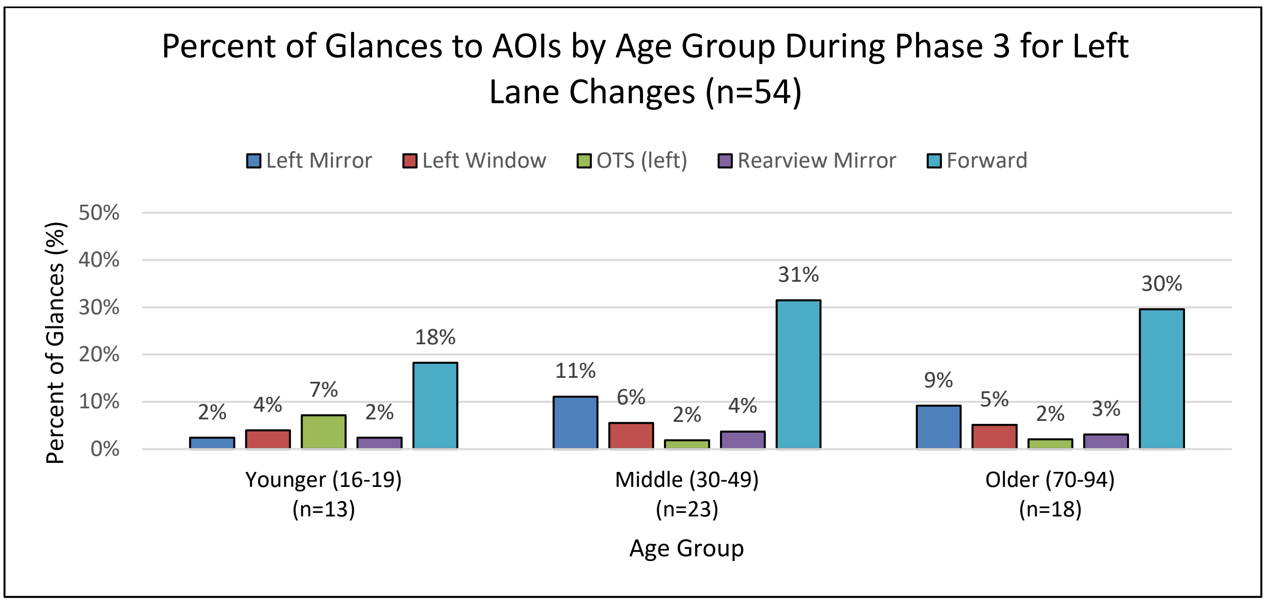


Figure 143. Chart. Percentage of glances to AOIs by age group for Phase 3 of interrupted left lane changes.

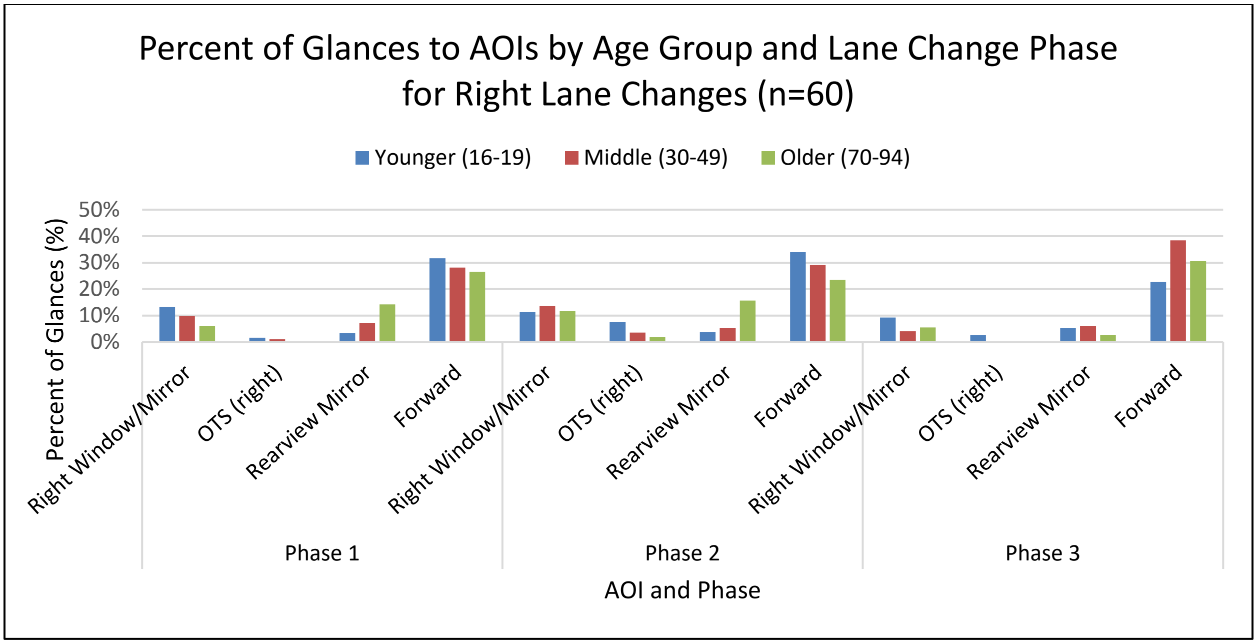


Figure 144. Chart. Percentage of glances to AOIs by lane change phase and age group for interrupted right lane changes.

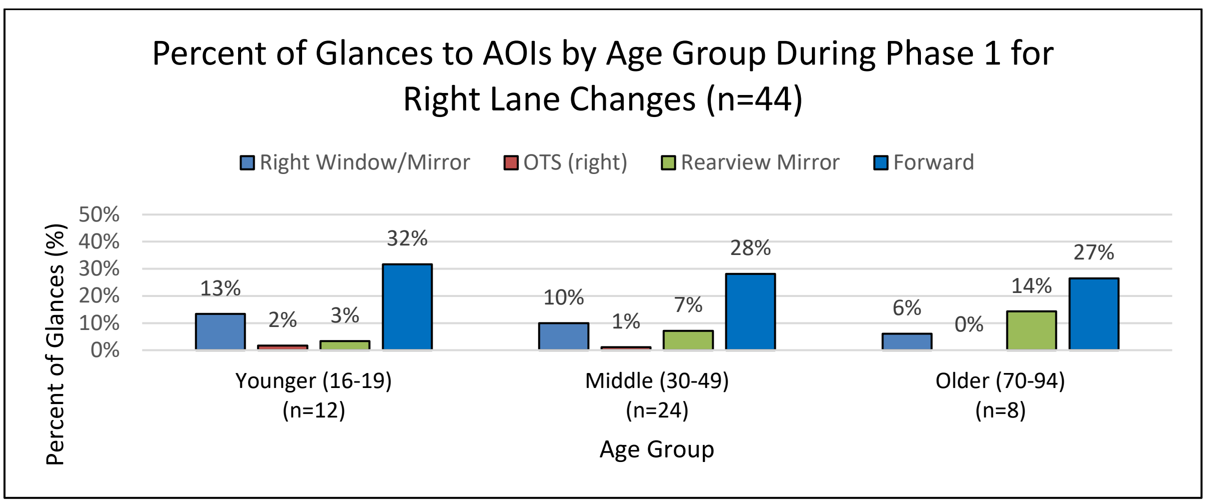


Figure 145. Chart. Percentage of glances to AOIs by age group for Phase 1 of interrupted right lane changes.

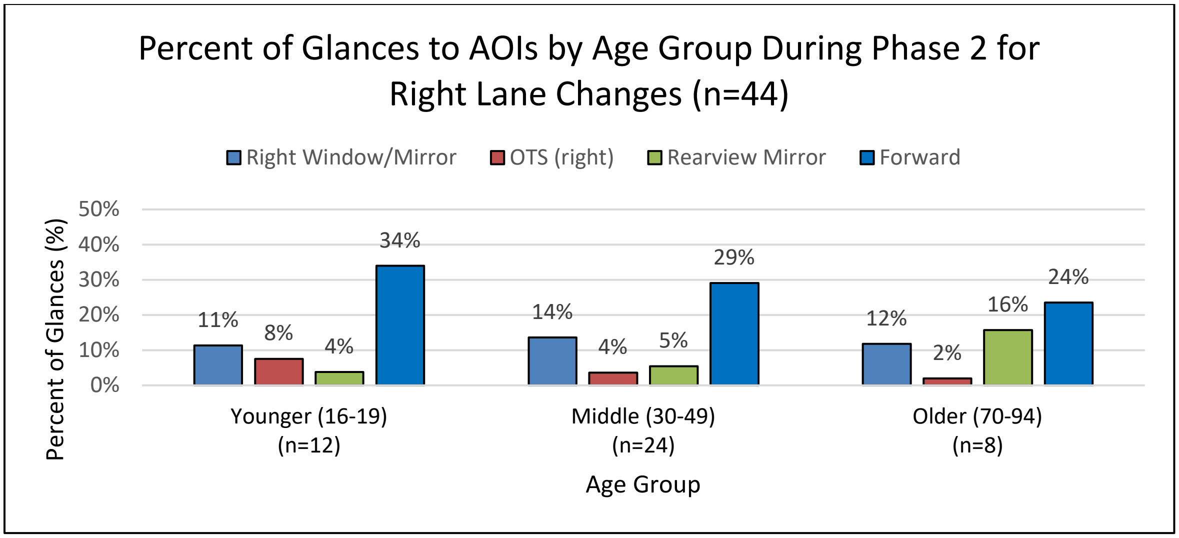


Figure 146. Chart. Percentage of glances to AOIs by age group for Phase 2 of interrupted right lane changes.

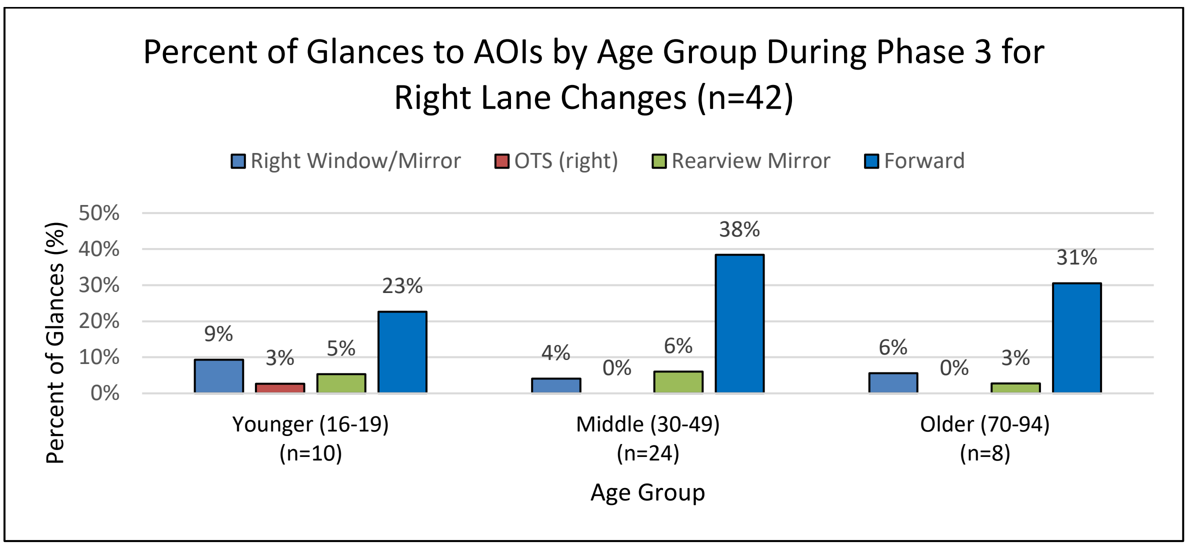


Figure 147. Chart. Percentage of glances to AOIs by age group for Phase 3 of interrupted right lane changes.

Glance Duration

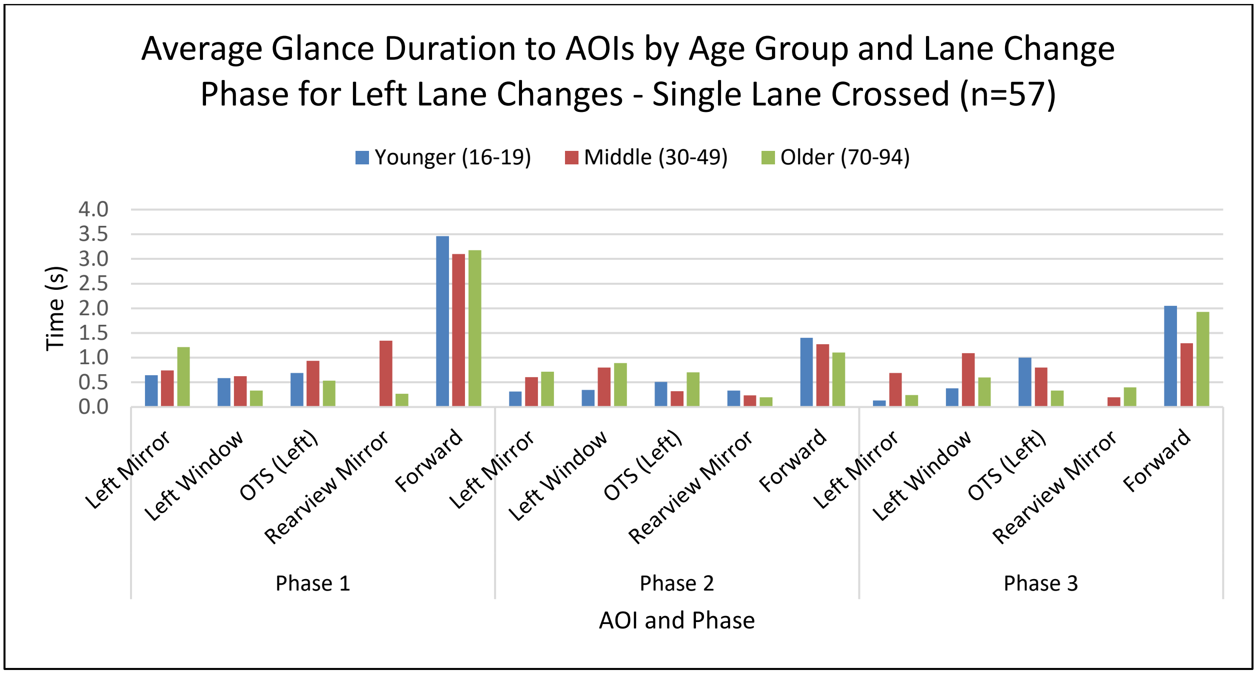


Figure 148. Chart. Average glance duration to AOIs by age group and lane change phase for interrupted left lane changes.

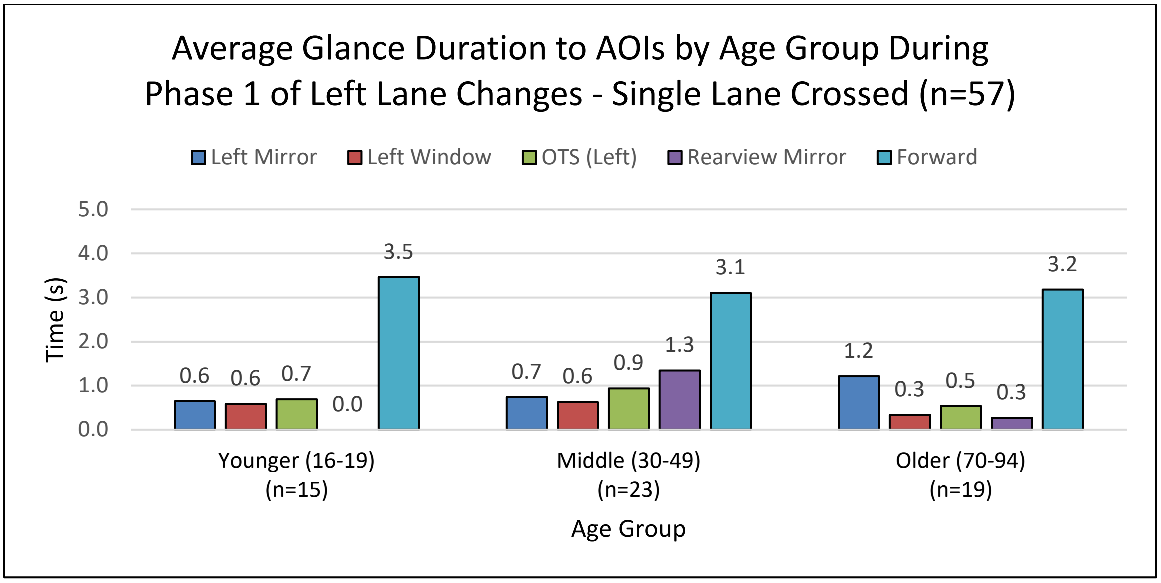


Figure 149. Chart. Average glance durations to AOIs for Phase 1 of interrupted left lane changes.

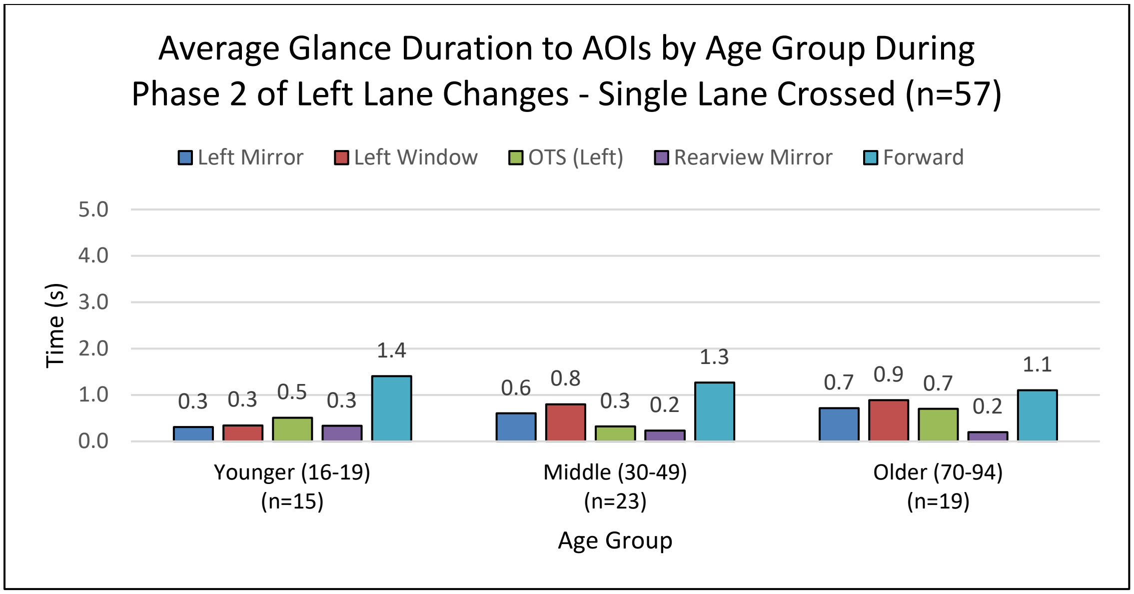


Figure 150. Chart. Average glance durations to AOIs for Phase 2 of interrupted left lane changes.

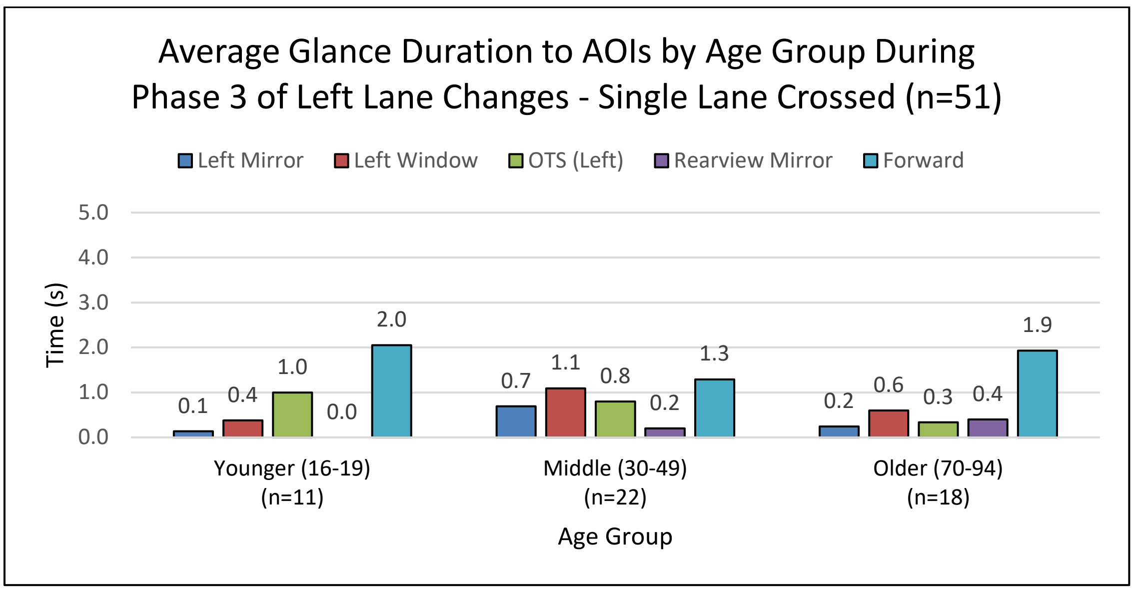


Figure 151. Chart. Average glance durations to AOIs for Phase 3 of interrupted left lane changes.

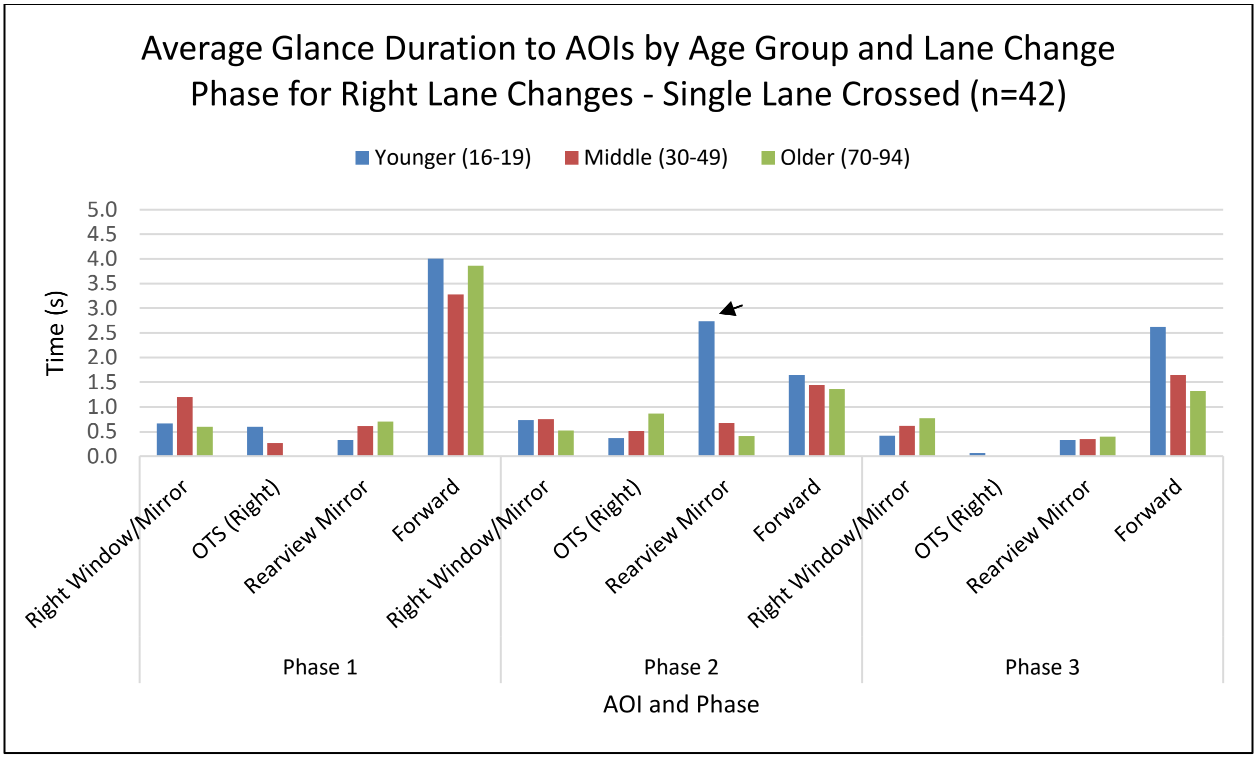


Figure 152. Chart. Average glance duration to AOIs by lane change phase and age group for interrupted right lane changes. Note that the value for younger drivers glance duration to the rearview mirror is for a single participant.

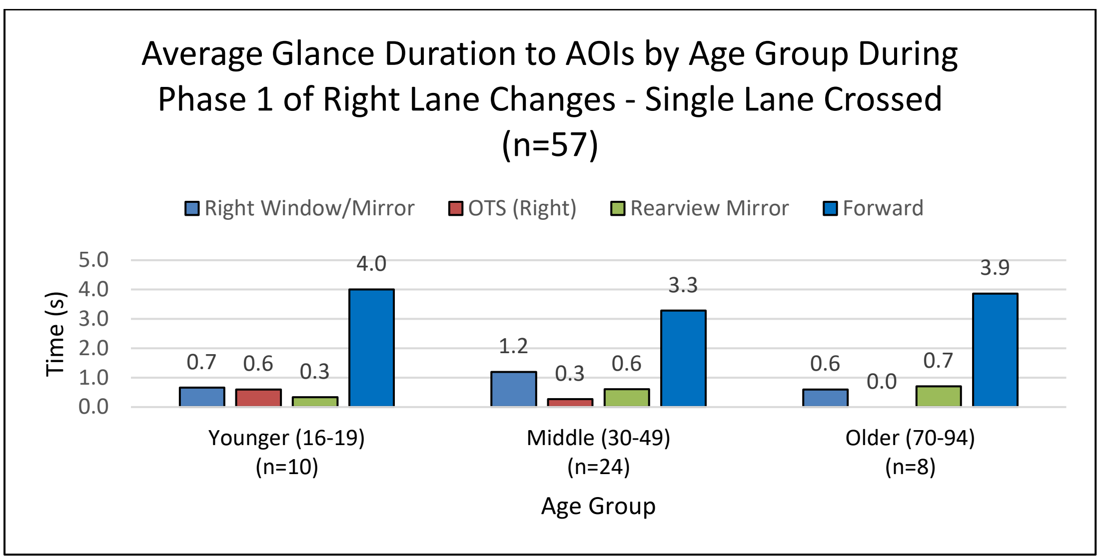


Figure 153. Chart. Average glance durations to AOIs for Phase 1 of interrupted right lane changes.

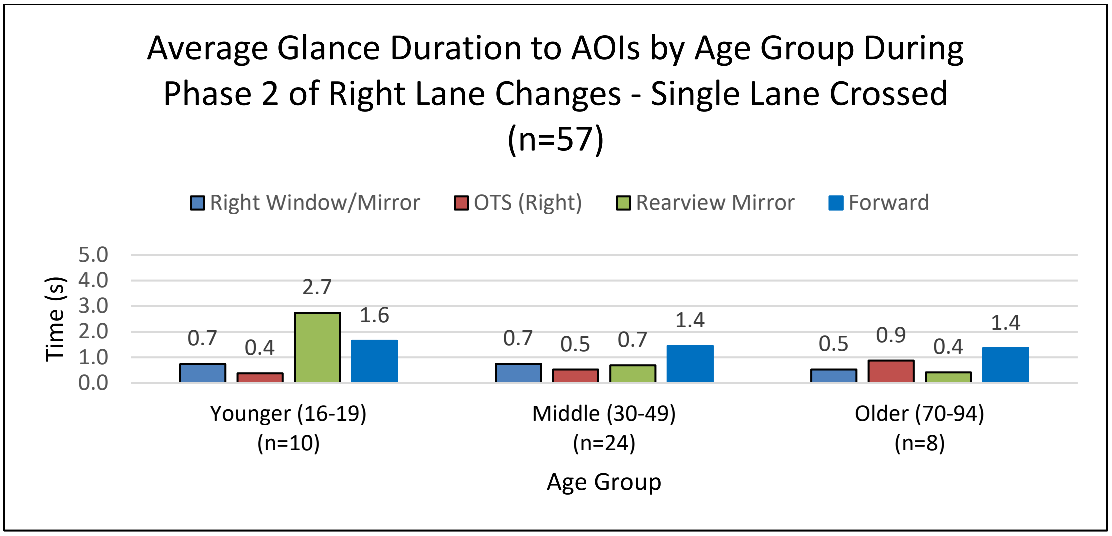


Figure 154. Chart. Average glance durations to AOIs for Phase 2 of interrupted right lane changes. Note that the average glance duration for younger drivers to the rearview mirror is for a single participant.

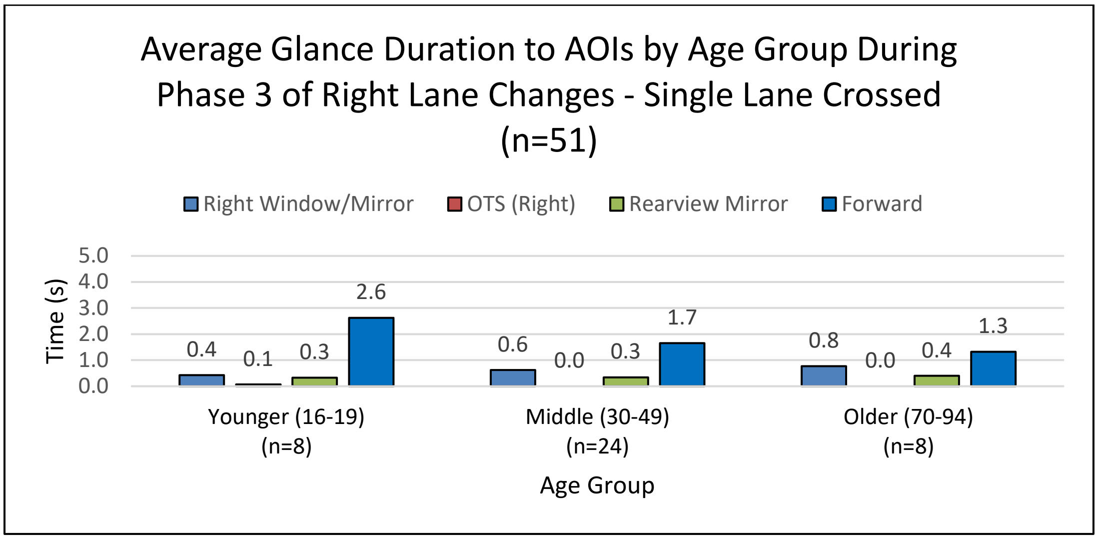


Figure 155. Chart. Average glance durations to AOIs for Phase 3 of interrupted right lane changes.

Glance Counts

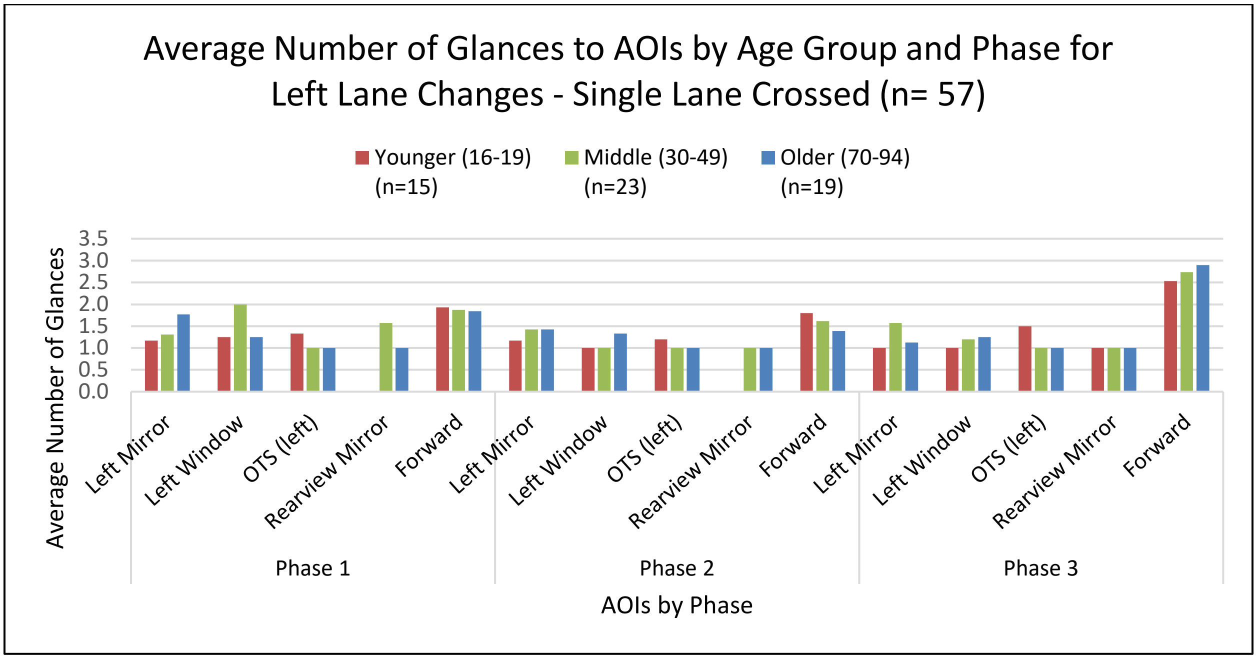


Figure 156. Chart. Average number of glances to AOIs by age group and lane change phase.

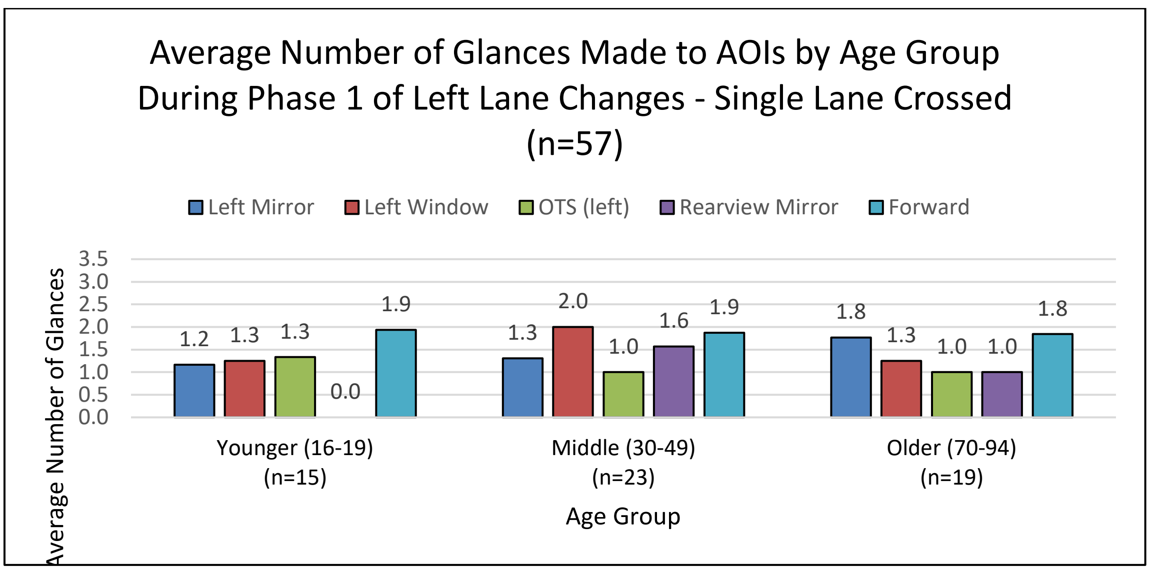


Figure 157. Chart. Average glance count made during Phase 1 of interrupted left lane changes.

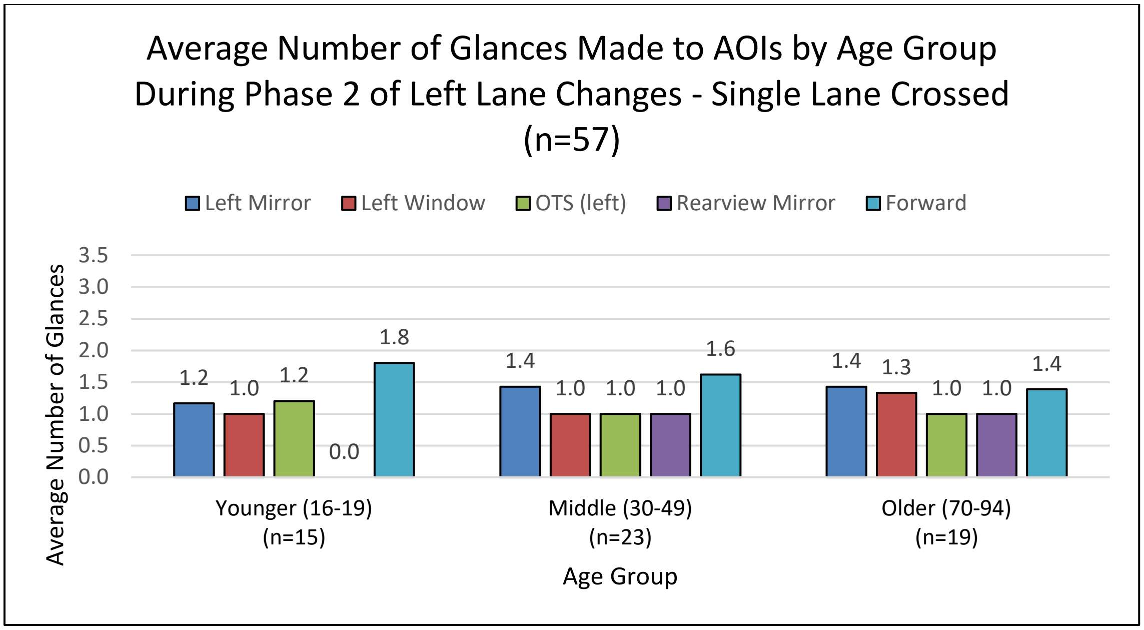


Figure 158. Chart. Average glance count made during Phase 2 of interrupted left lane changes.

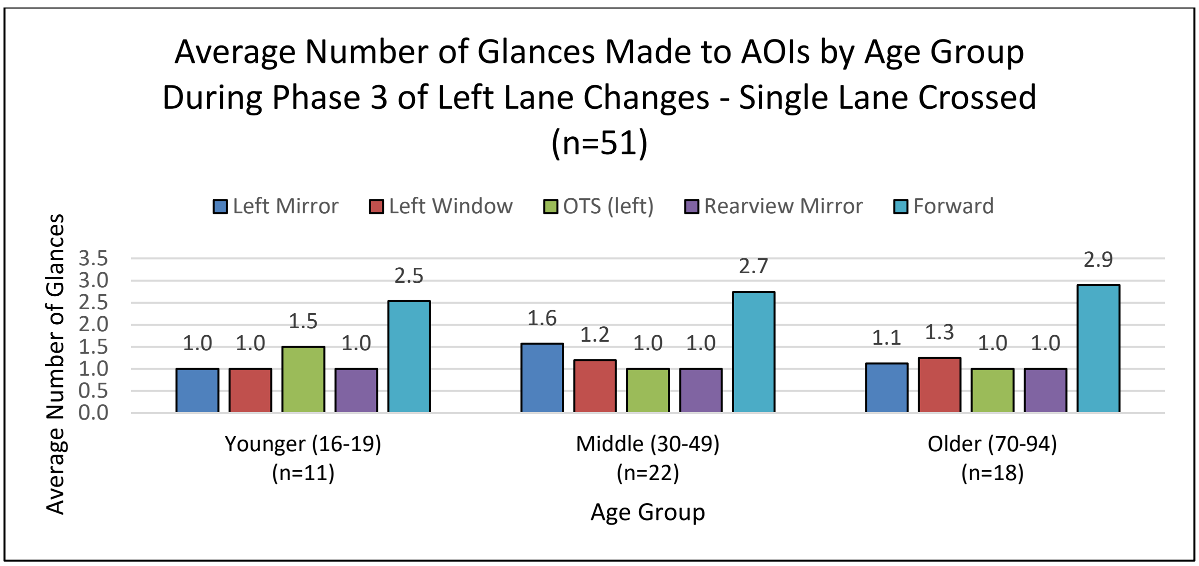


Figure 159. Chart. Average glance count made during Phase 3 of interrupted left lane changes.

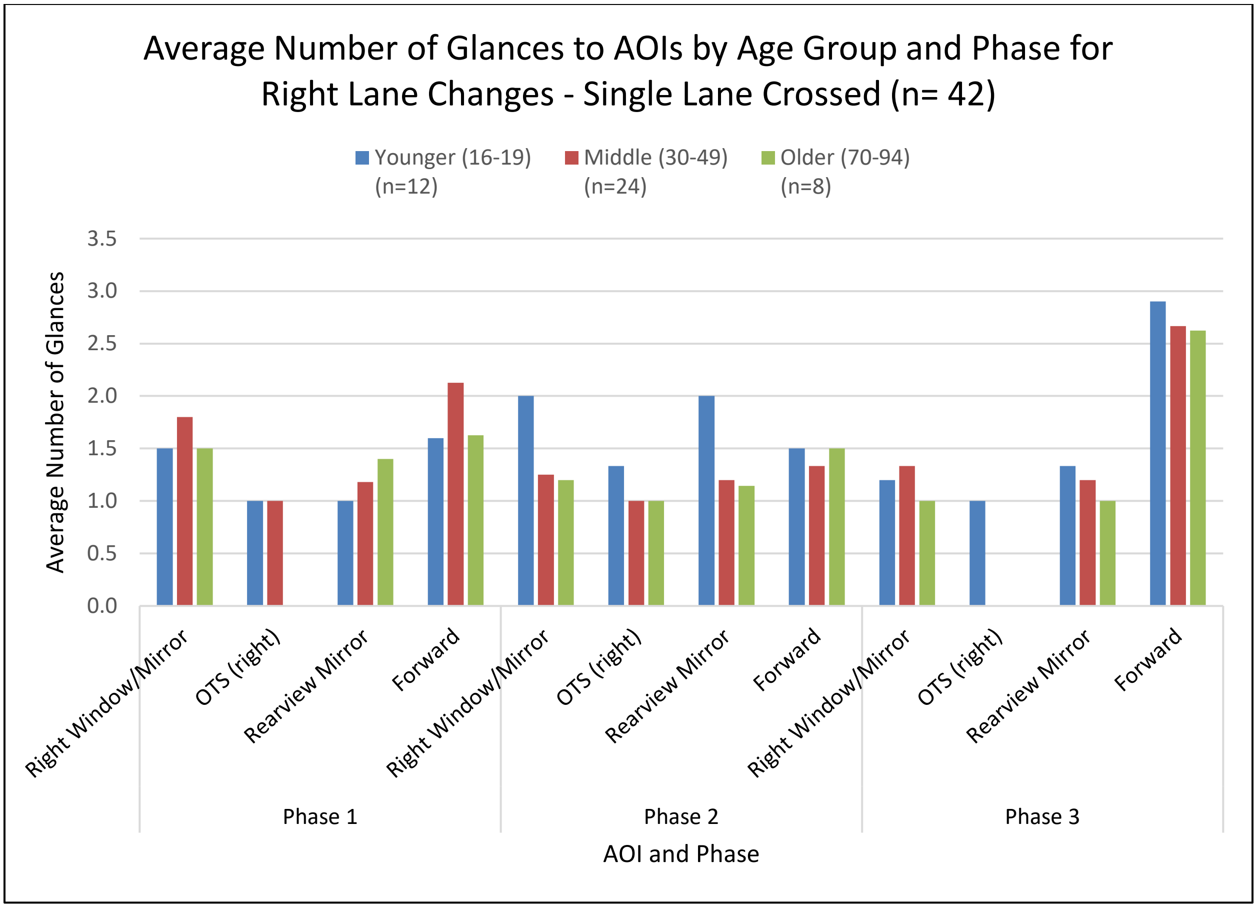


Figure 160. Chart. Average glance count by age and phase for right lane changes.

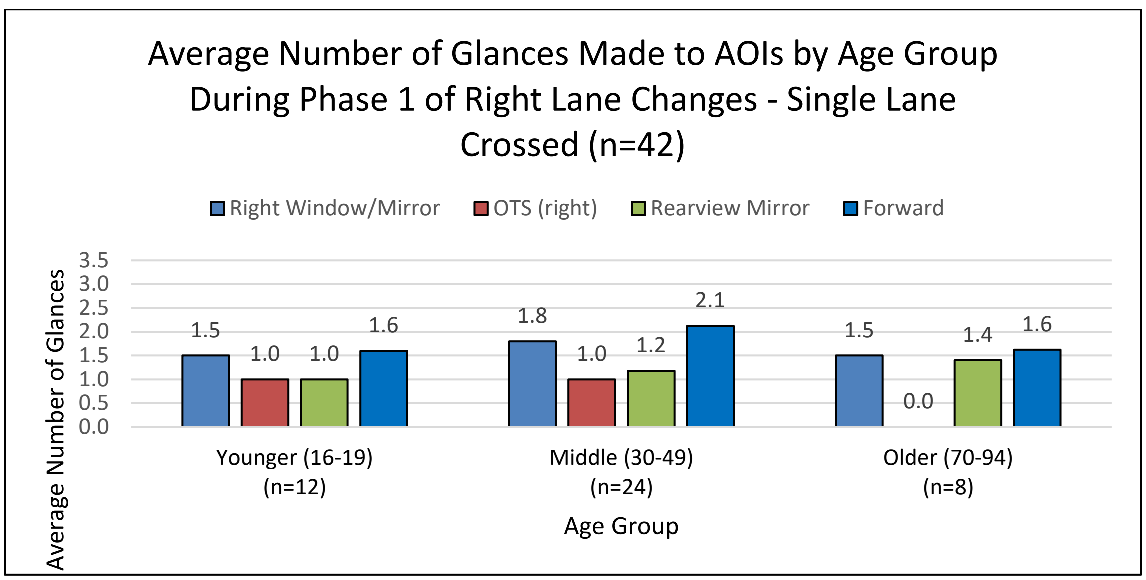


Figure 161. Chart. Average glance count made during Phase 1 of interrupted right lane changes.

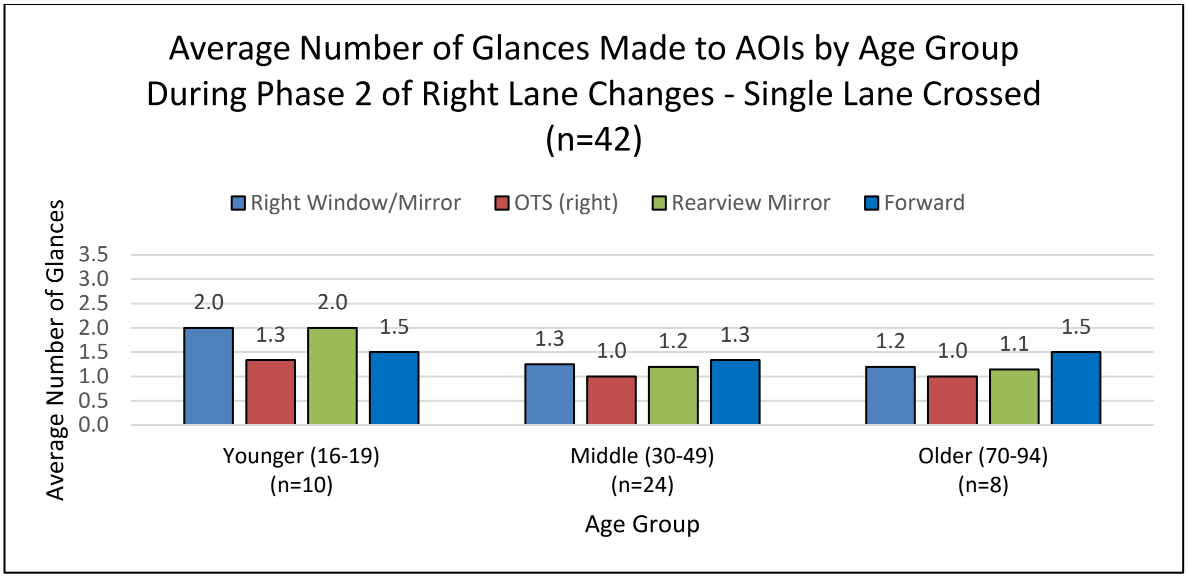


Figure 162. Chart. Average glance count made during Phase 2 of interrupted right lane changes.

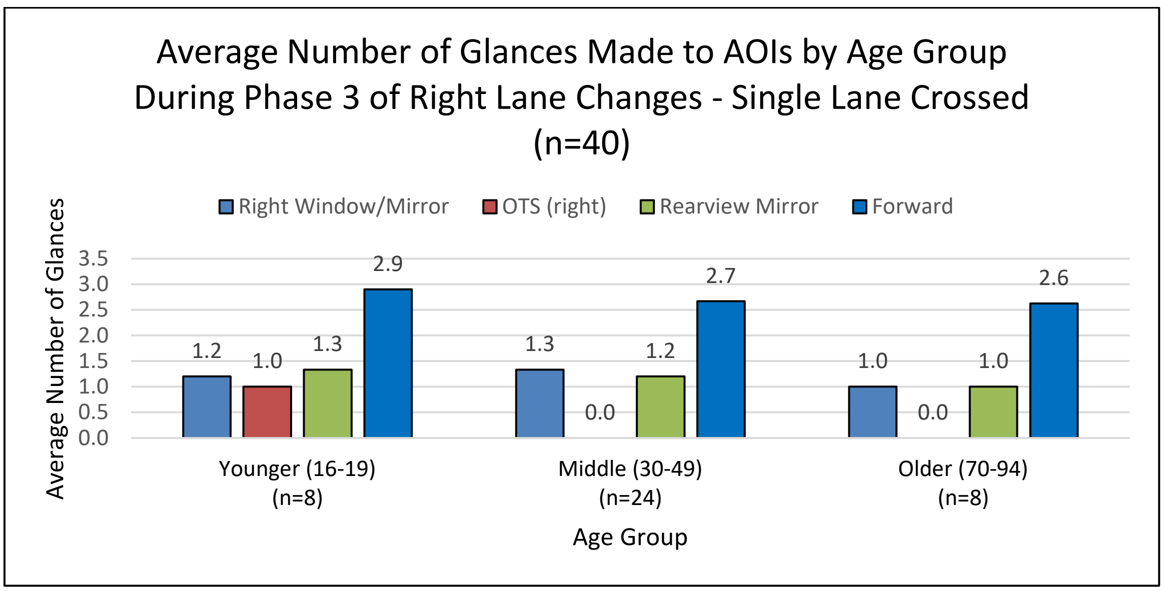


Figure 163. Chart. Average glance count made during Phase 3 of interrupted right lane changes.

Probability

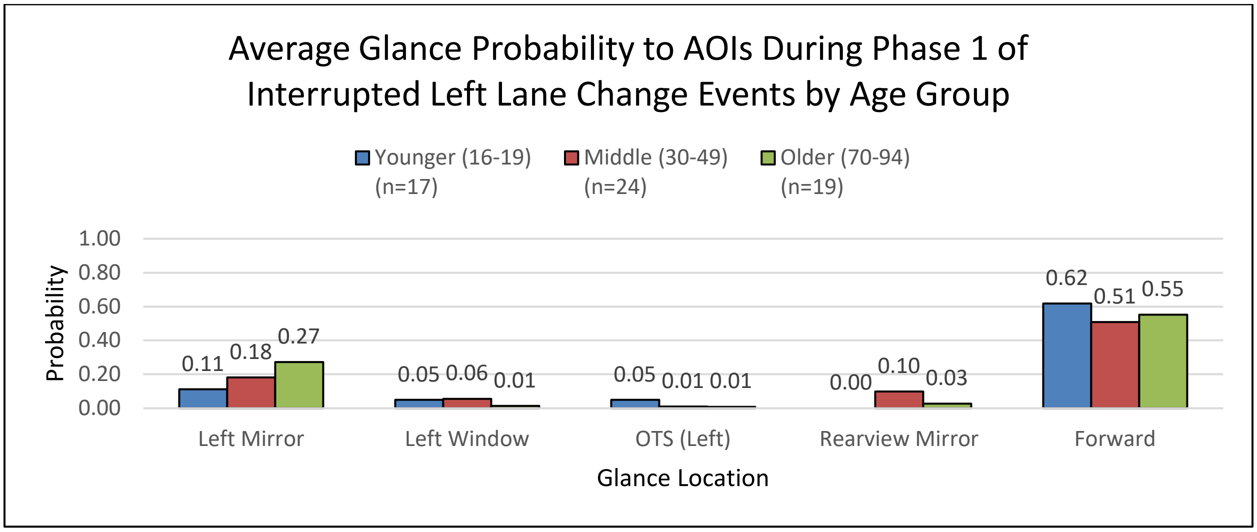


Figure 164. Chart. Average glance probability during Phase 1 of interrupted left lane changes.

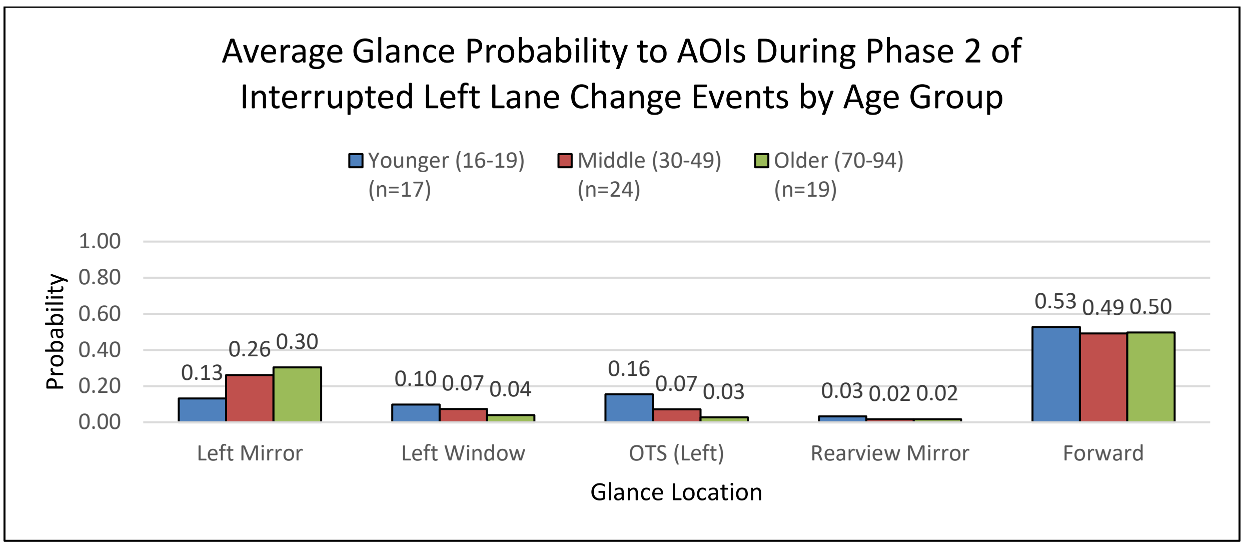


Figure 165. Chart. Average glance probability during Phase 2 of interrupted left lane changes.

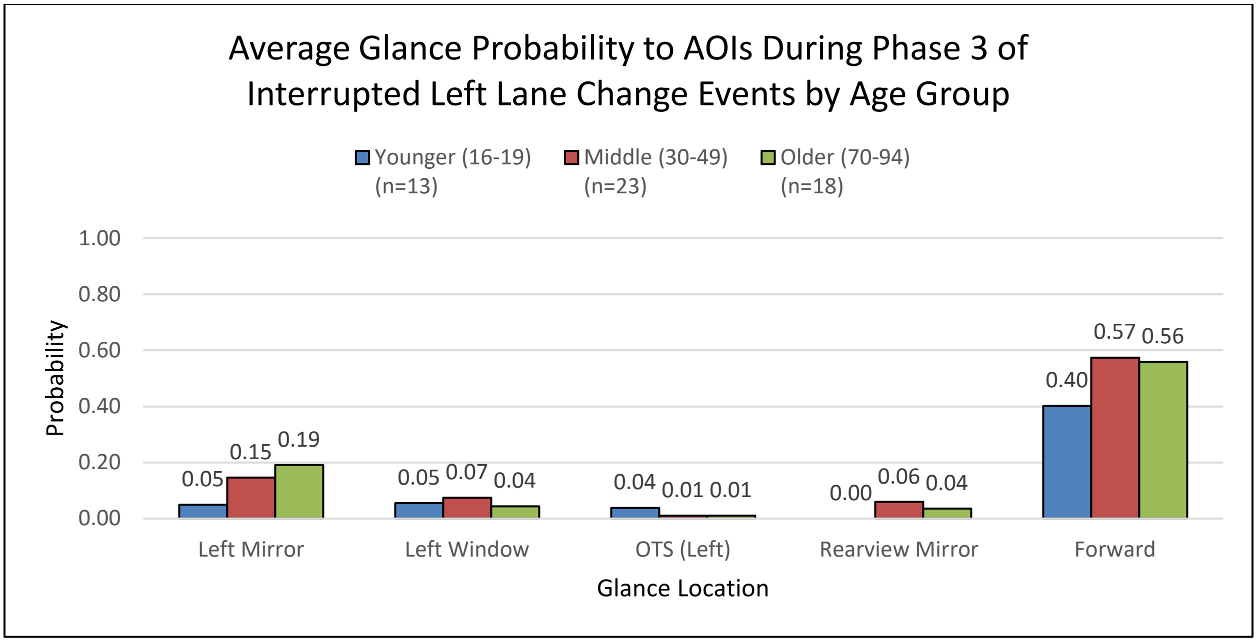


Figure 166. Chart. Average glance probability during Phase 3 of interrupted left lane changes.

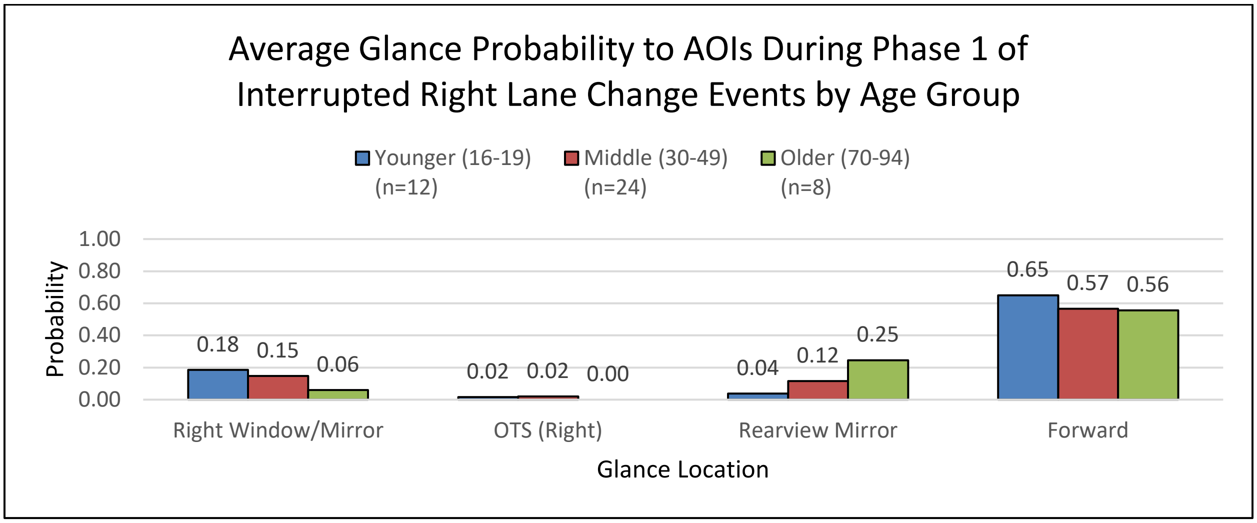


Figure 167. Chart. Average glance probability during Phase 1 of interrupted right lane changes.

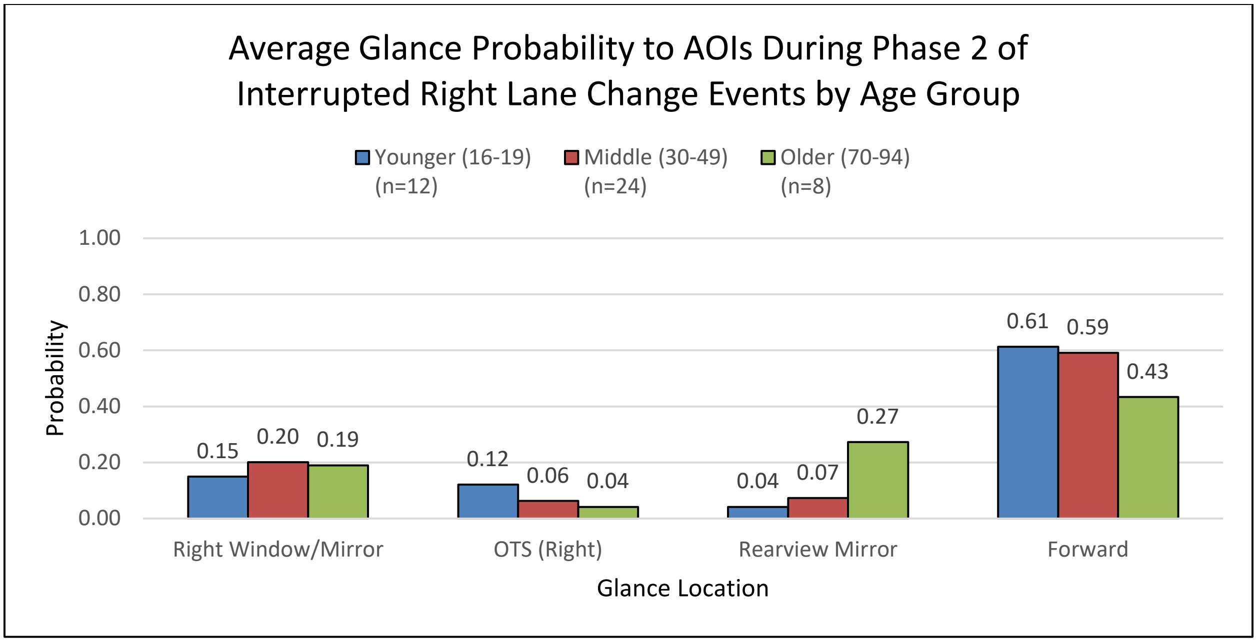


Figure 168. Chart. Average glance probability during Phase 2 of interrupted right lane changes.

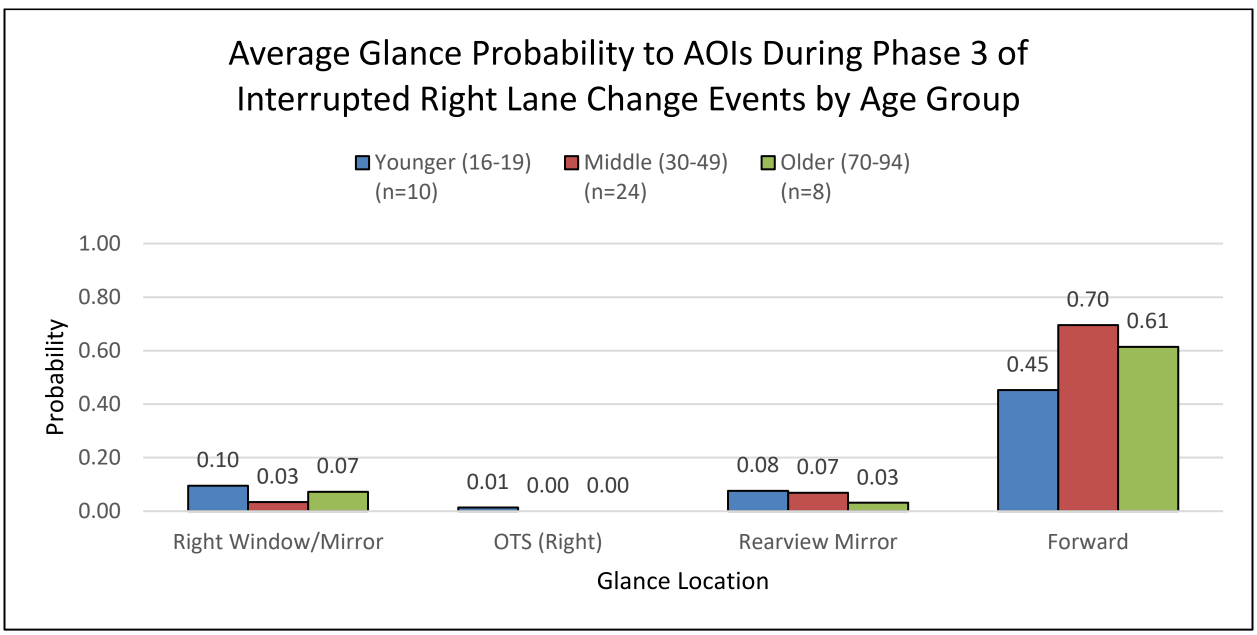


Figure 169. Chart. Average glance probability during Phase 3 of interrupted right lane changes.

Entropy

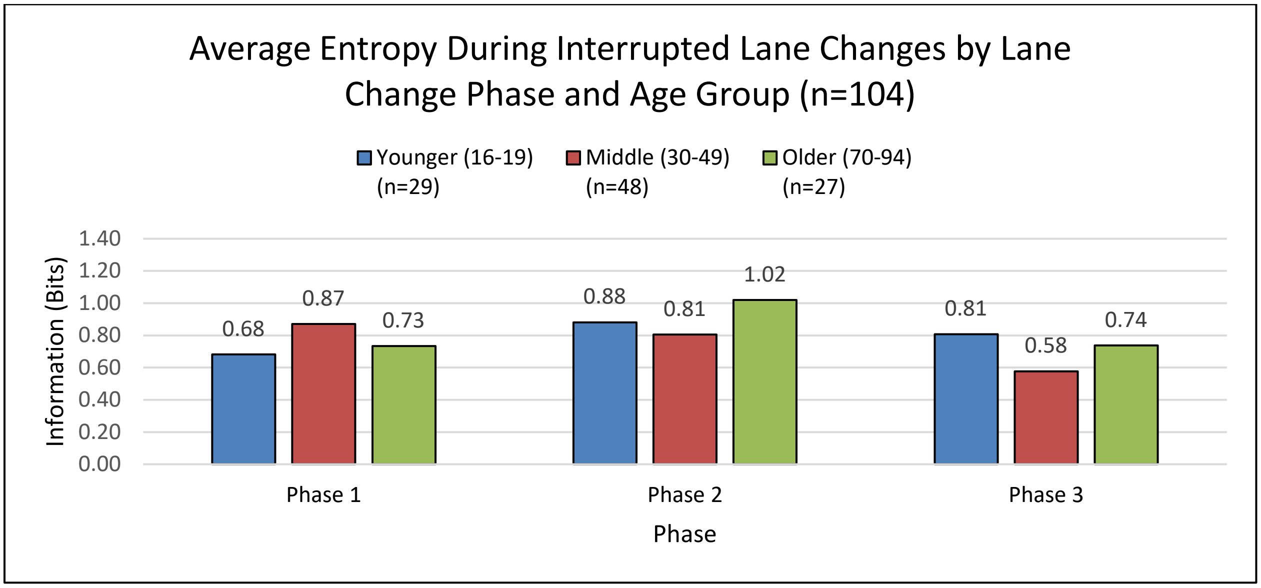


Figure 170. Chart. Average entropy during interrupted lane changes.

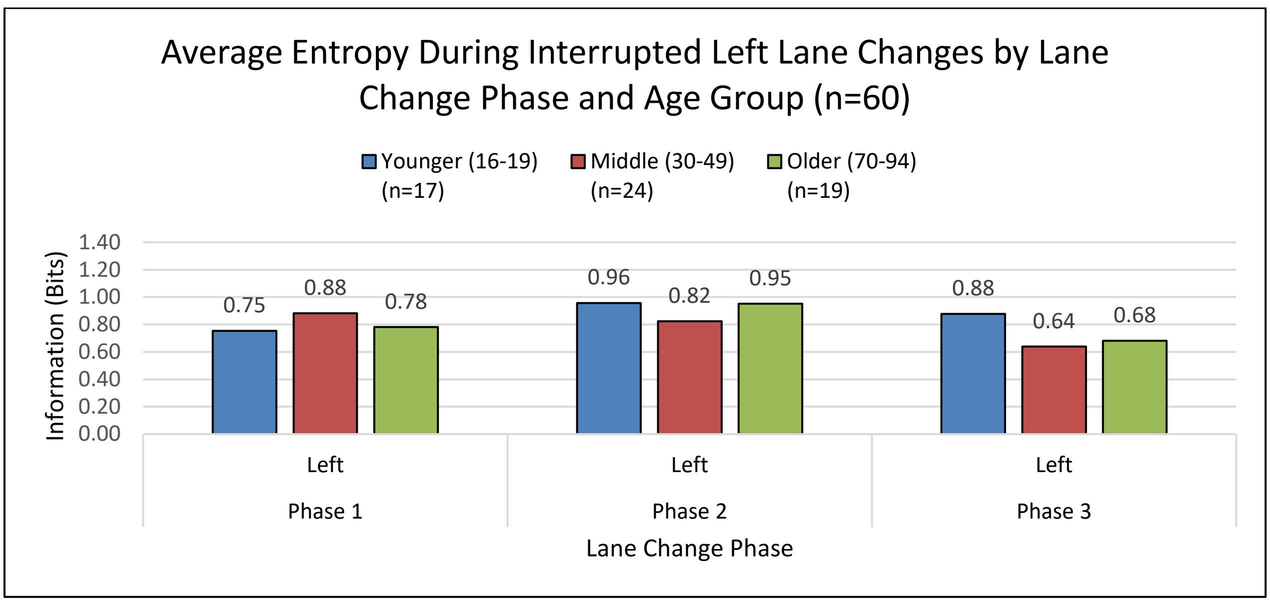


Figure 171. Chart. Average entropy during interrupted left lane changes.

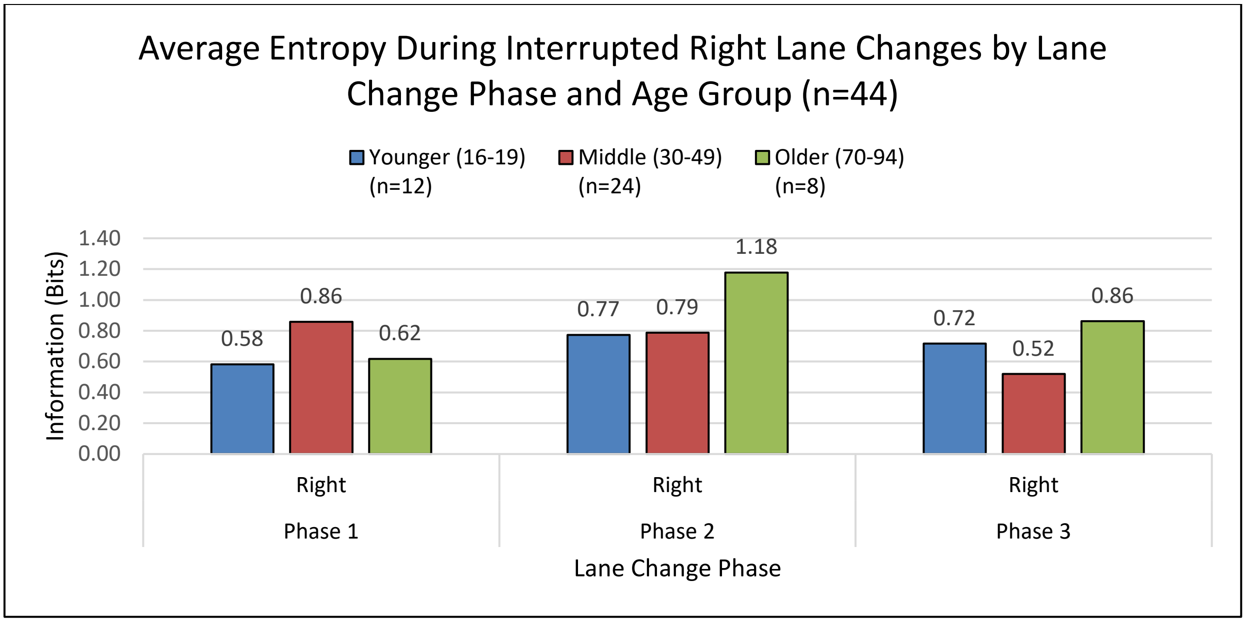


Figure 172. Chart. Average entropy during interrupted right lane changes.

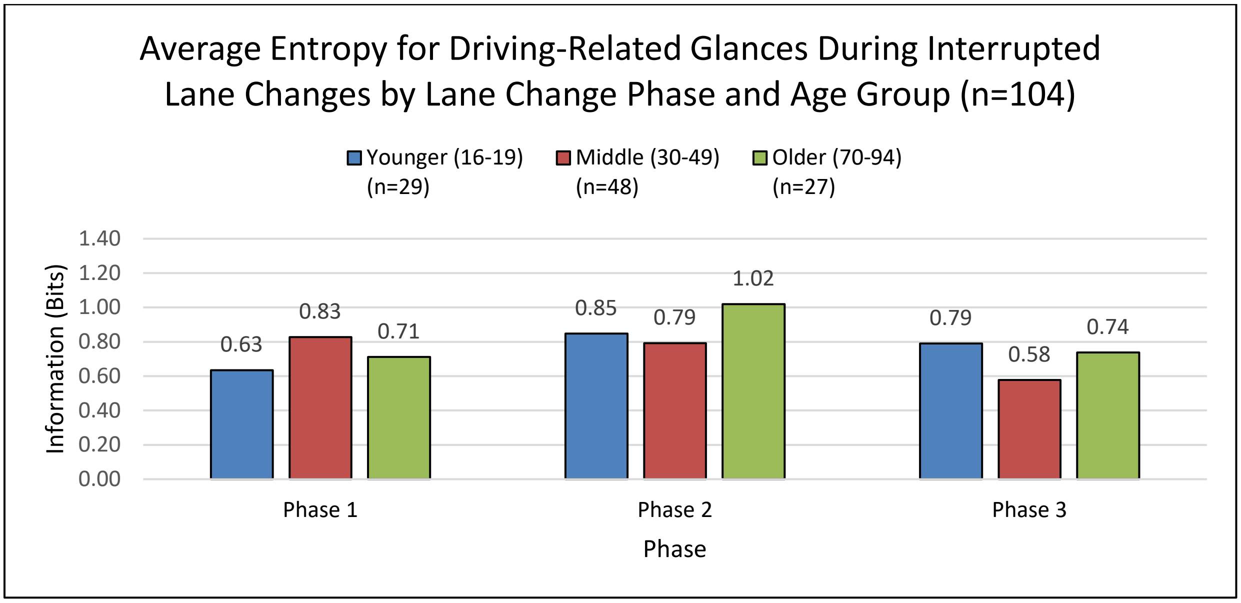


Figure 173. Chart. Average entropy during interrupted lane changes – driving-related glances only.

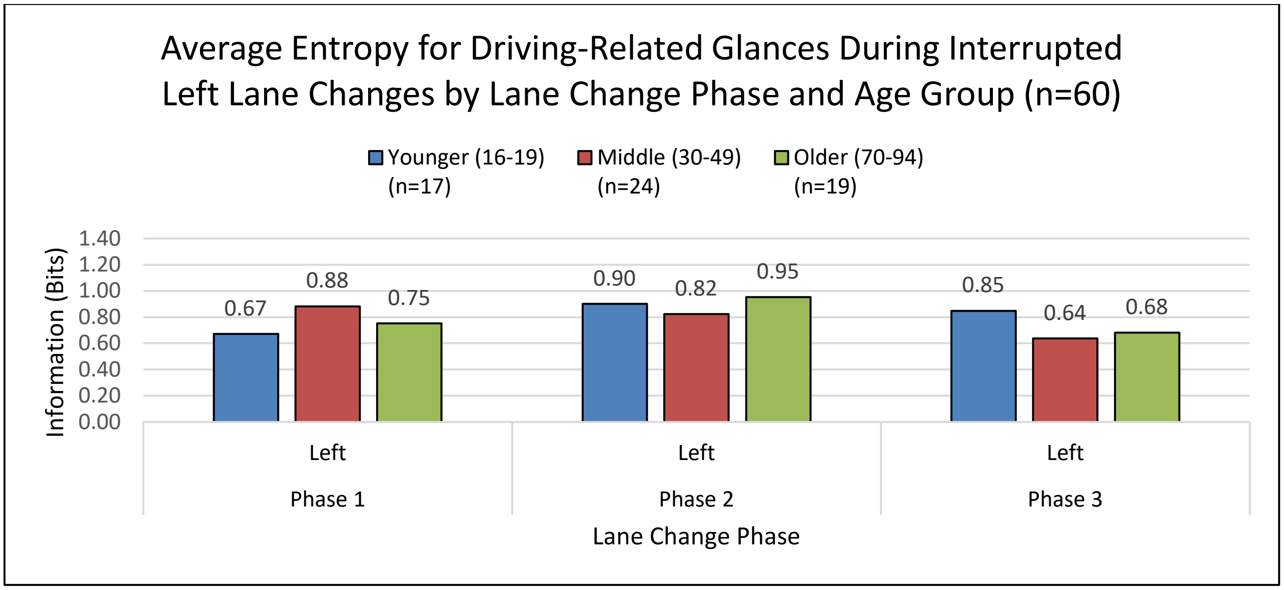


Figure 174. Chart. Average entropy during interrupted left lane changes – driving-related glances only.

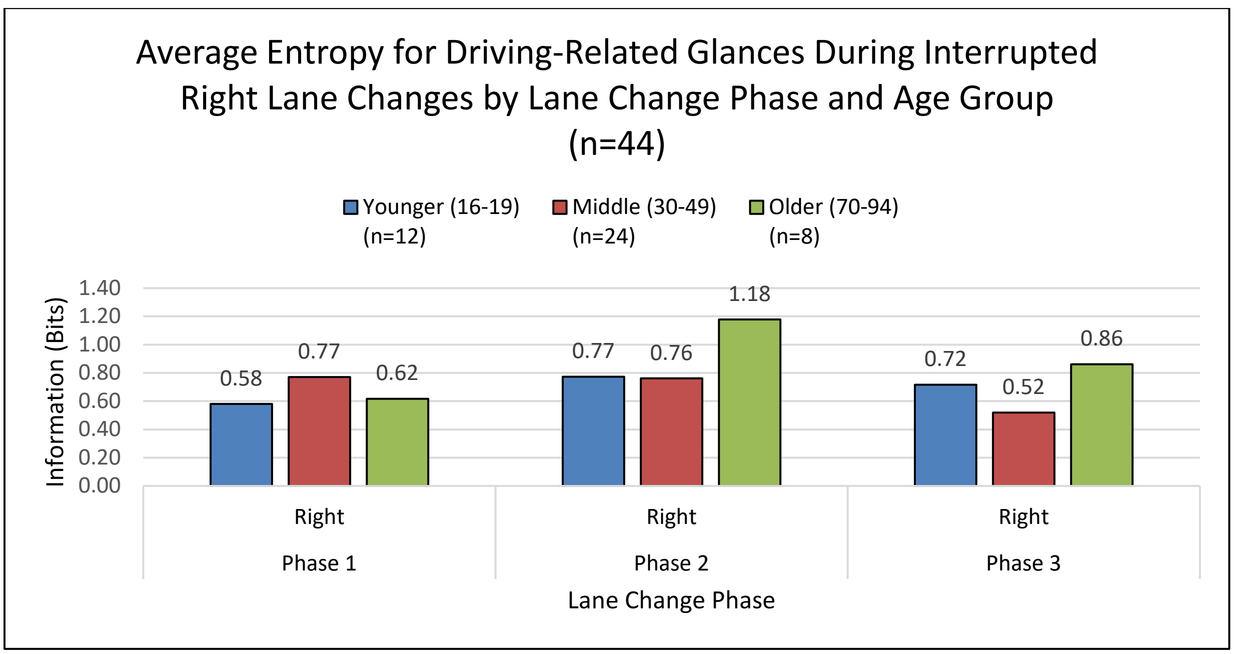


Figure 175. Chart. Average entropy during interrupted right lane changes – driving-related glances only.

Errors

Glance Errors

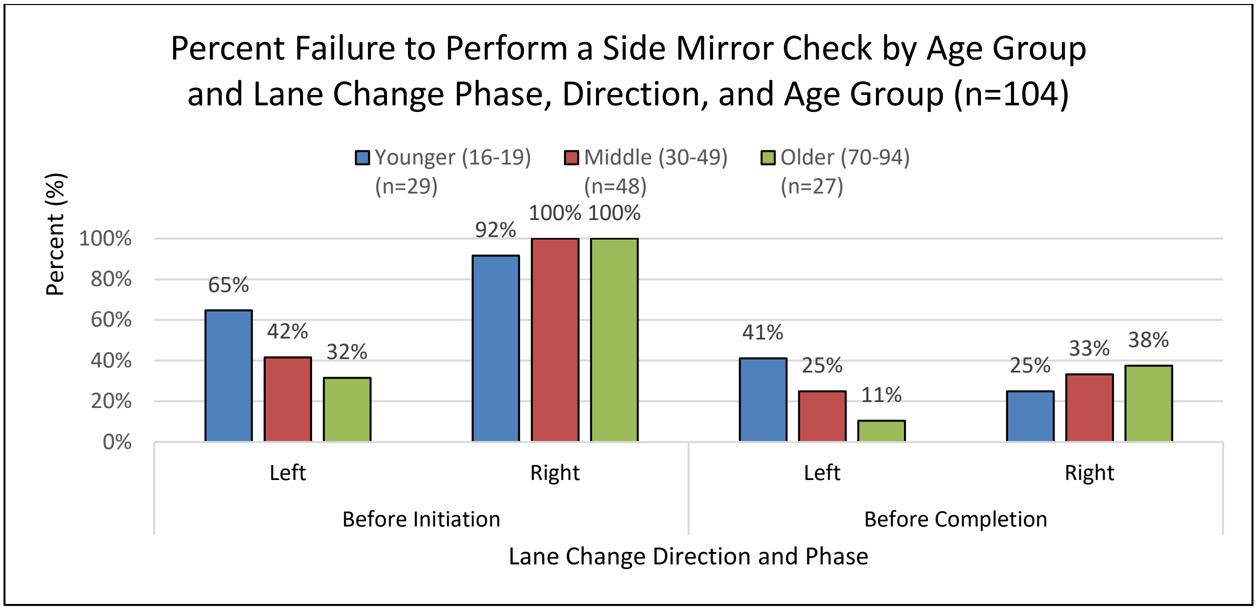


Figure 176. Chart. Failure to perform a side mirror check prior to initiating a lane change – for interrupted lane change events.

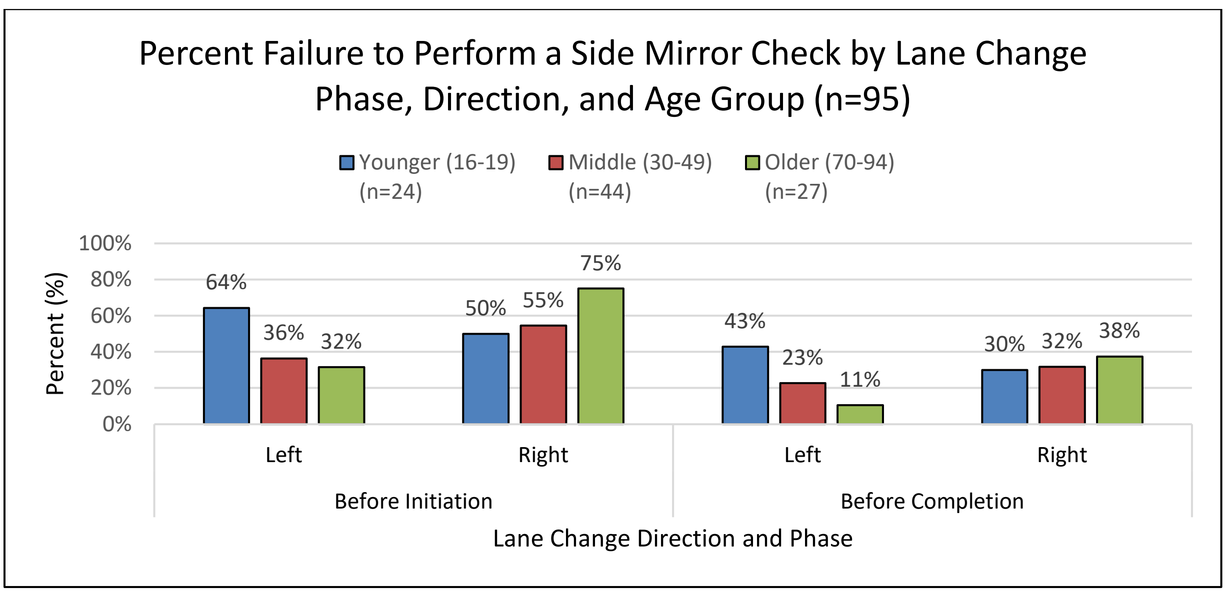


Figure 177. Chart. Failure to perform a side mirror check prior to initiating a lane change – for interrupted lane change events – events removed.

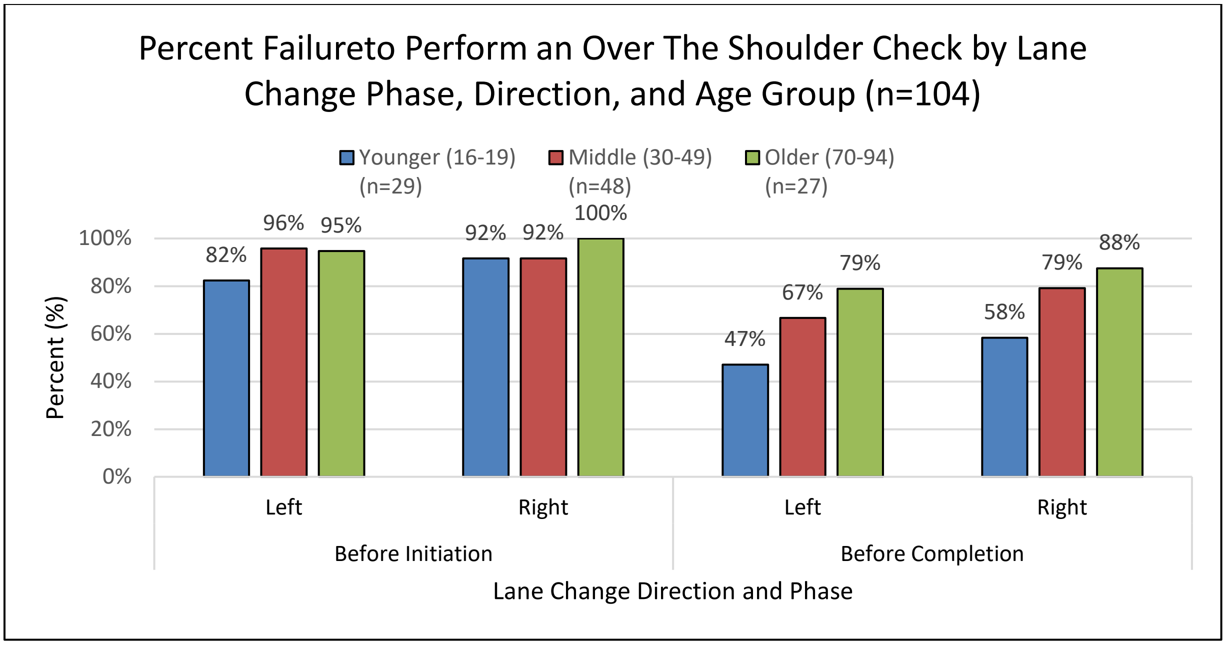


Figure 178. Chart. Failure to perform an OTS glance prior to initiation for interrupted lane change events.

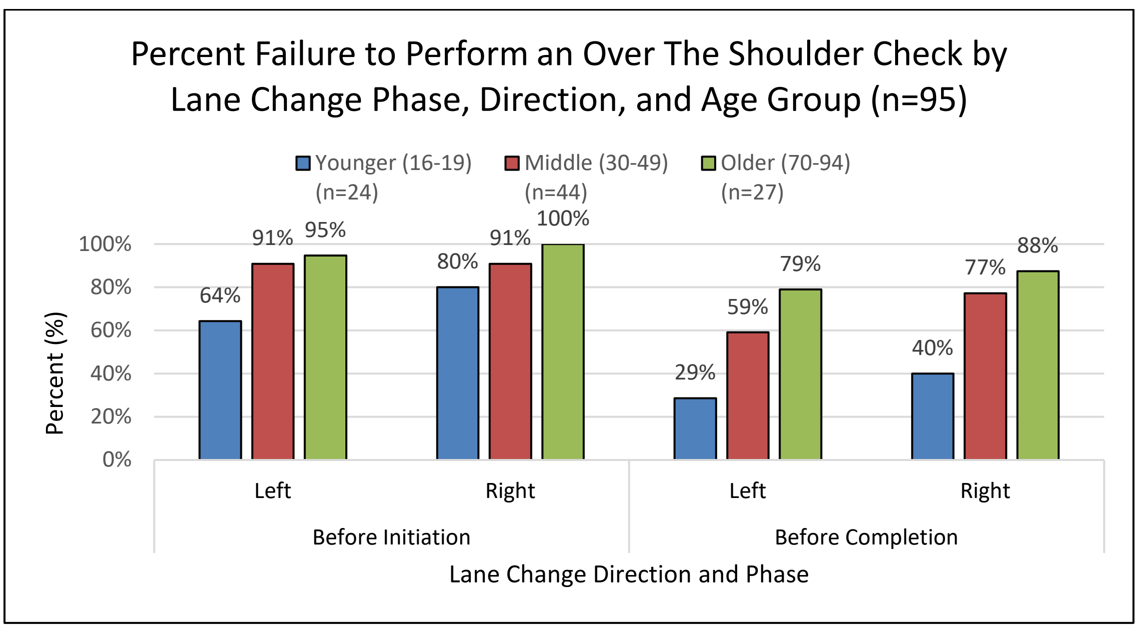


Figure 179. Chart. Failure to direct an OTS glance prior to lane change initiation for interrupted lane change events – events removed.

Turn Signal Errors

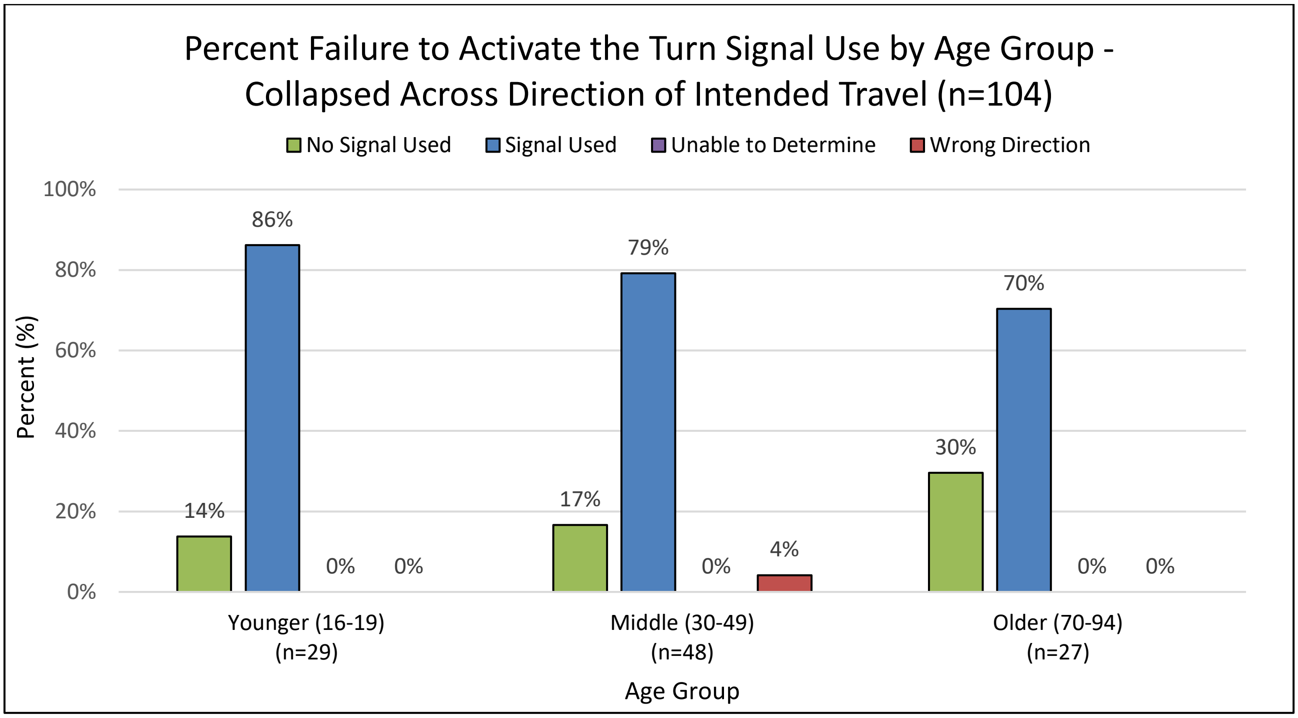


Figure 180. Chart. Turn signal use by age group for interrupted lane changes.

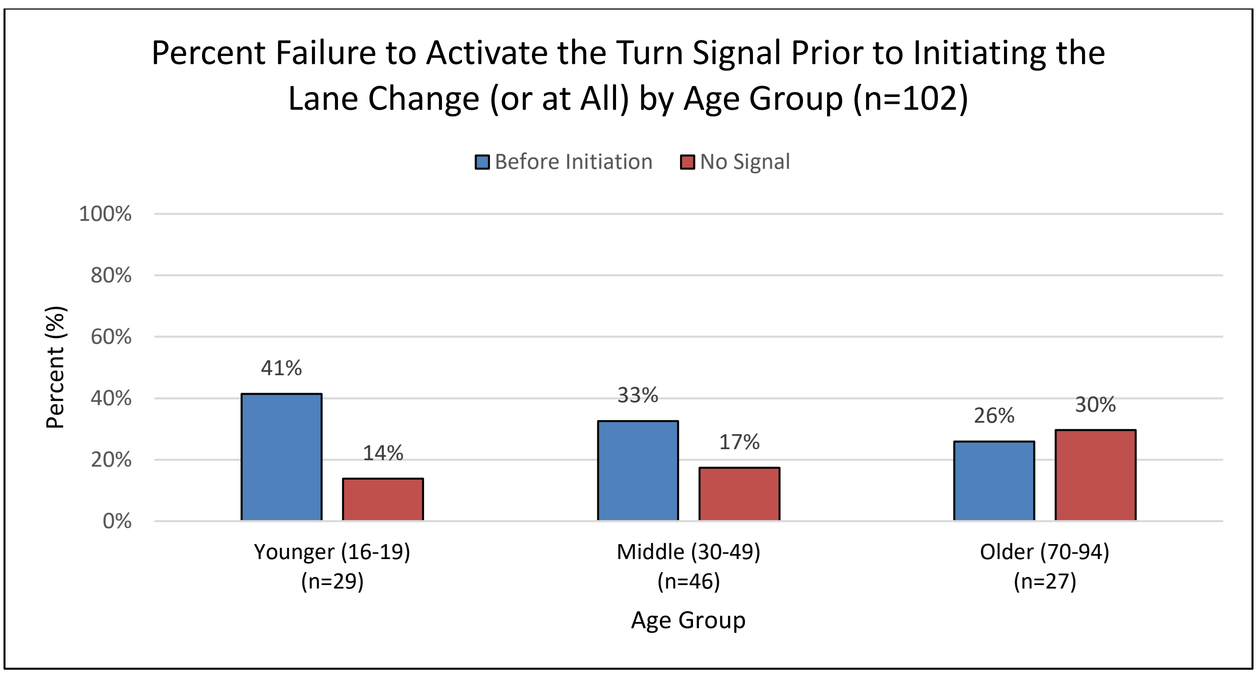


Figure 181. Chart. Turn signal activation prior to initiation for interrupted lane changes.

Cut-Off Errors

Table 7. Percentage of interrupted lane change events where driver cut off a trailing vehicle in the destination lane.

Age Group	Did Not Cut Off	Cut Off	Unable to Determine
Younger (16–19)	71%	19%	10%
Middle-Aged (30–49)	62%	27%	11%
Older (70–94)	68%	28%	4%

Level of Service

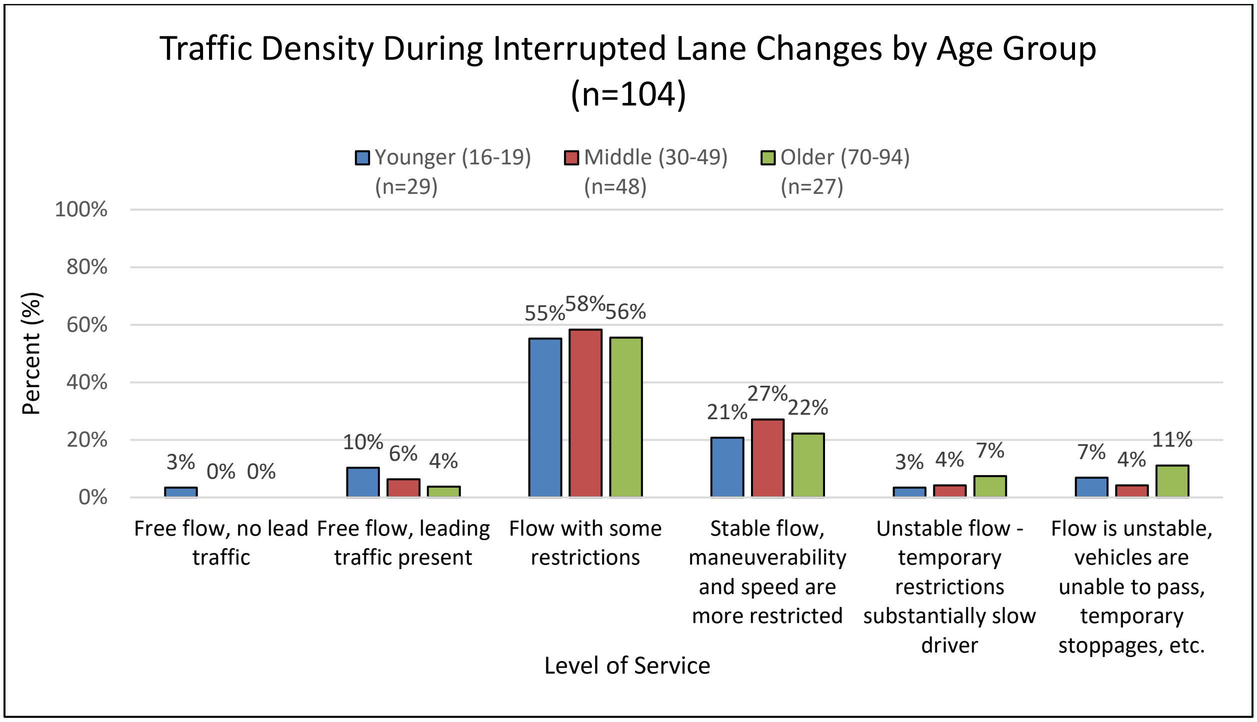


Figure 182. Chart. Traffic density by age group for interrupted lane changes.

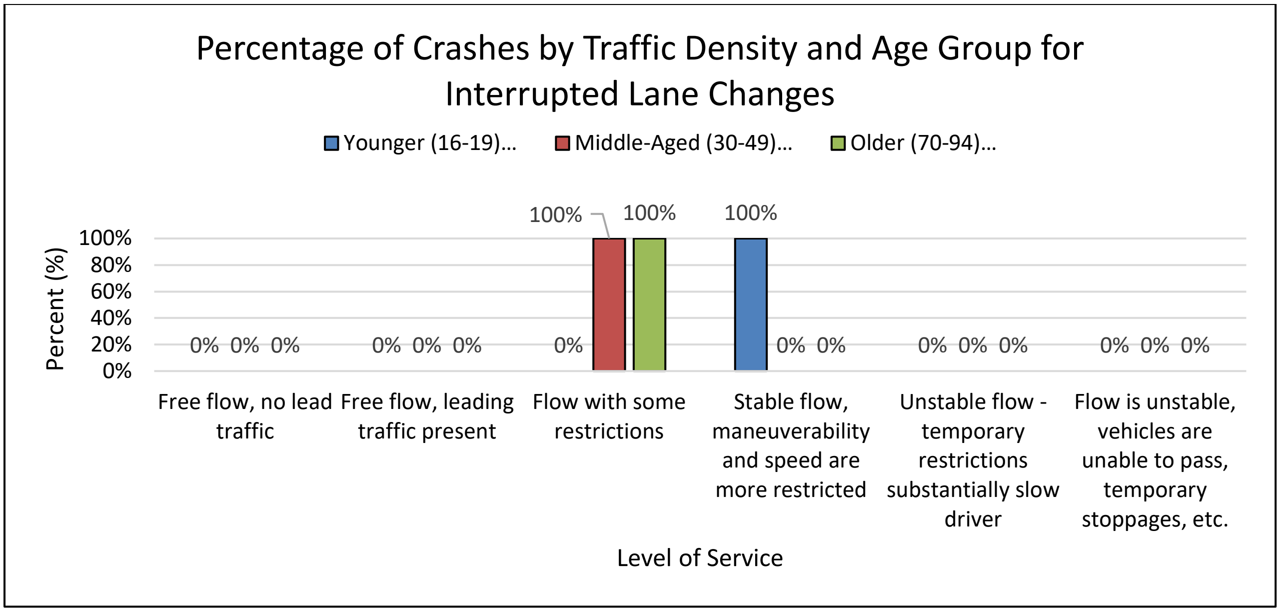


Figure 183. Chart. Percentage of crashes by traffic density for interrupted lane changes.

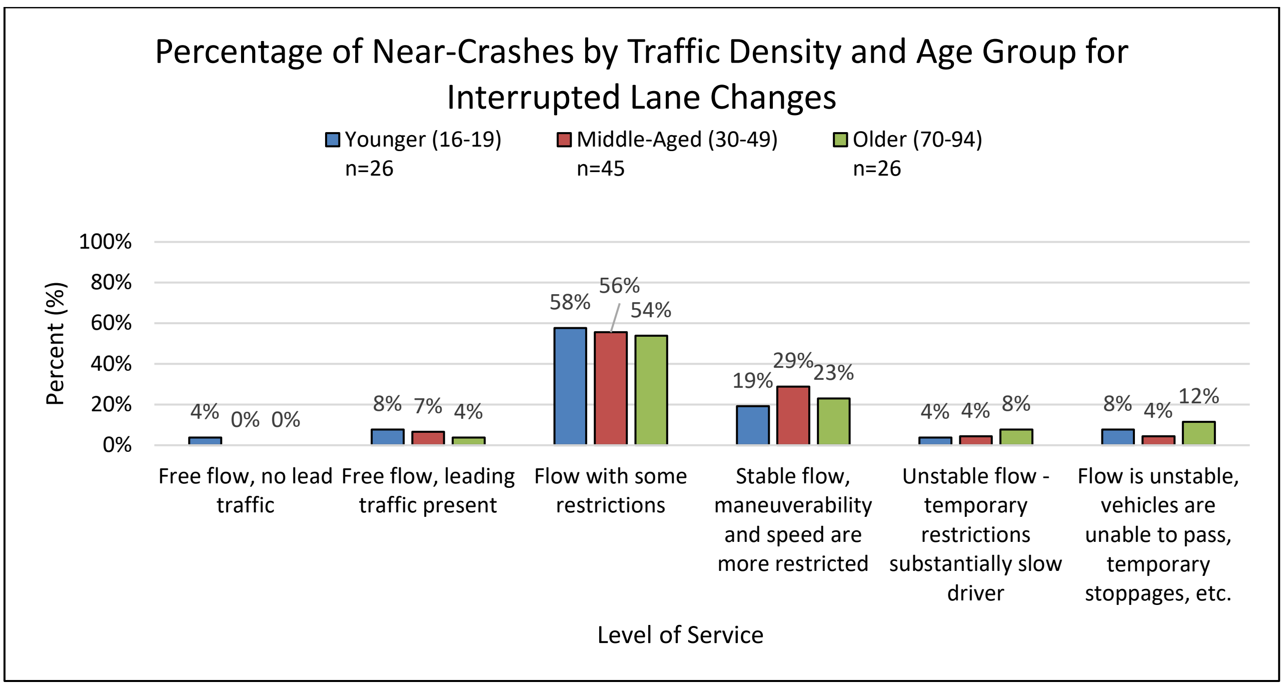


Figure 184. Chart. Percentage of near-crashes by traffic density for interrupted lane changes.

Passengers

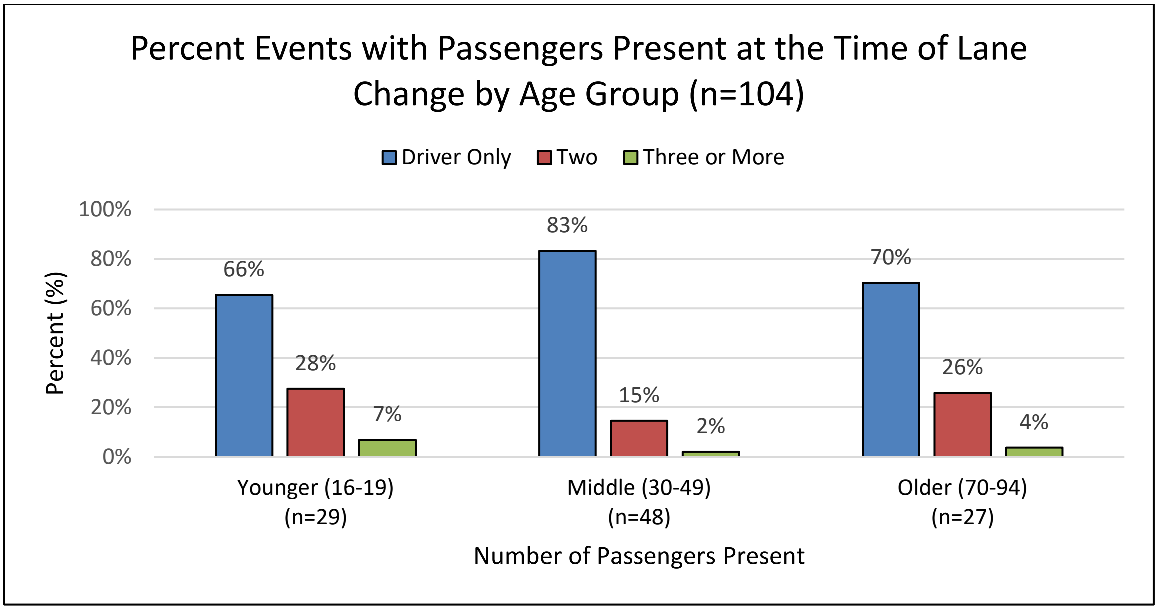


Figure 185. Chart. Passengers present by age group for interrupted lane changes.

Day of Week

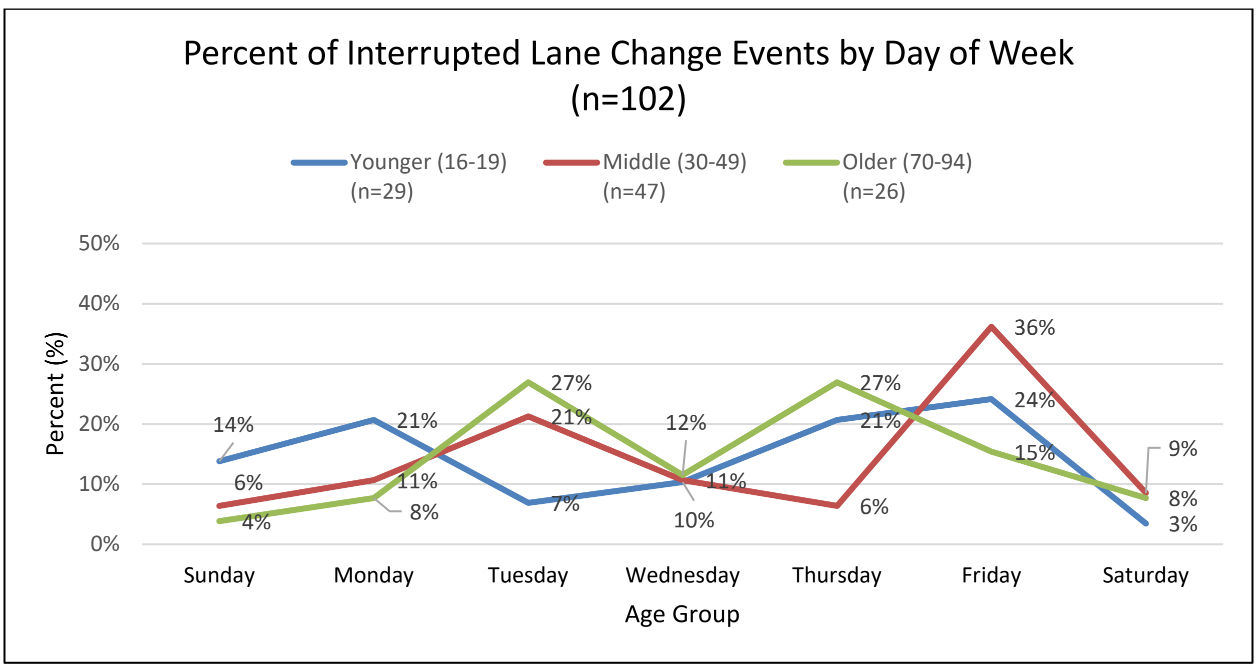


Figure 186. Chart. Percentage of lane changes by day of week for interrupted lane changes.

Time of Day

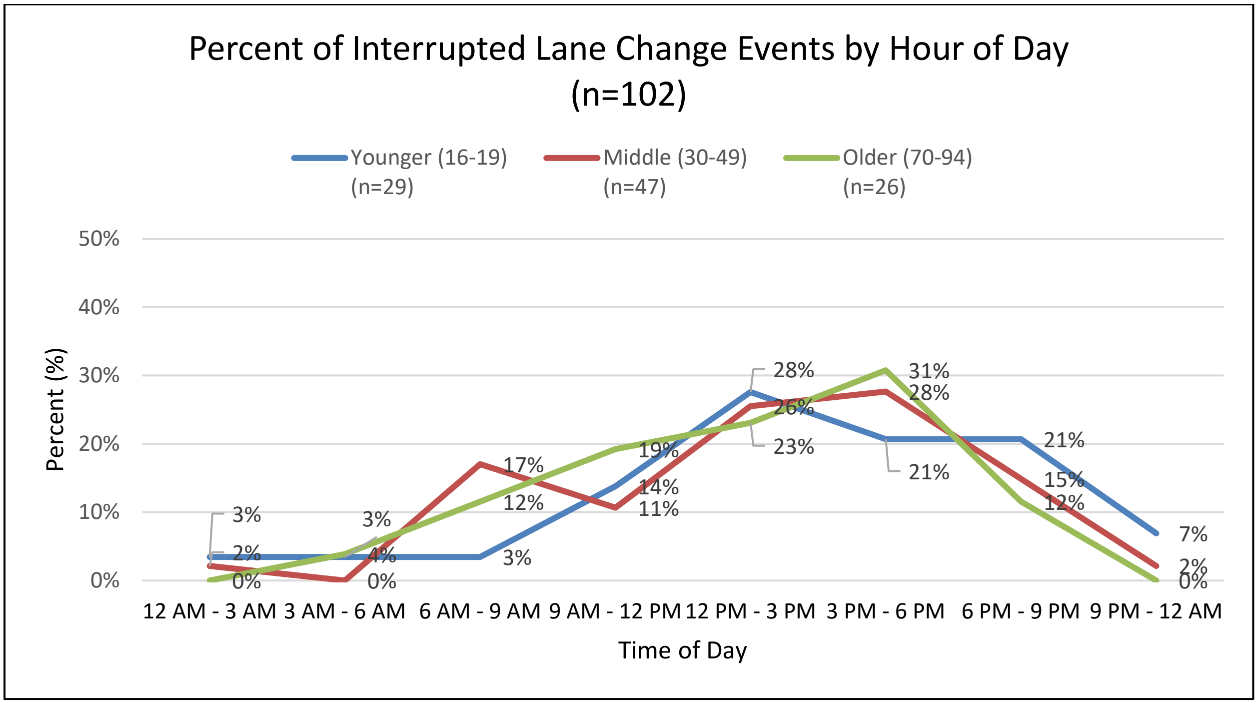


Figure 187. Chart. Percentage of lane changes by hour of day for interrupted lane changes.

Conflict Type

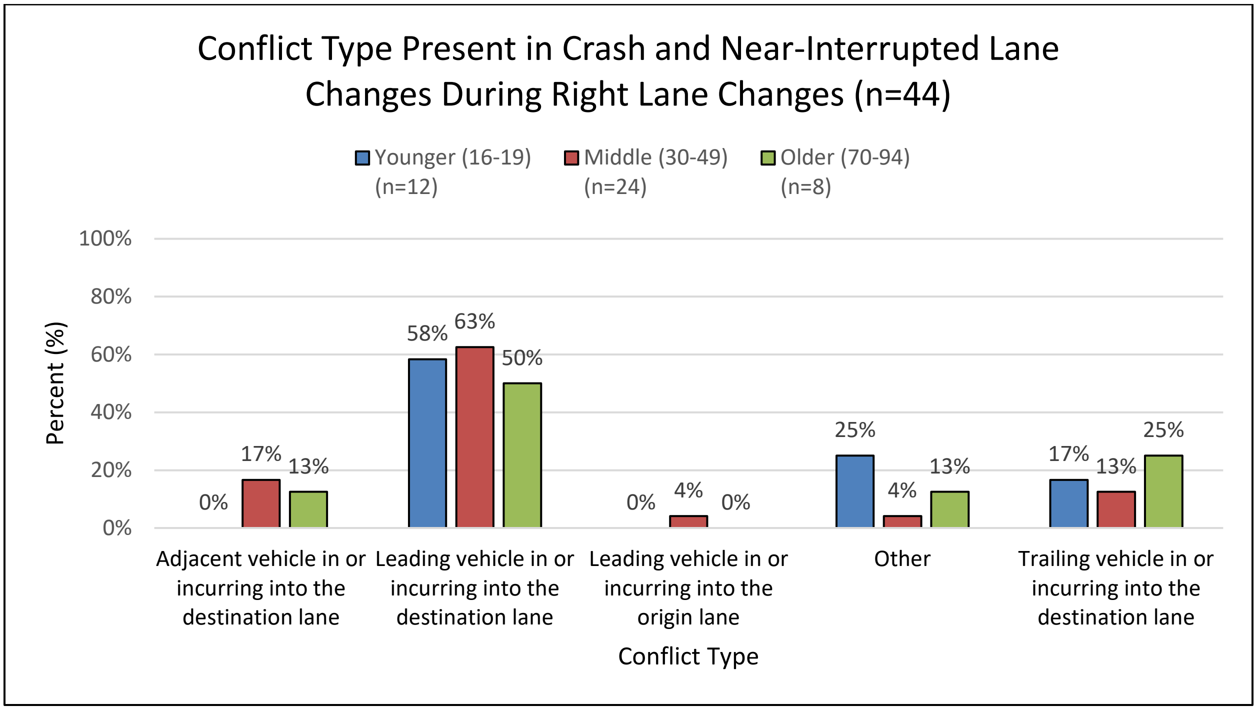


Figure 188. Chart. Conflict type by age group for interrupted right lane changes.

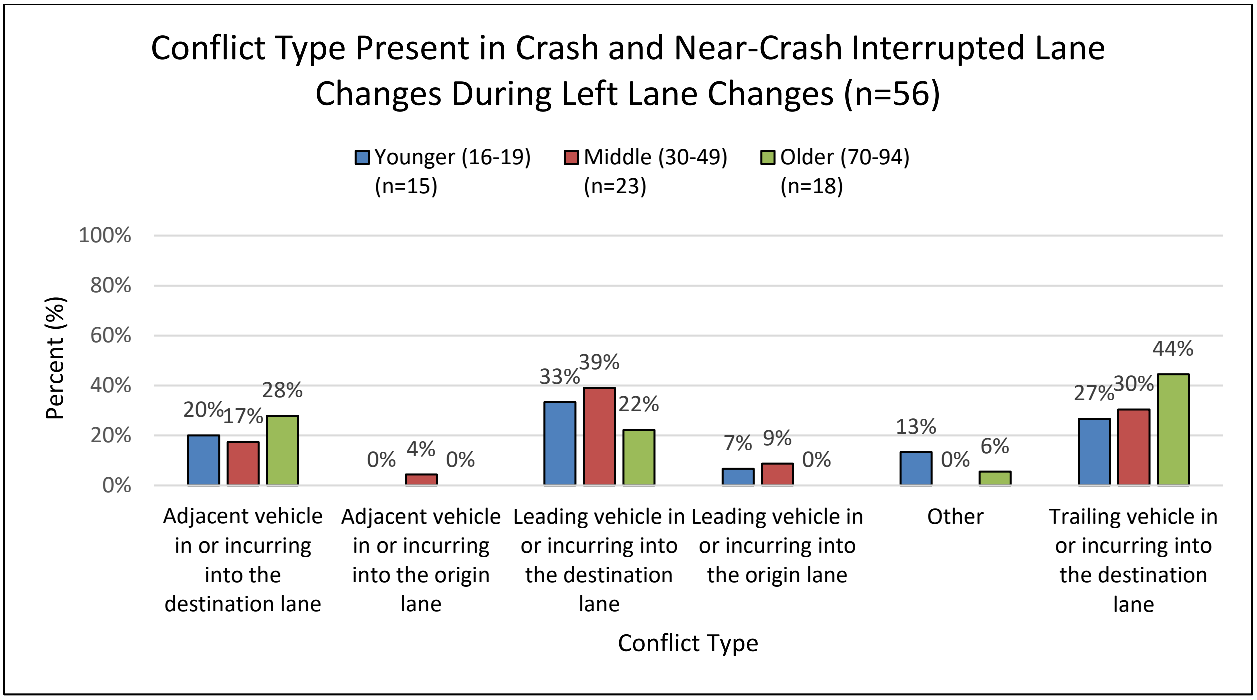


Figure 189. Chart. Conflict type by age group for interrupted left lane changes.

Aggressive or Sporty Driving

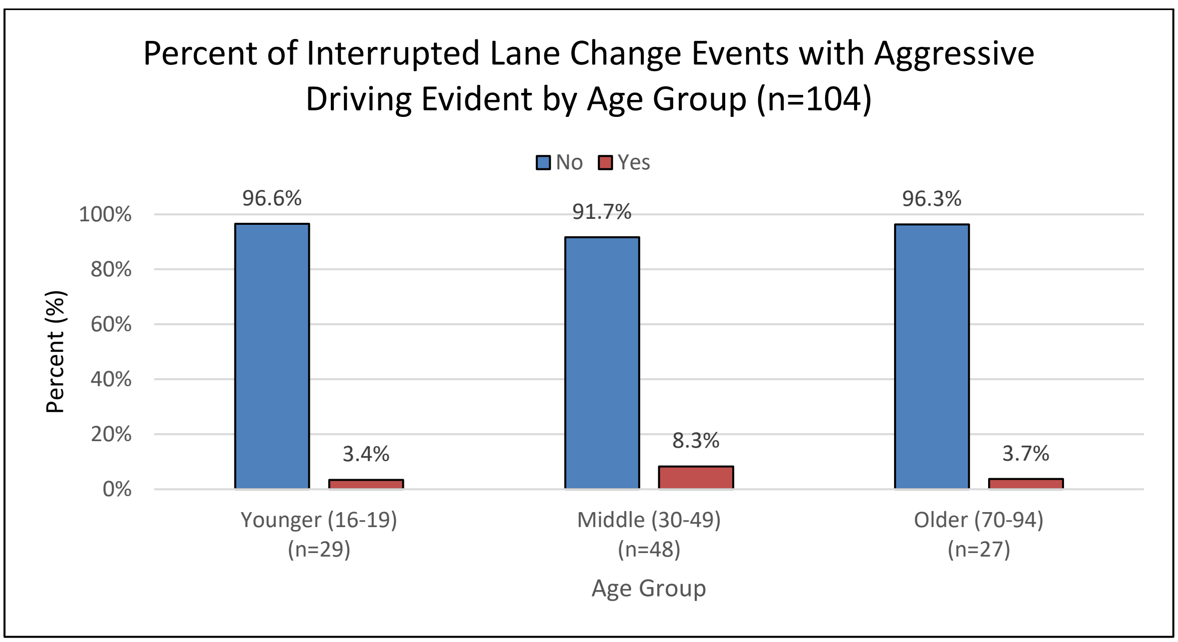


Figure 190. Chart. Aggressive driving present in interrupted lane change events.

Secondary Task Engagement

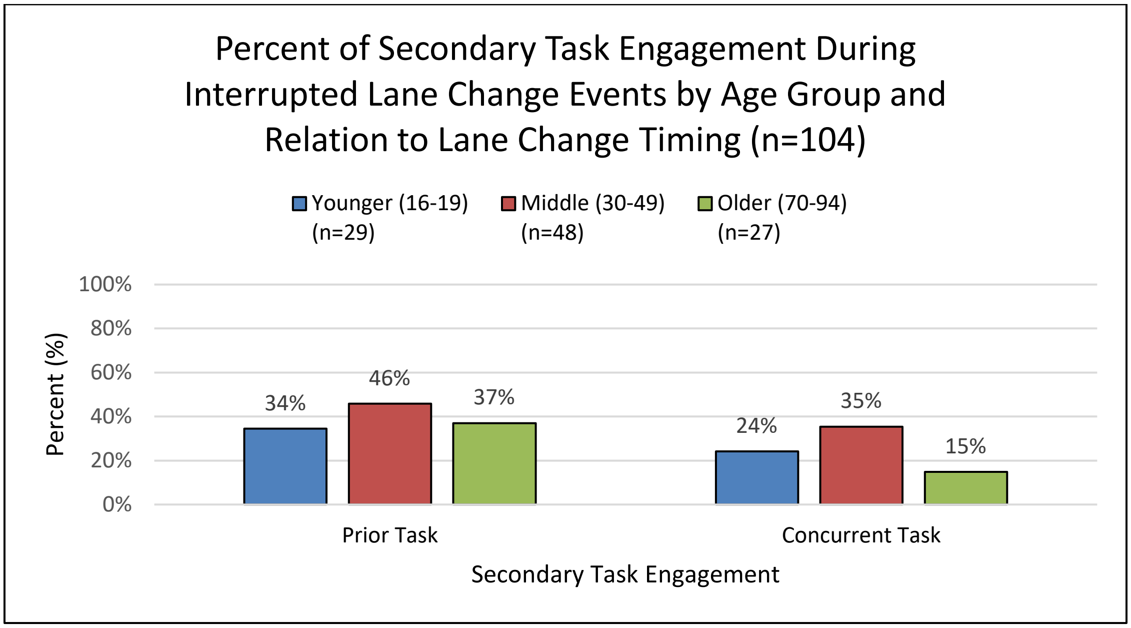


Figure 191. Chart. Secondary task engagement both prior to and during interrupted lane changes.

Direction

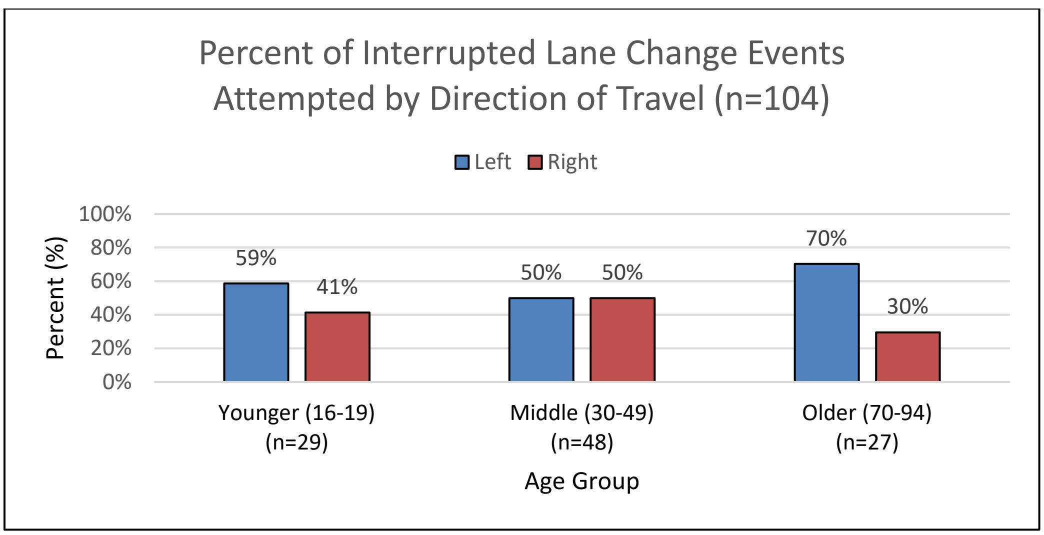


Figure 192. Chart. Percentage of interrupted lane changes directed by age group and direction.

APPENDIX D. RESULTS TABLES

Table 8. Percentage of time glancing at AOIs for uninterrupted left and right lane changes.

	Left Mirror	Left Window	OTS (Left)	Rearview Mirror	Forward
Phase 1					
Younger (16-19)	5%	3%	1%	3%	73%
Middle-Aged (30-49)	6%	4%	1%	1%	75%
Older (70-94)	5%	3%	0%	3%	76%
Phase 2					
Younger (16-19)	8%	4%	3%	1%	66%
Middle-Aged (30-49)	6%	7%	5%	2%	61%
Older (70-94)	11%	4%	0%	2%	70%
Phase 3					
Younger (16-19)	2%	3%	0%	3%	76%
Middle-Aged (30-49)	2%	1%	0%	2%	81%
Older (70-94)	2%	2%	0%	0%	85%

	Right Window/Mirror	OTS (Right)	Rearview Mirror	Forward
Phase 1				
Younger (16-19)	4%	1%	7%	71%
Middle-Aged (30-49)	5%	1%	5%	70%
Older (70-94)	4%	0%	8%	73%
Phase 2				
Younger (16-19)	4%	4%	7%	69%
Middle-Aged (30-49)	6%	3%	5%	67%
Older (70-94)	8%	1%	8%	68%
Phase 3				
Younger (16-19)	1%	0%	3%	82%
Middle-Aged (30-49)	1%	0%	4%	82%
Older (70-94)	0%	0%	4%	84%

Table 9. Percentage of time glancing at AOIs for interrupted left and right lane changes.

	Left Mirror	Left Window	OTS (Left)	Rearview Mirror	Forward
Phase 1					
Younger (16-19)	5%	3%	3%	0%	71%
Middle-Aged (30-49)	10%	3%	1%	8%	62%
Older (70-94)	17%	0%	1%	1%	65%
Phase 2					
Younger (16-19)	6%	4%	11%	2%	57%
Middle-Aged (30-49)	18%	5%	4%	1%	53%
Older (70-94)	23%	6%	3%	0%	46%
Phase 3					
Younger (16-19)	1%	3%	4%	0%	66%
Middle-Aged (30-49)	8%	10%	2%	2%	57%
Older (70-94)	4%	5%	1%	3%	74%

	Right Window/Mirror	OTS (Right)	Rearview Mirror	Forward
Phase 1				
Younger (16-19)	6%	1%	1%	77%
Middle-Aged (30-49)	10%	0%	6%	67%
Older (70-94)	3%	0%	9%	78%
Phase 2				
Younger (16-19)	11%	5%	9%	57%
Middle-Aged (30-49)	15%	4%	6%	60%
Older (70-94)	13%	4%	14%	52%
Phase 3				
Younger (16-19)	5%	0%	2%	66%
Middle-Aged (30-49)	3%	0%	3%	69%
Older (70-94)	7%	0%	2%	51%

Table 10. Percentage of glances to AOIs for uninterrupted left and right lane changes.

	Left Mirror	Left Window	OTS (Left)	Rearview Mirror	Forward
Phase 1					
Younger (16-19)	8%	5%	1%	4%	30%
Middle-Aged (30-49)	10%	6%	2%	3%	30%
Older (70-94)	8%	4%	0%	6%	33%
Phase 2					
Younger (16-19)	10%	5%	5%	2%	33%
Middle-Aged (30-49)	8%	7%	6%	3%	30%
Older (70-94)	12%	5%	1%	3%	35%
Phase 3					
Younger (16-19)	3%	2%	0%	4%	32%
Middle-Aged (30-49)	2%	2%	0%	4%	40%
Older (70-94)	4%	2%	0%	1%	35%

	Right Window/Mirror	OTS (Right)	Rearview Mirror	Forward
Phase 1				
Younger (16-19)	7%	2%	9%	29%
Middle-Aged (30-49)	7%	2%	8%	29%
Older (70-94)	6%	1%	12%	31%
Phase 2				
Younger (16-19)	7%	5%	10%	31%
Middle-Aged (30-49)	7%	4%	7%	31%
Older (70-94)	10%	1%	9%	33%
Phase 3				
Younger (16-19)	1%	0%	5%	34%
Middle-Aged (30-49)	1%	0%	5%	35%
Older (70-94)	0%	0%	4%	33%

Table 11. Percentage of glances to AOIs for interrupted left and right lane changes.

	Left Mirror	Left Window	OTS (Left)	Rearview Mirror	Forward
Phase 1					
Younger (16-19)	6%	3%	3%	0%	29%
Middle-Aged (30-49)	12%	3%	1%	6%	27%
Older (70-94)	18%	1%	1%	2%	28%
Phase 2					
Younger (16-19)	12%	6%	9%	0%	46%
Middle-Aged (30-49)	18%	3%	4%	2%	30%
Older (70-94)	20%	4%	1%	1%	26%
Phase 3					
Younger (16-19)	2%	4%	7%	2%	18%
Middle-Aged (30-49)	11%	6%	2%	4%	31%
Older (70-94)	9%	5%	2%	3%	30%

	Right Window/Mirror	OTS (Right)	Rearview Mirror	Forward
Phase 1				
Younger (16-19)	13%	2%	3%	32%
Middle-Aged (30-49)	10%	1%	7%	28%
Older (70-94)	6%	0%	14%	27%
Phase 2				
Younger (16-19)	11%	8%	4%	34%
Middle-Aged (30-49)	14%	4%	5%	29%
Older (70-94)	12%	2%	16%	24%
Phase 3				
Younger (16-19)	9%	3%	5%	23%
Middle-Aged (30-49)	4%	0%	6%	38%
Older (70-94)	6%	0%	3%	31%

Table 12. Average glance duration to AOIs for uninterrupted left and right lane changes.

	Left Mirror	Left Window	OTS (Left)	Rearview Mirror	Forward
Phase 1					
Younger (16-19)	0.7	0.6	0.5	0.6	3.7
Middle-Aged (30-49)	0.7	0.6	0.4	0.5	3.7
Older (70-94)	0.8	0.9	0.6	0.5	3.8
Phase 2					
Younger (16-19)	0.5	0.4	0.3	0.4	1.5
Middle-Aged (30-49)	0.6	0.6	0.4	0.3	1.5
Older (70-94)	0.8	0.5	0.3	0.4	1.7
Phase 3					
Younger (16-19)	0.5	0.8	0.3	0.6	2.0
Middle-Aged (30-49)	0.5	0.5	0.1	0.4	2.2
Older (70-94)	0.5	0.8	0.0	0.5	2.8

	Right Window/Mirror	OTS (Right)	Rearview Mirror	Forward
Phase 1				
Younger (16-19)	0.7	0.3	0.8	3.5
Middle-Aged (30-49)	0.8	0.5	0.7	3.6
Older (70-94)	0.7	0.4	0.8	3.6
Phase 2				
Younger (16-19)	0.5	0.4	0.5	2.0
Middle-Aged (30-49)	0.5	0.4	0.5	2.0
Older (70-94)	0.7	0.3	0.8	2.5
Phase 3				
Younger (16-19)	0.7	0.0	0.3	2.0
Middle-Aged (30-49)	0.7	0.6	0.5	1.9
Older (70-94)	0.1	0.4	0.8	2.3

Table 13. Average glance duration to AOIs for interrupted left and right lane changes.

	Left Mirror	Left Window	OTS (Left)	Rearview Mirror	Forward
Phase 1					
Younger (16-19)	0.6	0.6	0.7	0.0	3.5
Middle-Aged (30-49)	0.7	0.6	0.9	1.3	3.1
Older (70-94)	1.2	0.3	0.5	0.3	3.2
Phase 2					
Younger (16-19)	0.3	0.3	0.5	0.3	1.4
Middle-Aged (30-49)	0.6	0.8	0.3	0.2	1.3
Older (70-94)	0.7	0.9	0.7	0.2	1.1
Phase 3					
Younger (16-19)	0.1	0.4	1.0	0.0	2.0
Middle-Aged (30-49)	0.7	1.1	0.8	0.2	1.3
Older (70-94)	0.2	0.6	0.3	0.4	1.9

	Right Window/Mirror	OTS (Right)	Rearview Mirror	Forward
Phase 1				
Younger (16-19)	0.7	0.6	0.3	4.0
Middle-Aged (30-49)	1.2	0.3	0.6	3.3
Older (70-94)	0.6	0.0	0.7	3.9
Phase 2				
Younger (16-19)	0.7	0.4	2.7	1.6
Middle-Aged (30-49)	0.7	0.5	0.7	1.4
Older (70-94)	0.5	0.9	0.4	1.4
Phase 3				
Younger (16-19)	0.4	0.1	0.3	2.6
Middle-Aged (30-49)	0.6	0.0	0.3	1.7
Older (70-94)	0.8	0.0	0.4	1.3

Table 14. Average number of glances to AOIs for uninterrupted left and right lane changes.

	Left Mirror	Left Window	OTS (Left)	Rearview Mirror	Forward
Phase 1					
Younger (16-19)	1.7	1.1	1.0	1.2	2.0
Middle-Aged (30-49)	1.4	1.3	1.1	1.3	1.9
Older (70-94)	1.5	1.3	1.0	1.3	1.9
Phase 2					
Younger (16-19)	1.2	1.1	1.0	1.1	1.4
Middle-Aged (30-49)	1.3	1.2	1.1	1.1	1.5
Older (70-94)	1.4	1.0	1.0	1.0	1.4
Phase 3					
Younger (16-19)	1.2	1.1	1.0	1.1	1.4
Middle-Aged (30-49)	1.3	1.2	1.1	1.1	1.4
Older (70-94)	1.4	1.0	1.0	1.0	1.3

	Right Window/Mirror	OTS (Right)	Rearview Mirror	Forward
Phase 1				
Younger (16-19)	1.4	1.0	1.4	2.0
Middle-Aged (30-49)	1.4	1.0	1.5	1.9
Older (70-94)	1.4	1.0	1.5	2.0
Phase 2				
Younger (16-19)	1.2	1.0	1.2	1.5
Middle-Aged (30-49)	1.1	1.0	1.2	1.7
Older (70-94)	1.2	1.0	1.4	1.8
Phase 3				
Younger (16-19)	1.0	0.0	1.0	1.3
Middle-Aged (30-49)	1.0	1.0	1.1	1.3
Older (70-94)	1.0	1.0	1.3	1.3

Table 15. Average number of glances to AOIs for interrupted left and right lane changes.

	Left Mirror	Left Window	OTS (Left)	Rearview Mirror	Forward
Phase 1					
Younger (16-19)	1.2	1.3	1.3	0.0	1.9
Middle-Aged (30-49)	1.3	2.0	1.0	1.6	1.9
Older (70-94)	1.8	1.3	1.0	1.0	1.8
Phase 2					
Younger (16-19)	1.2	1.0	1.2	0.0	1.8
Middle-Aged (30-49)	1.4	1.0	1.0	1.0	1.6
Older (70-94)	1.4	1.3	1.0	1.0	1.4
Phase 3					
Younger (16-19)	1.0	1.0	1.5	1.0	2.5
Middle-Aged (30-49)	1.6	1.2	1.0	1.0	2.7
Older (70-94)	1.1	1.3	1.0	1.0	2.9

	Right Window/Mirror	OTS (Right)	Rearview Mirror	Forward
Phase 1				
Younger (16-19)	1.5	1.0	1.0	1.6
Middle-Aged (30-49)	1.8	1.0	1.2	2.1
Older (70-94)	1.5	0.0	1.4	1.6
Phase 2				
Younger (16-19)	2.0	1.3	2.0	1.5
Middle-Aged (30-49)	1.3	1.0	1.2	1.3
Older (70-94)	1.2	1.0	1.1	1.5
Phase 3				
Younger (16-19)	1.2	1.0	1.3	2.9
Middle-Aged (30-49)	1.3	0.0	1.2	2.7
Older (70-94)	1.0	0.0	1.0	2.6

Table 16. Average glance probability for uninterrupted left and right lane changes.

	Forward	Left Mirror	Left Window	OTS (Left)	Rearview Mirror
Phase 1					
Younger (16-19)	0.63	0.09	0.07	0.02	0.05
Middle-Aged (30-49)	0.61	0.14	0.08	0.03	0.03
Older (70-94)	0.65	0.10	0.05	0.00	0.09
Phase 2					
Younger (16-19)	0.62	0.13	0.06	0.07	0.03
Middle-Aged (30-49)	0.61	0.10	0.10	0.08	0.04
Older (70-94)	0.68	0.14	0.07	0.01	0.04
Phase 3					
Younger (16-19)	0.74	0.04	0.04	0.00	0.04
Middle-Aged (30-49)	0.83	0.02	0.02	0.01	0.04
Older (70-94)	0.87	0.05	0.02	0.00	0.01

	Forward	Right Window/Mirror	OTS (Right)	Rearview Mirror
Phase 1				
Younger (16-19)	0.59	0.09	0.02	0.12
Middle-Aged (30-49)	0.59	0.10	0.04	0.10
Older (70-94)	0.63	0.08	0.01	0.16
Phase 2				
Younger (16-19)	0.62	0.09	0.06	0.12
Middle-Aged (30-49)	0.60	0.11	0.06	0.11
Older (70-94)	0.64	0.13	0.02	0.12
Phase 3				
Younger (16-19)	0.81	0.01	0.00	0.07
Middle-Aged (30-49)	0.82	0.01	0.00	0.07
Older (70-94)	0.86	0.01	0.00	0.05

Table 17. Average glance probability for interrupted left and right lane changes.

	Forward	Left Mirror	Left Window	OTS (Left)	Rearview Mirror
Phase 1					
Younger (16-19)	0.62	0.11	0.05	0.05	0.00
Middle-Aged (30-49)	0.51	0.18	0.06	0.01	0.10
Older (70-94)	0.55	0.27	0.01	0.01	0.03
Phase 2					
Younger (16-19)	0.53	0.13	0.10	0.16	0.03
Middle-Aged (30-49)	0.49	0.26	0.07	0.07	0.02
Older (70-94)	0.50	0.30	0.04	0.03	0.02
Phase 3					
Younger (16-19)	0.40	0.05	0.05	0.04	0.00
Middle-Aged (30-49)	0.57	0.15	0.07	0.01	0.06
Older (70-94)	0.56	0.19	0.04	0.01	0.04

	Forward	Right Window/Mirror	OTS (Right)	Rearview Mirror
Phase 1				
Younger (16-19)	0.65	0.18	0.02	0.04
Middle-Aged (30-49)	0.57	0.15	0.02	0.12
Older (70-94)	0.56	0.06	0.00	0.25
Phase 2				
Younger (16-19)	0.61	0.15	0.12	0.04
Middle-Aged (30-49)	0.59	0.20	0.06	0.07
Older (70-94)	0.43	0.19	0.04	0.27
Phase 3				
Younger (16-19)	0.45	0.10	0.01	0.08
Middle-Aged (30-49)	0.70	0.03	0.00	0.07
Older (70-94)	0.61	0.07	0.00	0.03

Table 18. Average entropy (bits) for uninterrupted left and right lane changes.

	Collapsed Across Direction	Left Lane Changes	Right Lane Changes
Phase 1			
Younger (16-19)	0.76	0.72	0.81
Middle-Aged (30-49)	0.72	0.69	0.76
Older (70-94)	0.67	0.61	0.73
Phase 2			
Younger (16-19)	0.70	0.68	0.72
Middle-Aged (30-49)	0.79	0.77	0.80
Older (70-94)	0.65	0.61	0.70
Phase 3			
Younger (16-19)	0.44	0.51	0.37
Middle-Aged (30-49)	0.37	0.38	0.36
Older (70-94)	0.32	0.34	0.30

Table 19. Average entropy (bits) for interrupted left and right lane changes.

	Collapsed Across Direction	Left Lane Changes	Right Lane Changes
Phase 1			
Younger (16-19)	0.68	0.75	0.58
Middle-Aged (30-49)	0.87	0.88	0.86
Older (70-94)	0.73	0.78	0.62
Phase 2			
Younger (16-19)	0.88	0.96	0.77
Middle-Aged (30-49)	0.81	0.82	0.79
Older (70-94)	1.02	0.95	1.18
Phase 3			
Younger (16-19)	0.81	0.88	0.72
Middle-Aged (30-49)	0.58	0.64	0.52
Older (70-94)	0.74	0.68	0.86

Table 20. Average entropy (bits) for driving-related glances during uninterrupted left and right lane changes.

	Collapsed Across Direction	Left Lane Changes	Right Lane Changes
Phase 1			
Younger (16-19)	0.69	0.65	0.73
Middle-Aged (30-49)	0.69	0.66	0.72
Older (70-94)	0.66	0.61	0.71
Phase 2			
Younger (16-19)	0.68	0.66	0.70
Middle-Aged (30-49)	0.76	0.75	0.78
Older (70-94)	0.63	0.59	0.67
Phase 3			
Younger (16-19)	0.38	0.43	0.33
Middle-Aged (30-49)	0.33	0.34	0.31
Older (70-94)	0.29	0.33	0.25

Table 21. Average entropy (bits) for driving-related glances for interrupted left and right lane changes.

	Collapsed Across Direction	Left Lane Changes	Right Lane Changes
Phase 1			
Younger (16-19)	0.63	0.67	0.58
Middle-Aged (30-49)	0.83	0.88	0.77
Older (70-94)	0.71	0.75	0.62
Phase 2			
Younger (16-19)	0.85	0.90	0.77
Middle-Aged (30-49)	0.79	0.82	0.76
Older (70-94)	1.02	0.95	1.18
Phase 3			
Younger (16-19)	0.79	0.85	0.72
Middle-Aged (30-49)	0.58	0.64	0.52
Older (70-94)	0.74	0.68	0.86

APPENDIX E. TURN SIGNAL USE PIE CHARTS

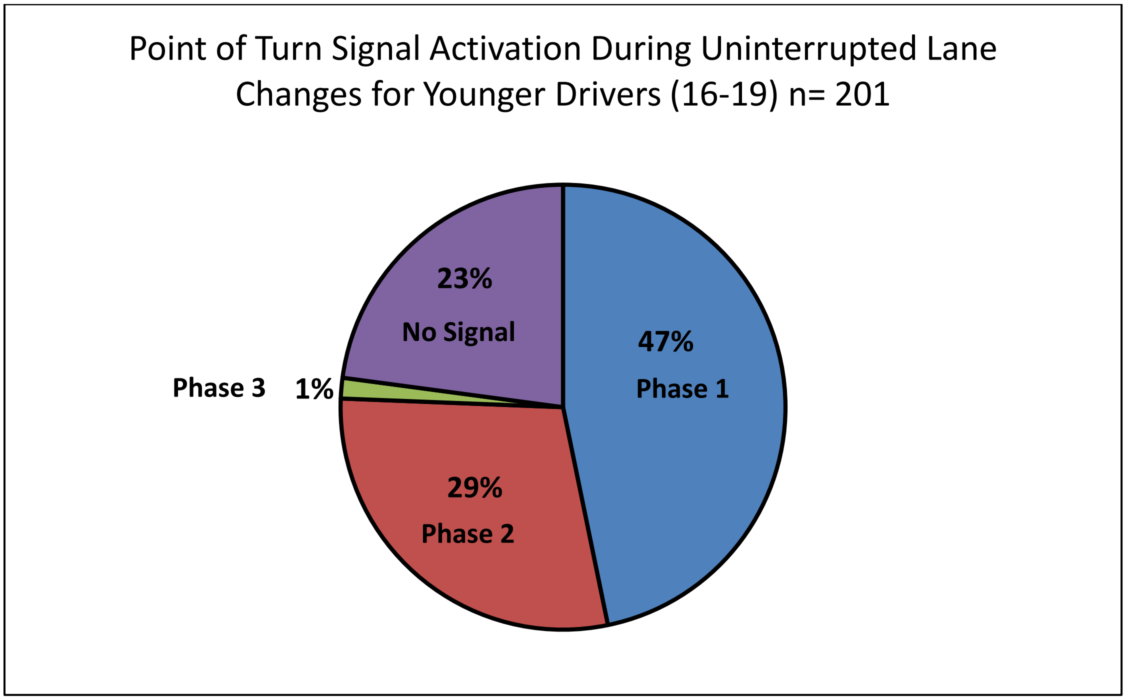


Figure 193. Chart. Point of signal activation by phase for younger drivers during uninterrupted lane changes.

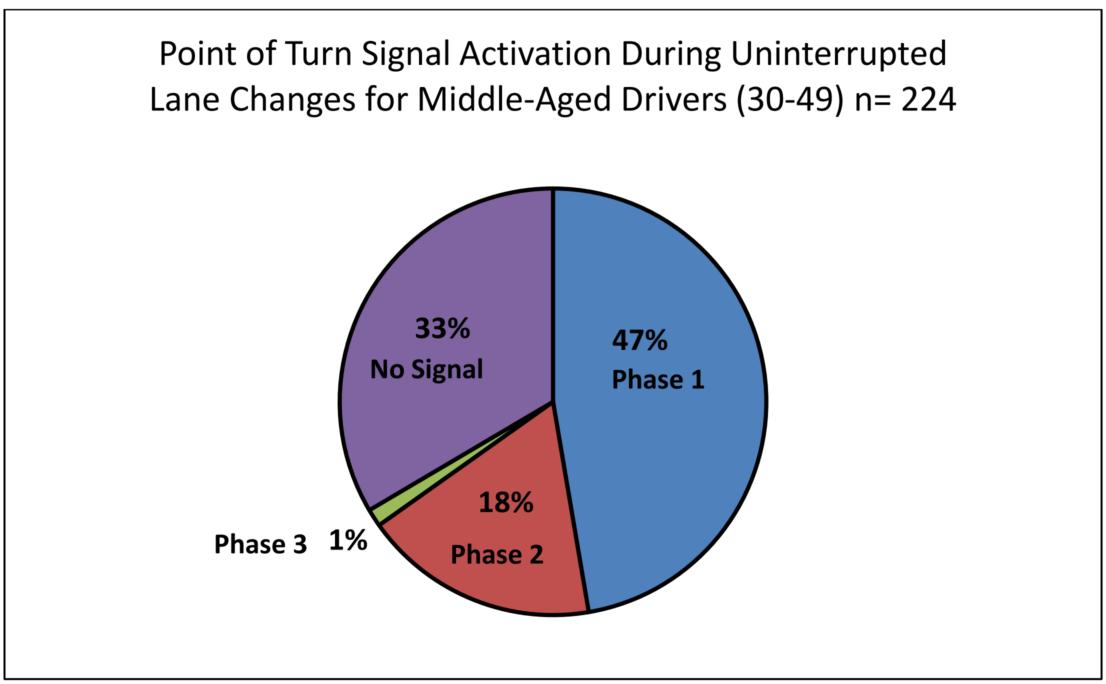


Figure 194. Chart. Point of signal activation by phase for middle-aged drivers during uninterrupted lane changes.

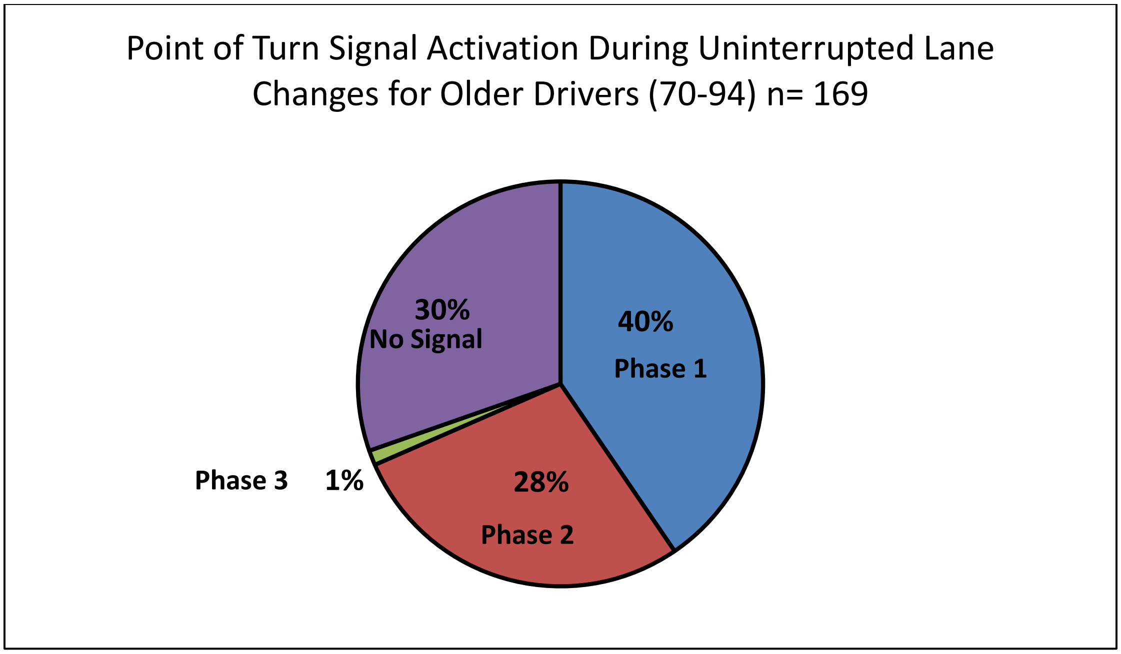


Figure 195. Chart. Point of signal activation by phase for older drivers during uninterrupted lane changes.

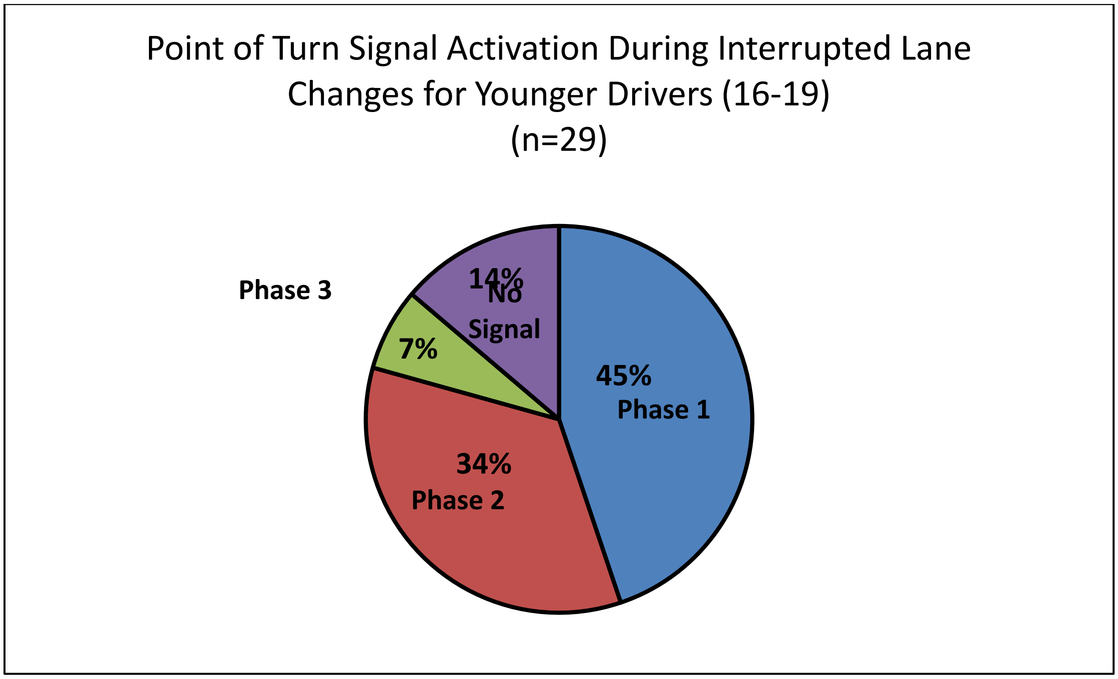


Figure 196. Chart. Point of signal activation by phase for younger drivers during interrupted lane changes.

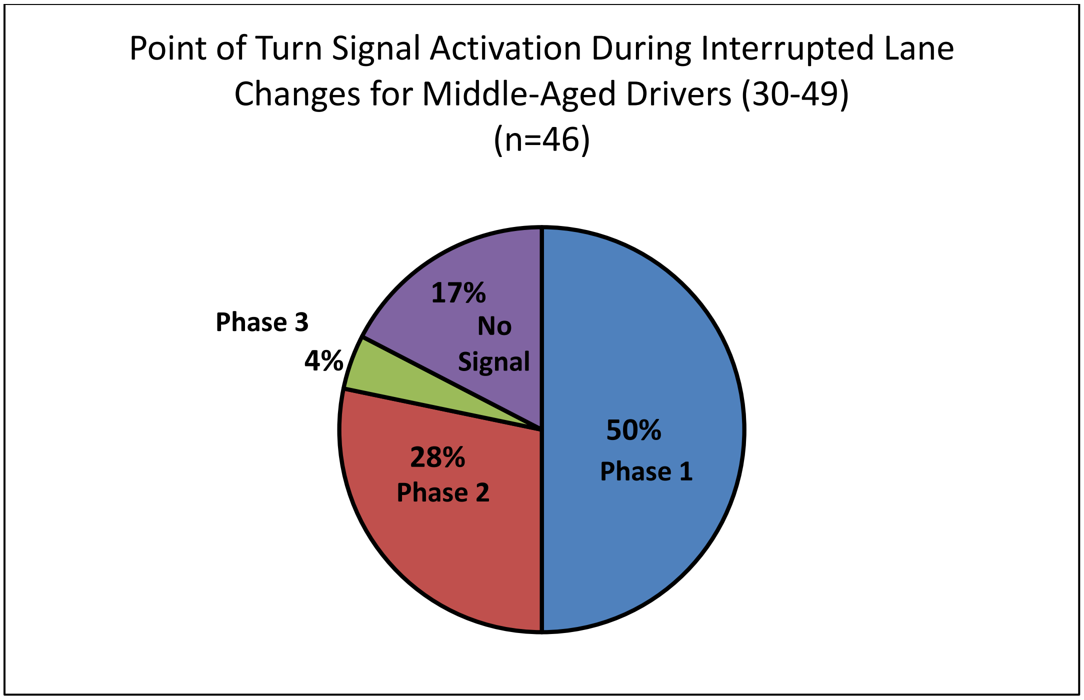


Figure 197. Chart. Point of signal activation by phase for middle-aged drivers during interrupted lane changes.

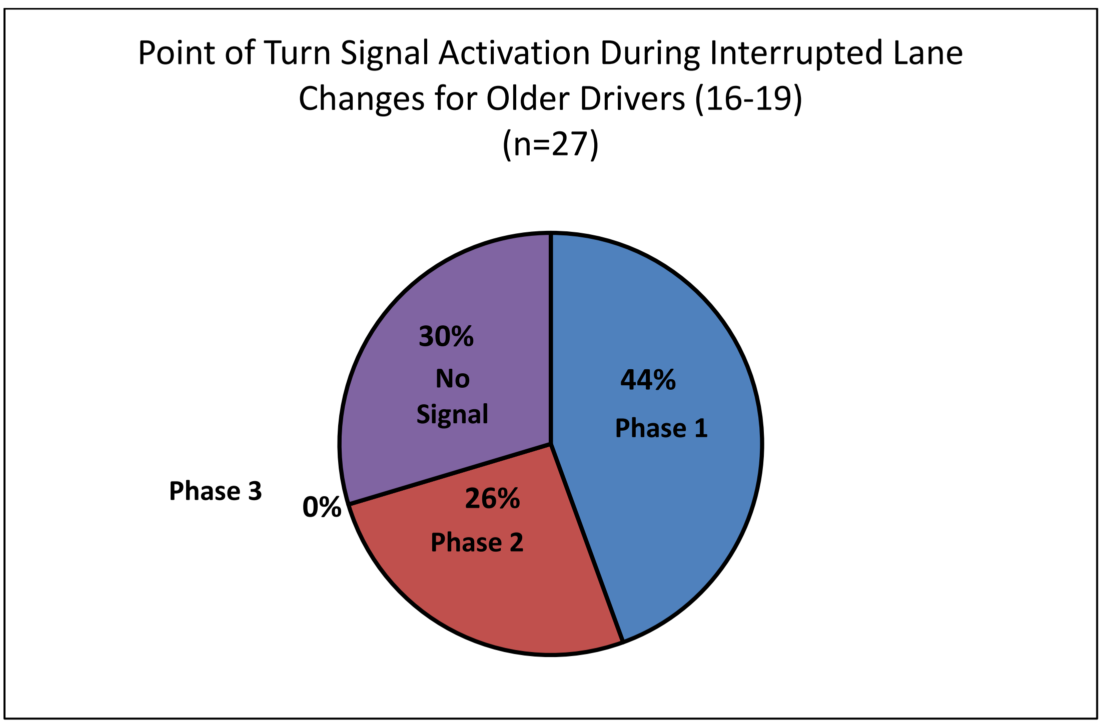


Figure 198.Chart. Point of signal activation by phase for older drivers during interrupted lane changes.

APPENDIX F. SECONDARY TASK PIE CHARTS

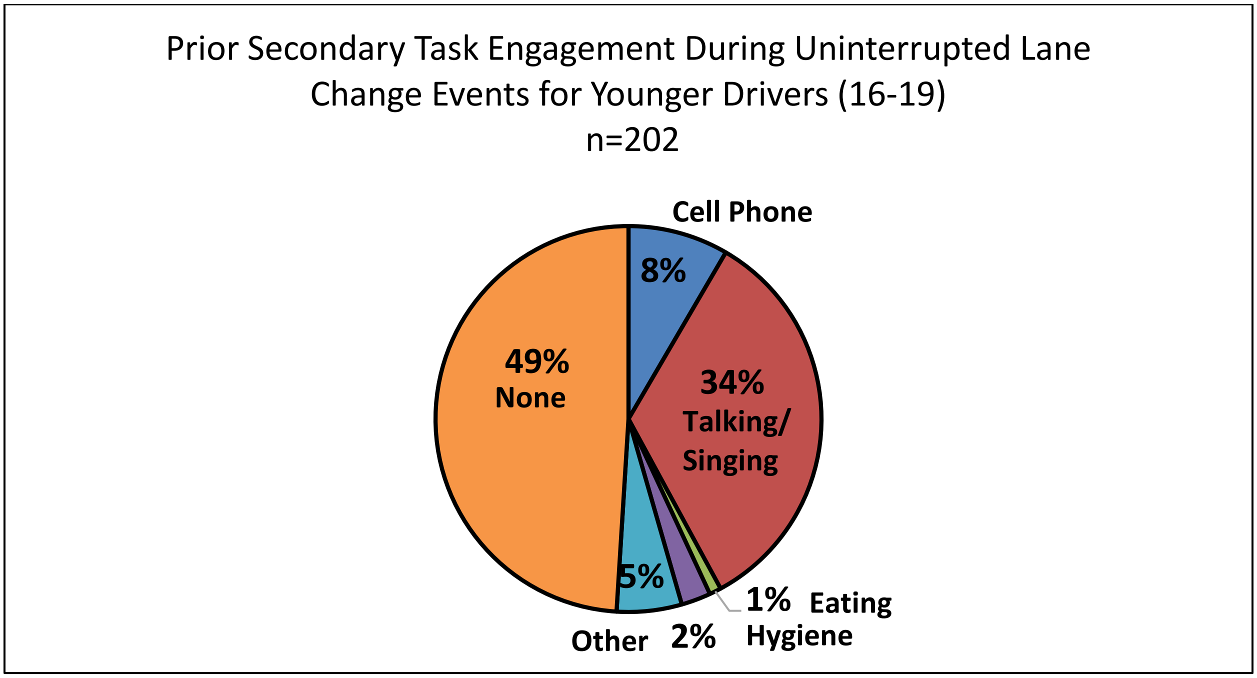


Figure 199. Chart. Prior secondary task engagement for younger drivers during uninterrupted lane changes.

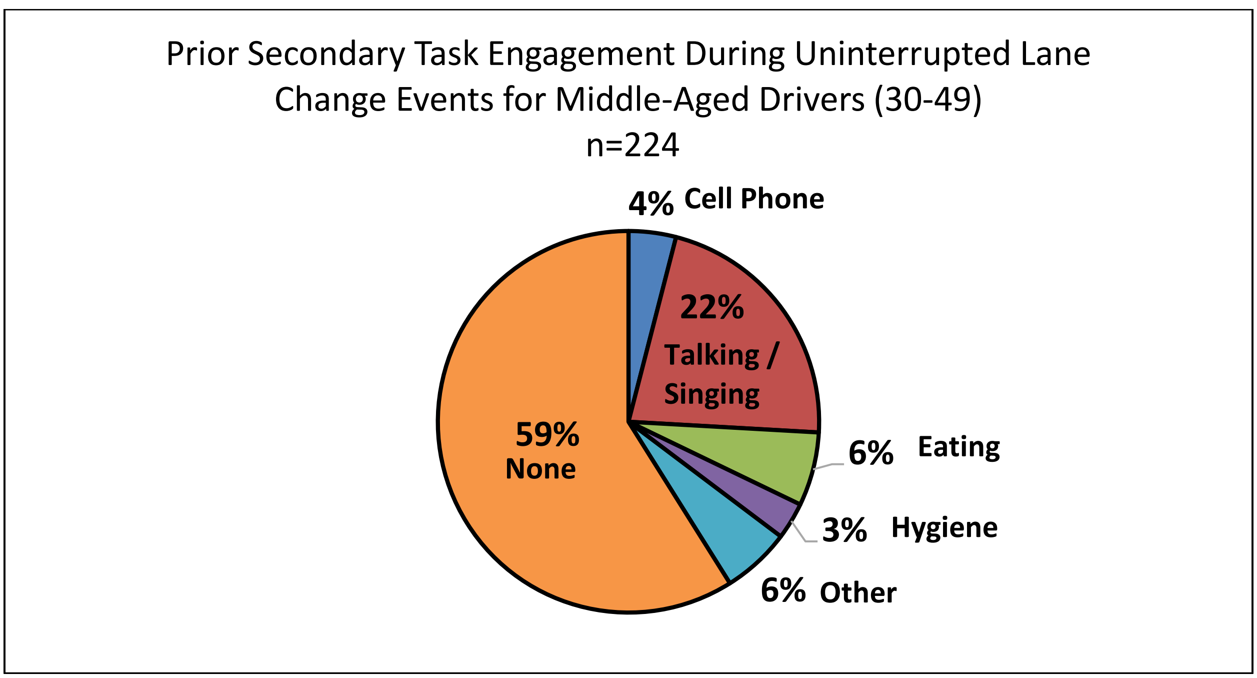


Figure 200. Chart. Prior secondary task engagement for middle-aged drivers during uninterrupted lane changes.

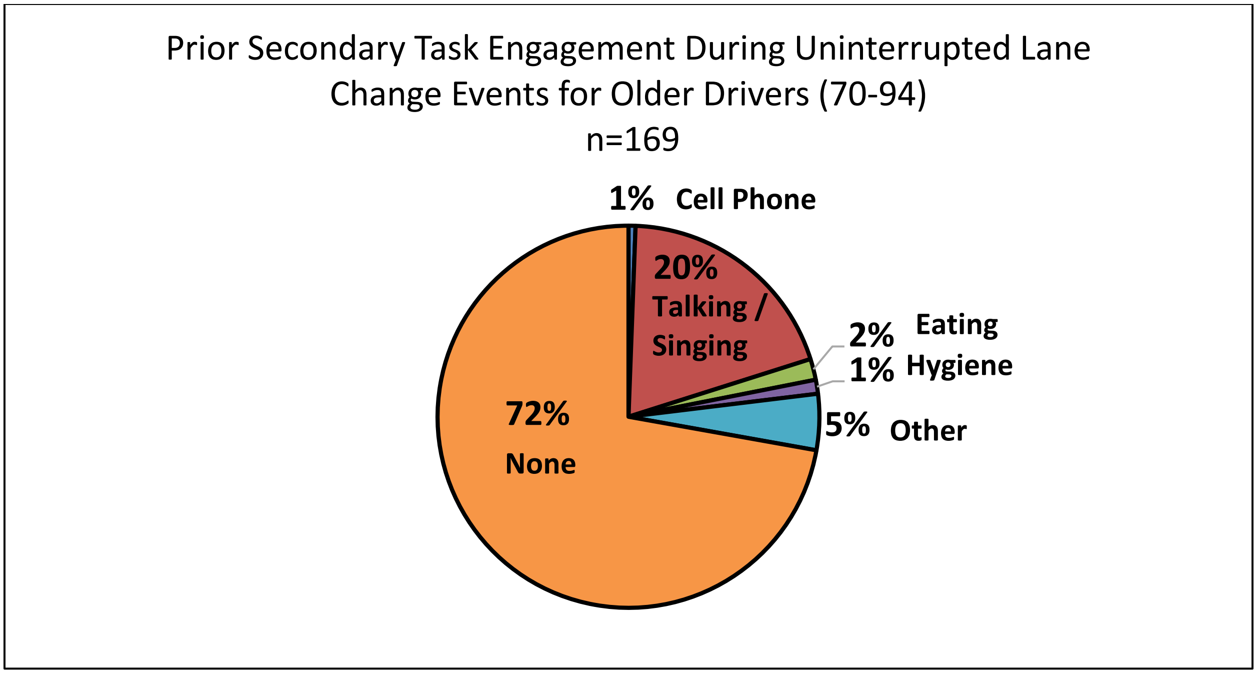


Figure 201. Chart. Prior secondary task engagement for older drivers during uninterrupted lane changes.

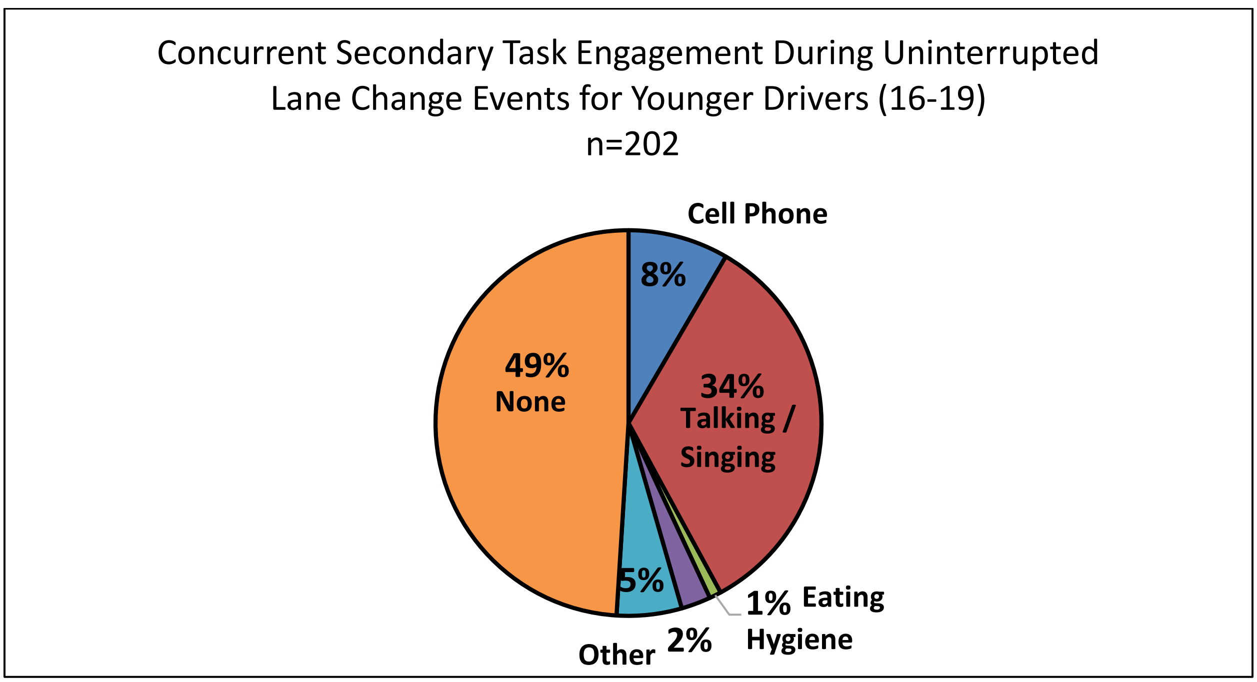


Figure 202. Chart. Concurrent secondary task engagement for younger drivers during uninterrupted lane changes.

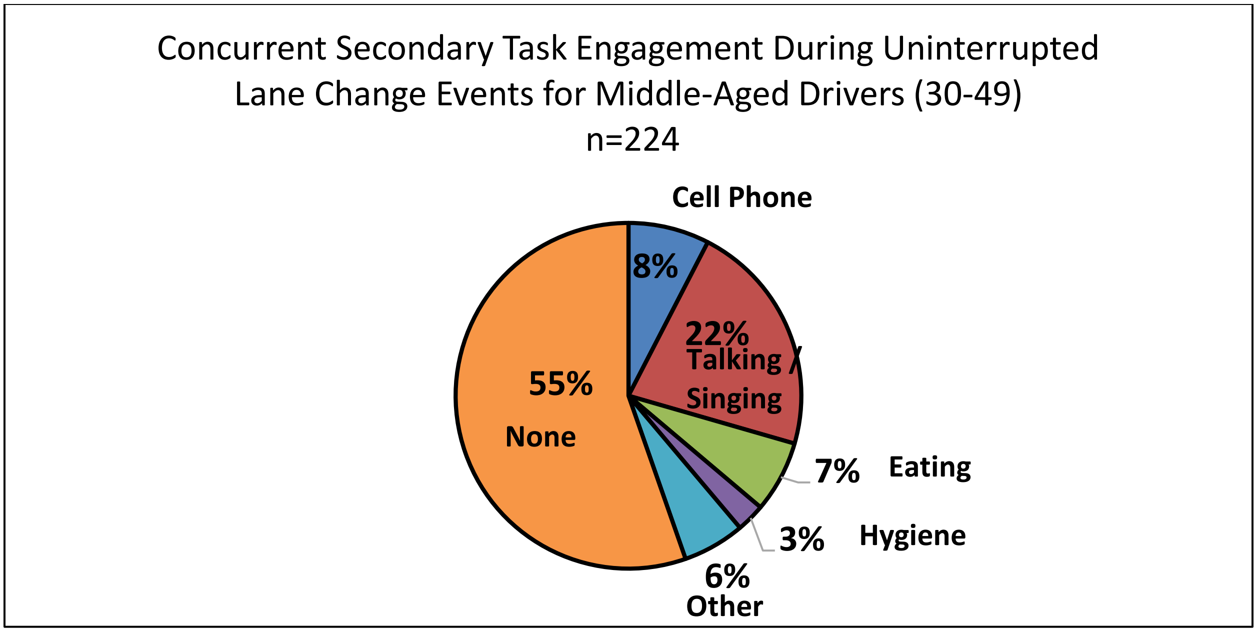


Figure 203. Chart. Concurrent secondary task engagement for middle-aged drivers during uninterrupted lane changes.

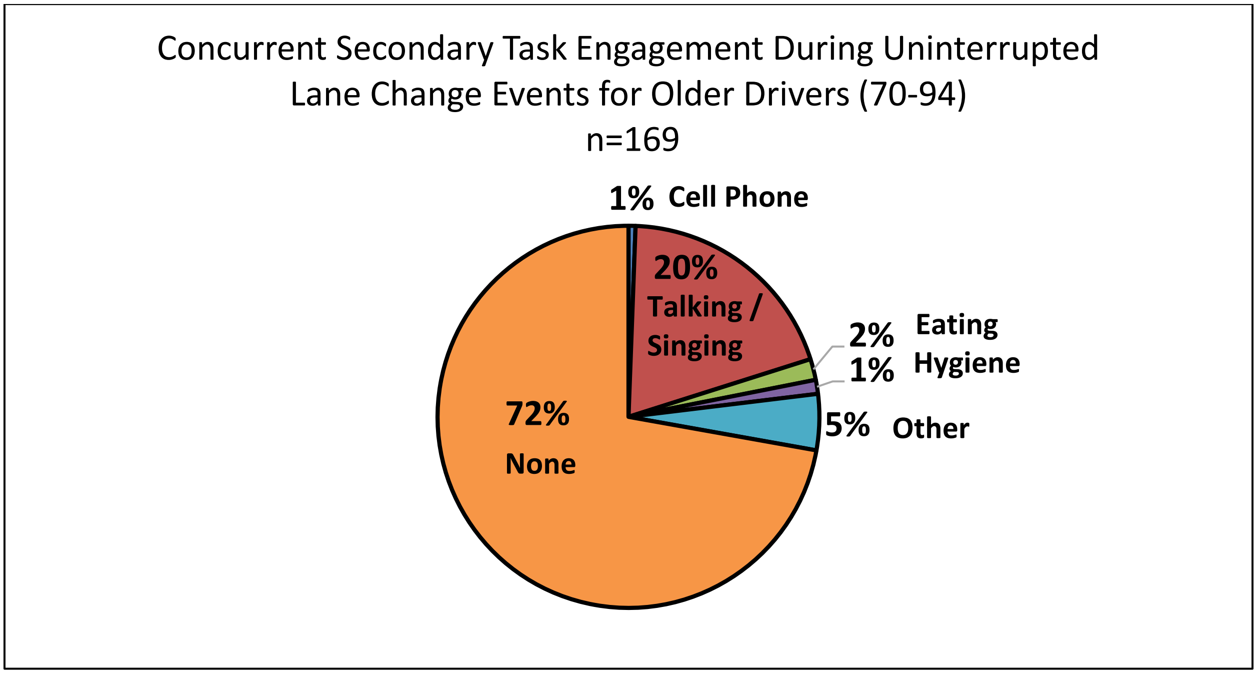


Figure 204. Chart. Concurrent secondary task engagement for older drivers during uninterrupted lane changes.

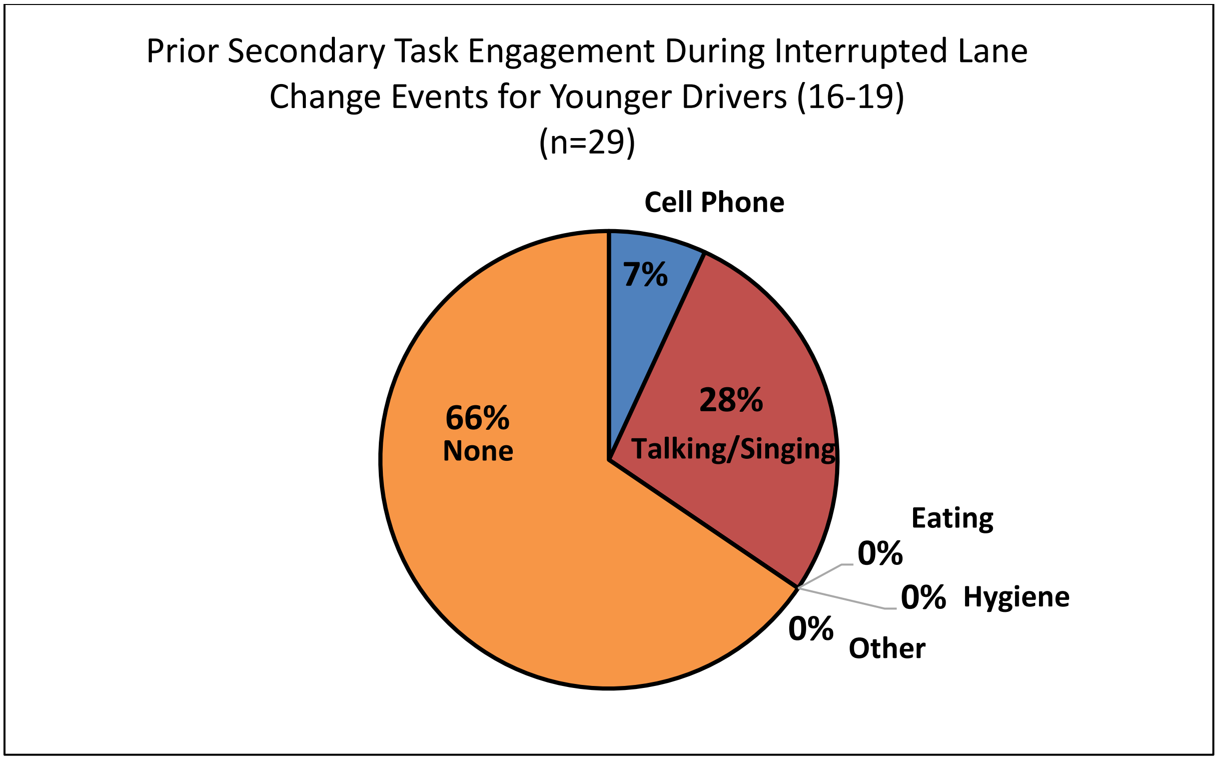


Figure 205. Chart. Prior secondary task engagement for younger drivers during interrupted lane changes.

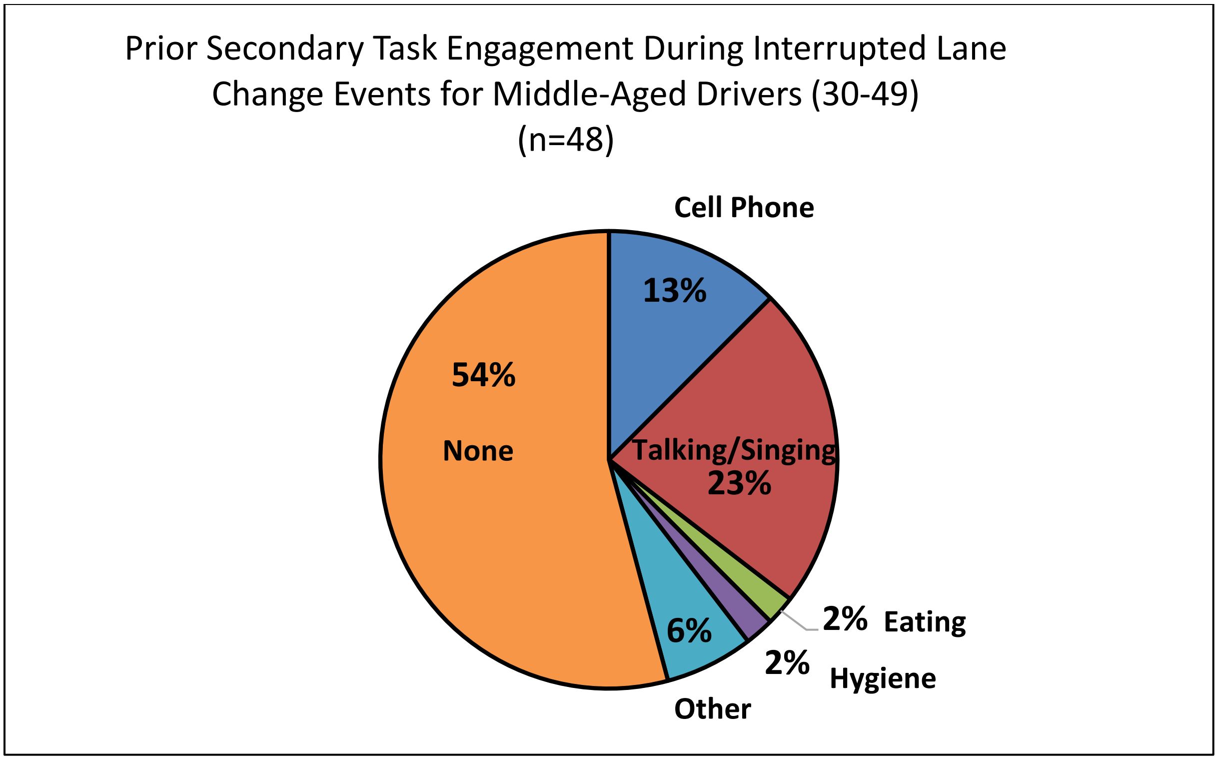


Figure 206. Chart. Prior secondary task engagement for middle-aged drivers during interrupted lane changes.

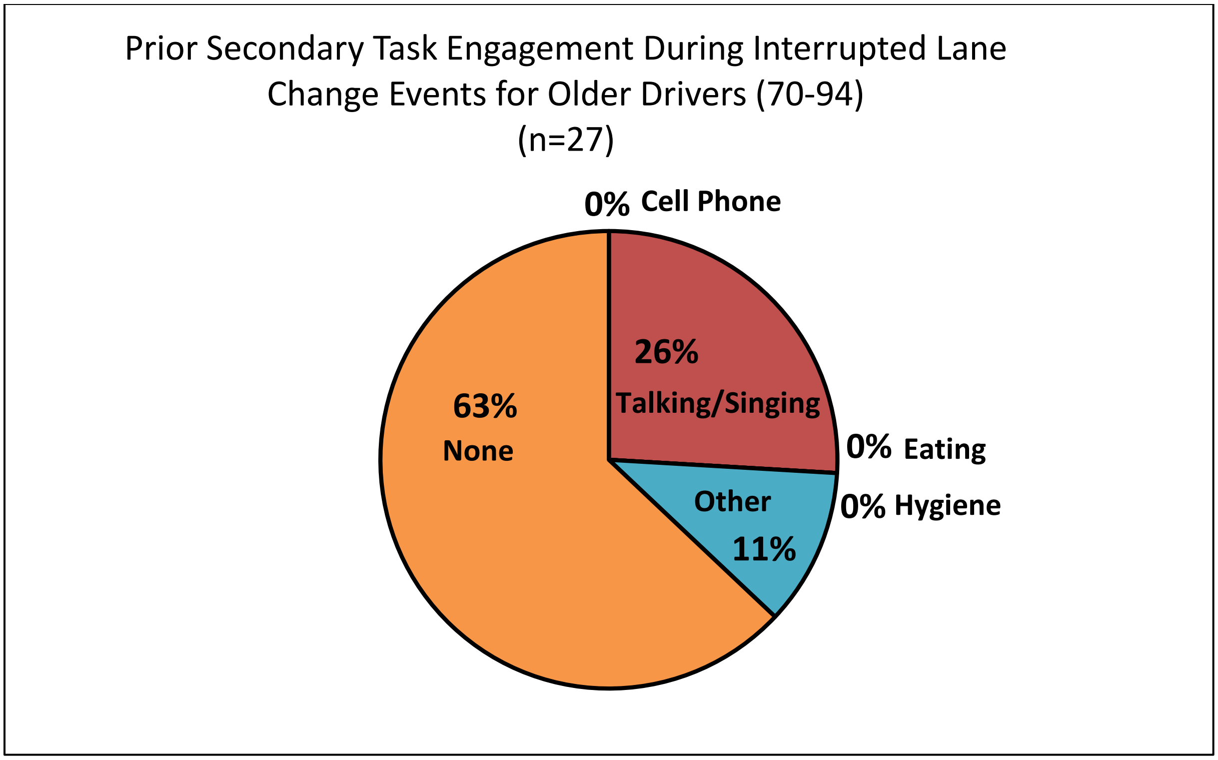


Figure 207. Chart. Prior secondary task engagement for older drivers during interrupted lane changes.

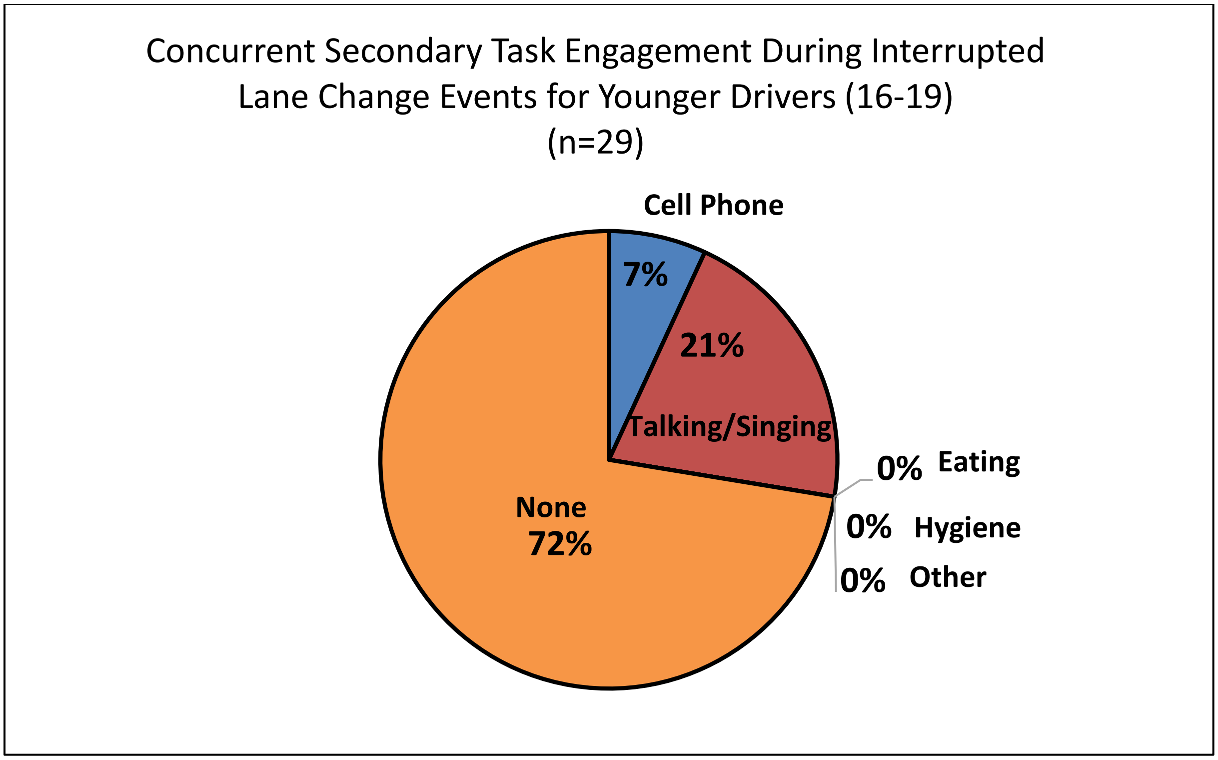


Figure 208. Chart. Concurrent secondary task engagement for younger drivers during interrupted lane changes.

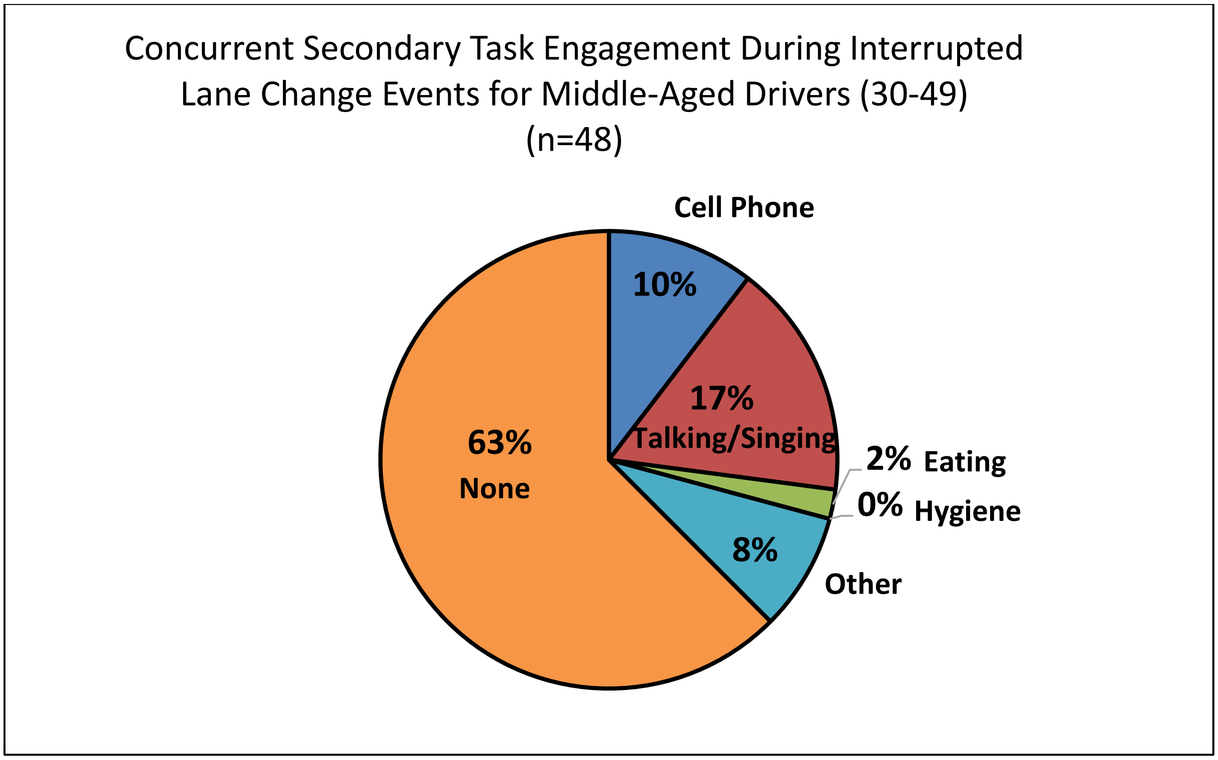


Figure 209. Chart. Concurrent secondary task engagement for middle-aged drivers during interrupted lane changes.

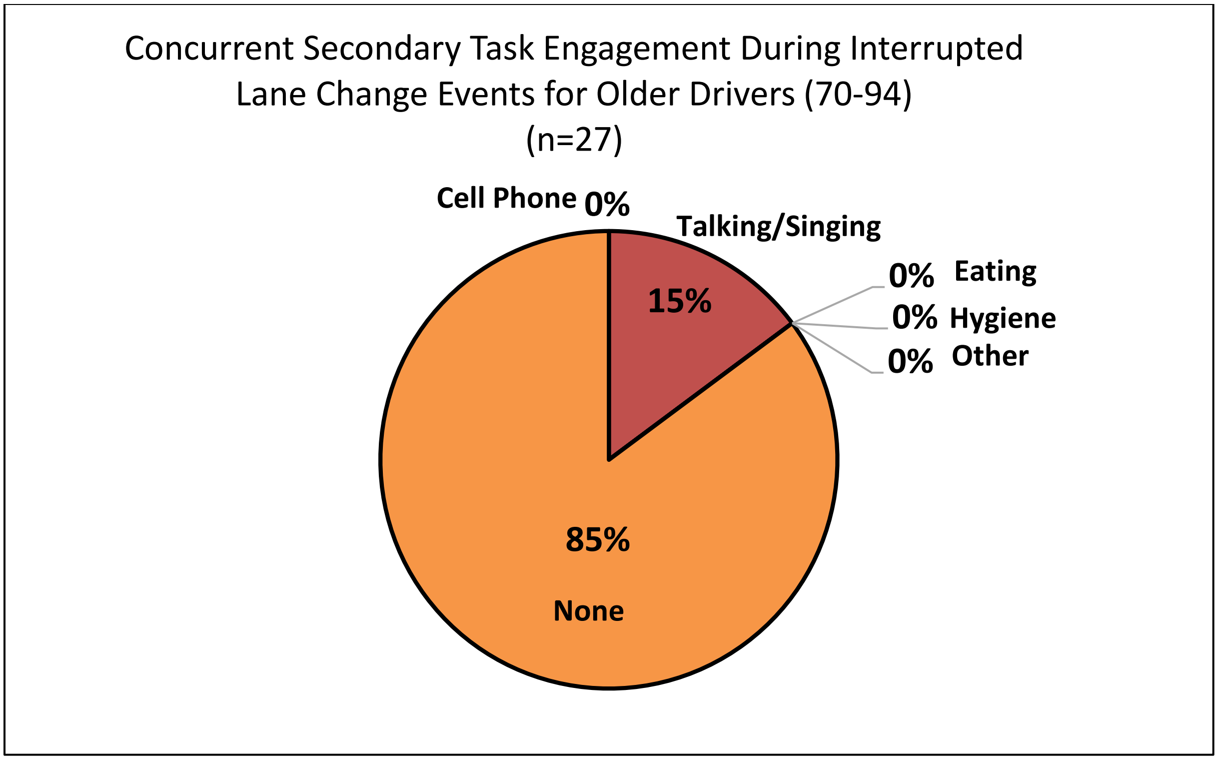


Figure 210. Chart. Concurrent secondary task engagement for older drivers during interrupted lane changes.

APPENDIX G. CUT-OFF BEHAVIOR PIE CHARTS

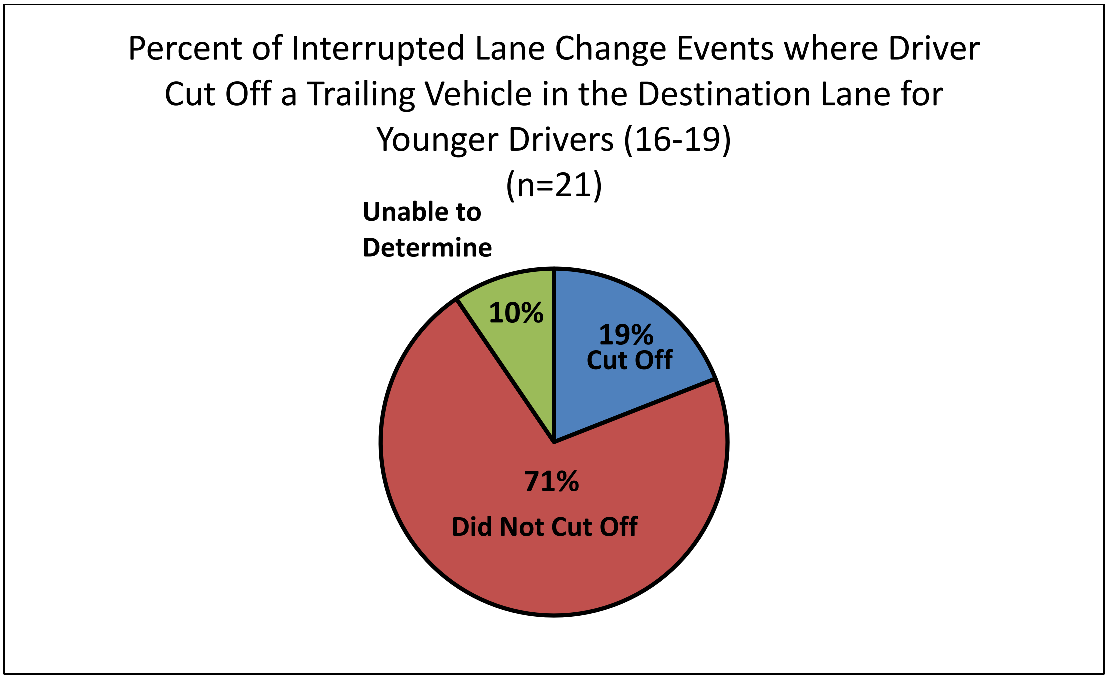


Figure 211. Chart. Percentage of cut-off events for younger drivers.

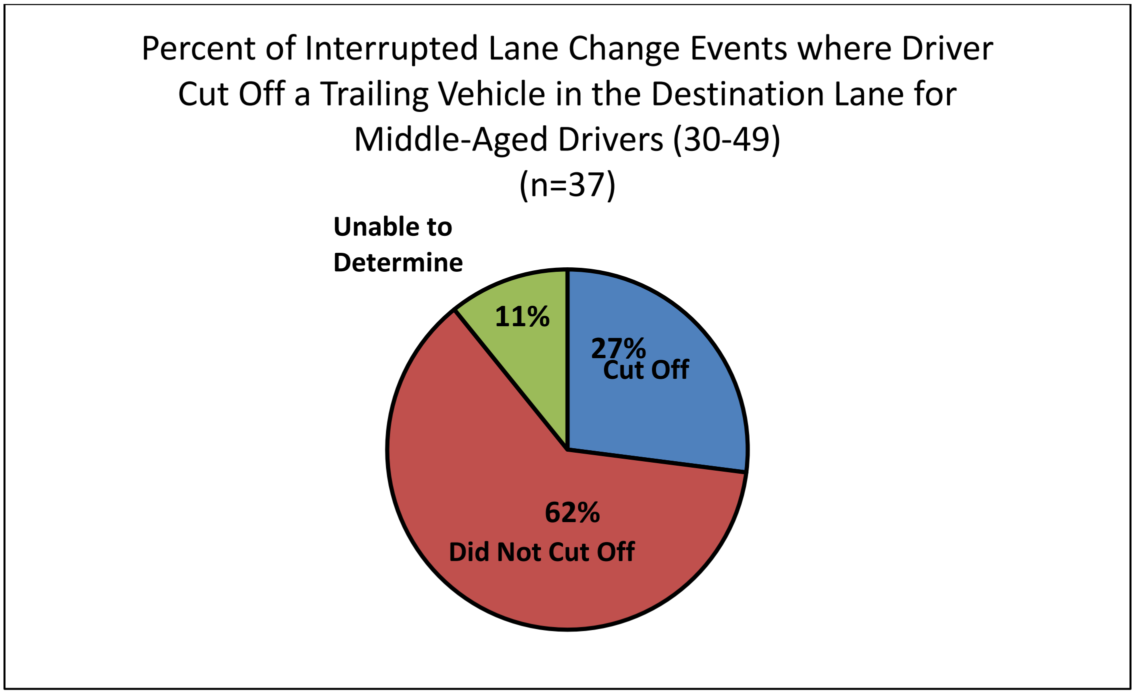


Figure 212. Chart. Percentage of cut-off events for middle-aged drivers.

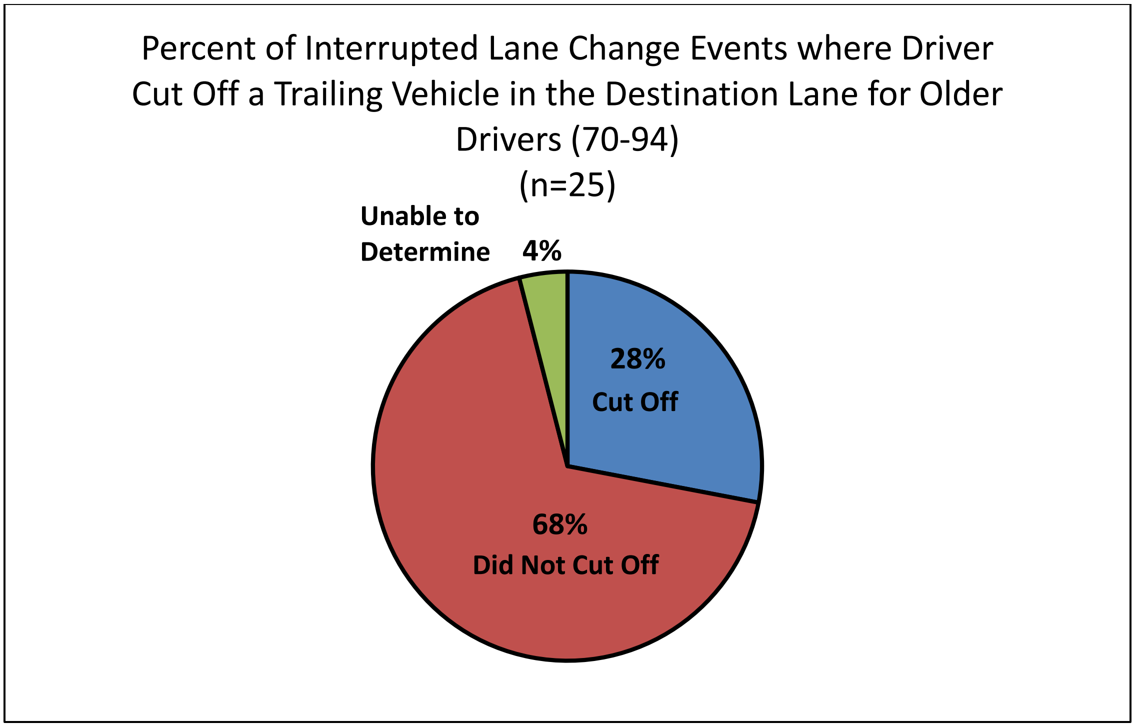


Figure 213. Chart. Percentage of cut-off events for older drivers.

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