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Human-Machine Interface Review: A Comparison of Legacy and Touch-Based Center Stack Controls

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EXECUTIVE SUMMARY

Introduction

The current study investigated the effect of center stack design on driver distraction. Replacing physical center stack controls with touchscreens is an emerging trend in automotive design. This design decision requires a driver to take their eyes off the forward roadway to interact with a touchscreen center stack, as there is no tactile feedback like touching physical controls. Multiple resource theory (Wickens, 2004) suggests that performing dual tasks (i.e., driving and touchscreen interaction) that compete for similar resources (i.e., visual attention and manual input) can degrade performance on both tasks. It is important to understand the impact of touchscreen controls on driver distraction to ensure safe human-machine interface design.

Method

Data from three naturalistic driving studies (NDSs) were utilized. Data from legacy vehicles with physical center stack controls were extracted from the Second Strategic Highway Research Program, an NDS focusing on driver behavior over time in personal vehicles. Data from modern vehicles with touchscreen designs were extracted from the Virginia Connected Corridor 50 Elite Vehicle NDS and Virginia Tech Transportation Institute Level 2 NDS, both focusing on driver behavior in personal vehicles equipped with SAE Level 2 (L2) driving automation features. Twenty-second events that had a center stack interaction (CSI) and minimum speed of 35-mph or greater were selected from each dataset. For the modern vehicle dataset, L2 system status was coded for each event as L2 active or L2 inactive, and task type was coded as visual or visual-manual. The legacy vehicle dataset only had visual-manual CSIs. Driver distraction was defined as eye glances towards the center stack (eyes on center stack; EOCS) during the 20-second event. EOCS was split into total time, mean time, single longest glance, number of glances, and glances over 2 seconds in duration. Total time on task was recorded for the modern vehicles.

Results

Results suggest that CSIs with modern vehicle touchscreens have higher EOCS compared to legacy vehicle physical controls. Notably, these differences are even more pronounced when comparing visual-manual CSIs (e.g., adjusting climate control) across display type. Modern vehicle CSIs were also more likely to include glances over 2 seconds compared to legacy vehicle CSIs. Within the modern vehicle dataset, all EOCS metrics (except number of glances), time on task, and glances over 2 seconds were significantly higher when L2 systems were active versus inactive. Visual-manual CSIs were higher for all variables compared to visual CSIs. Glances over 2 seconds were more likely when L2 systems were active for all visual CSIs, but not for visual-manual CSIs.

Conclusion

Touchscreen center stack designs are shown to be more distracting than legacy designs comprised of physical controls. When L2 systems are active, CSIs are more distracting than when L2 systems are inactive. Although display type has been shown to have a distracting effect, comparison of specific tasks (e.g., adjusting climate controls) is needed to represent true differences in driver distraction, as more complex tasks that are possible in modern vehicles versus legacy vehicles could contribute to the results of the current study.

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LIST OF ABBREVIATIONS

ACC	adaptive cruise control
CSI	center stack interaction
EOCS	eyes on center stack
IVIS	in-vehicle infotainment system
JAMA	Japan Automobile Manufacturers Association
LCA	lane centering assist
L2	Level 2 vehicle automation
MEOCS	mean eyes on center stack
MY	model year of vehicle
NDRC	non-driving-related vehicle control
NDS	naturalistic driving study
NHTSA	National Highway Transportation Safety Administration
NOG	number of center stack glances
SHRP 2	Strategic Highway Research Program
SLG	single longest center stack glance
TEOCS	total eyes on center stack
TOT	time on task
VCC50	Virginia Connected Corridor 50 Elite
VTTI	Virginia Tech Transportation Institute
VTTI L2	Virginia Tech Transportation Institute Level 2

CHAPTER 1. INTRODUCTION

Secondary task engagement is a leading cause of crash risk (Dingus et al., 2016; Atwood et al., 2018). In the transportation domain, secondary tasks are categorized as any tasks other than those required to safely drive a vehicle (e.g., eyes on the forward roadway, lateral/longitudinal vehicle control). Common secondary tasks include talking to a passenger, focusing on an external distraction, or interacting with a cell phone while driving (e.g., browsing, texting). Although cell-phone use significantly influences driver distraction (Klauer et al., 2014) and crash risk (Owens et al., 2018), other sources of distraction can be found within the vehicle cabin. Center stacks offer a range of non-driving-related vehicle controls (NDRCs; e.g., radio, heating, ventilation, air conditioning) for the driver to interact with while the vehicle is in motion. In legacy vehicles, these controls consisted of knobs and dials that allowed tactile interaction. As consumer technology has progressed (e.g., introduction of smartphones), touchscreen interaction has become ubiquitous and in-cabin technology has followed suit. Modern center stacks tend to relegate more NDRCs to a touchscreen, thereby removing the legacy knobs/dials (Grand View Research, 2021).

Touchscreen controls are presumably included to make consumers view a vehicle as more modern and attractive than older legacy models. However, the implications of this change should be investigated for any driver distraction consequences. Driving, as a task, can be defined as visual-manual in nature, as it requires hands on the steering wheel and eyes on the forward roadway. When adjusting NDRCs while driving, the driver of a legacy vehicle could memorize the feel and location of knobs and dials required to complete the task. Adjustments could thus be performed with one hand while keeping the other on the wheel and the eyes forward. Touchscreen-based NDRCs require precise tapping of icons on a smooth surface. This demands both visual and manual engagement while driving, even if the location of the icon and submenu path has been memorized. Multiple resource theory suggests that time-sharing tasks that compete for the same cognitive resources such as driving and touchscreen engagement can lead to performance degradation (Wickens, 2004). Indeed, a very recent study with modern cars on a test track suggested that driver safety performance while interacting with physical buttons may be superior to performance while interacting with touchscreens (Vikström, 2022). Further, Mazda recently announced that it was moving away from touchscreens altogether, after identifying that some drivers unintentionally applied torque to the steering wheel while operating the touch-based center stack console (Halvorson, 2019).

Modern vehicles with touchscreen center stacks are often equipped with automated vehicle features, such as adaptive cruise control (ACC) and lane centering assist (LCA). When these features are used simultaneously, they are defined as Level 2 (L2) automation, with LCA controlling lateral positioning and ACC monitoring longitudinal movement of the vehicle (SAE, 2021). When L2 systems are active, the driver is responsible for monitoring the forward roadway and being vigilant about responding to any requests to intervene that a system may issue. Engagement in NDRCs may distract a driver from performing this responsibility. Indeed, previous research suggests that secondary task engagement is higher when L2 features are active compared to when they are inactive (Llaneras et al., 2013; Noble et al., 2021).

The current study sought to understand the driver distraction implications of NDRCs transitioning from knobs/dials to touchscreen controls. Only by filling this gap is it possible to ensure the adoption of the newest human-machine interfaces in a manner safe for all road users (Cliff, 2022). The following research questions were analyzed:

1. What is the difference in eyes on center stack (EOCS) behavior when performing center stack tasks with physical controls compared to touchscreens?
2. Does driving automation influence interactions with the center stack?

CHAPTER 2. METHOD

This study evaluated center stack interactions (CSIs) across three naturalistic driving studies (NDSs) performed by the Virginia Tech Transportation Institute (VTTI). This chapter provides an overview on extracting data from the NDS datasets, differences in how each dataset was coded, a description of variables of interest, and the analytic approach.

OVERVIEW OF NDS DATABASES

NDSs involve recording driver behavior over time by instrumenting a vehicle. This instrumentation includes installing a data acquisition system on a vehicle to collect video and kinematic data. Video data includes feeds internal (e.g., over-the-shoulder) and external (e.g., forward roadway) to the vehicle, while kinematic data includes vehicle dynamics (e.g., yaw rate). Each NDS dataset for the current study is listed below:

1) Legacy Vehicles
    a. Dataset 1 – Second Strategic Highway Research Program 2 (SHRP 2) NDS
2) Modern Vehicles
    a. Dataset 2 – Virginia Connected Corridor 50 Elite (VCC50) NDS
    b. Dataset 3 – Virginia Tech Transportation Institute Level 2 (VTTI L2) NDS

Datasets and Participants

Legacy vehicle data were extracted from SHRP 2 (Dingus et al., 2015), an NDS focusing on driver behavior in personal vehicles that concluded in 2013. Vehicle model year (MY) from SHRP 2 was restricted to 2009 and older (final range of 1991–2009) to ensure that center stack designs were comprised of only physical controls. Modern vehicle data were comprised of two datasets: VCC50 and VTTI L2, both of which are NDSs focusing on personal vehicles equipped with L2 automated features. VCC50 ended collection in 2018 (see Dunn et al., 2019, and Kim et al., 2022, for study details) while VTTI L2 NDS is ongoing (see Perez et al., 2024, for further details). For the current dataset, vehicles from VTTI L2 NDS were restricted to Subarus (MY 2017–2021) and Teslas (MY 2018–2022) and VCC50 to only Teslas (MY 2015–2017). Other makes and models from these datasets were excluded to focus on vehicles with touchscreen center stacks. See Table 1 for a summary of dataset demographics.

Table 1. Demographics for legacy and modern vehicle datasets.

	Drivers	Gender	Age [Mean (Standard Deviation)]
SHRP 2*	363	M = 156; F = 198	32.92 (19.84)
VCC50	10	M = 7; F = 3	48.8 (12.06)
VTTI L2 NDS**	46	M = 23; F = 23	45.70 (18.70)

* 11 drivers were missing age; 8 drivers were missing gender ** 3 Drivers were missing driver age

DATA SAMPLING & CODING

For the current study, 20-second events were selected from each dataset using the following general sampling criteria:

- Minimum speed for the 20-second event was > 35 mph (minimum speed for L2 feature activation)
- CSI was present (see VTTI task reduction protocol and Appendix B for task definitions across datasets)

As the focus of this project was CSIs, L2 feature status (i.e., ACC and lane centering active or not active) was not used as sampling criteria for events from VCC50 or VTTI L2 NDS. That is, L2 status was reported based on the result of the general sampling criteria listed above.

Each dataset was reduced following the same general procedures for secondary task and eye-glance reduction. For secondary task engagement, randomly selected 20-second segments of driving were reviewed for drivers performing secondary tasks. These segments were then further reduced for driver eye-glance behavior where reductionists reviewed each frame for driver eye-glance location (see Appendix A for detailed eye-glance reduction protocol). Data from VCC50 (Noble et al., 2021) and SHRP 2 (Dingus et al., 2015) had already been reduced in previous efforts and needed no further reduction.

However, VTTI L2 NDS is a new dataset and thus did require reduction. Within this project, 5,000 randomly selected 20-second segments of driving were reviewed for CSIs. These 5,000 events were selected using the minimum speed requirement outlined above, as CSI status was unknown. CSI task reduction required additional considerations compared to VCC50 and SHRP 2 due to camera view limitations. For this dataset, only one driver-facing camera view was available to understand driver secondary task engagement (see top left of Figure 1). This limited the level of detail that could be understood about an engagement with the center stack. As such for this dataset, CSI was coded as visual-manual or visual-only. Visual-manual was coded for engagements where the driver's arm and visual gaze were in the direction of the center stack. Visual-only glances was coded when driver made repeated glances to the center stack in rapid succession. See Appendix B for the CSI task reduction protocol for this dataset. Eye-glance behavior was coded using the same protocol as VCC50 and SHRP 2 (Appendix A).

Figure 1. Photos. VTTI L2 NDS camera views used for reduction.

The final distribution of CSIs by dataset and task type are represented in Table 2.

Table 2. Distribution of center stack interactions by dataset.

		CSI Type			
	CSIs	Visual-Manual		Visual	
Legacy Dataset					
SHRP 2	440	440		N/A*	
Modern Dataset		L2 Active	L2 Inactive	L2 Active	L2 Inactive
VCC50	193	14	6	97	76
VTTI L2 NDS	498**	57	64	124	227

* SHRP 2 does not have visual interactions with center stack due to the physical design
** Twenty-six CSIs were affected in VTTI L2 NDS. Seventeen could not be assigned as only visual or visual-manual due to mixed CSIs within the segment. Ten segments had an unidentifiable L2 status.

VARIABLES

Independent variables

- **Display type** – Modern vehicles are equipped with L2 automated features and have touchscreen-based center stacks, while legacy vehicles are equipped with physical control (i.e., knob and dial)-based center stacks.

- **Task type** – Visual or visual-manual CSIs. Restricted to modern vehicles, as visual CSIs were not available in legacy vehicles.

- **L2 activation** – L2 features are active or L2 features are inactive. L2 active was coded when ACC and LCA were active simultaneously. L2 inactive was coded when both ACC and LCA were deactivated.

Dependent Variables

Eyes-off-road metrics were calculated using the glance locations coded for each segment following Appendix A. For this project, eyes-off-road was defined as any glance towards the center stack to focus on distraction as a function of center stack design. See Table 3 for a summary of glance locations that were coded and were relevant to the current project.

Table 3. Eye-glance operationalization.

EOCS Definition	Glance Type	
	Inconsequential	Relevant
All center stack glances are off-road	Forward Left or right mirror/window/windshield Rearview mirror Instrument cluster Eyes closed Over-the-shoulder (left or right) Passenger Cell phone Portable media device Interior object	Center stack

By focusing on glances towards the center stack, eyes-off-road metrics for this project can be thought of as EOCS time. EOCS and other project metrics are as follows.

- Total EOCS Time (TEOCS; seconds) – the summation of EOCS behavior during the driving segment.
- Mean EOCS Time (MEOCS; seconds) – the average EOCS time per each EOCS instance (calculated as total EOCS divided by the number of center stack glances).
- Single Longest Glance (SLG; seconds) – the longest EOCS glance for that driving segment.
- Number of Off-Road Glances (NOG; frequency) – the number of EOCS glances for that driving segment.
- Glances over 2 seconds – glances towards the center stack that are over 2 seconds in duration. Off-road glances towards any location over 2 seconds in duration have been established to at least double crash risk over typical driving (Klauer et al., 2006).

- Time on task (TOT; seconds) – the total amount of time engaged in a CSI during the 20-second segment. This metric was restricted to modern vehicles, as the legacy vehicle dataset only had the final 6 seconds of the 20-second segment coded for secondary task time. The modern vehicle dataset had secondary task time coded for the entire 20-second segment.

Analysis

Mixed effect analysis of variance was used to investigate EOCS variables and TOT. Fixed effects included the independent variables listed in Variables. Driver ID was included in each model as a random effect due to participants having more than one observation. For analyses investigating glances over 2 seconds, a chi-squared test of independence was used to compare frequency of such glances in a variety of independent variable combinations.

CHAPTER 3. RESULTS

RQ1: WHAT IS THE DIFFERENCE IN EOCS BEHAVIOR WHEN PERFORMING CENTER STACK TASKS WITH PHYSICAL CONTROLS COMPARED TO TOUCHSCREENS?

This research question reviewed the effect of display type on EOCS behavior and glances over 2 seconds. Results suggest that CSIs with touchscreen center stacks increase EOCS behavior and glances over 2 seconds versus physical controls, especially when comparing visual-manual CSIs. See Table 4 for a summary of RQ1 EOCS results.

Table 4. RQ1 eyes on center stack results summary.

	TEOCS		MEOCS		SLG		EOCS Glances	
	Legacy	Modern	Legacy	Modern	Legacy	Modern	Legacy	Modern
	M (SE)	M (SE)	M (SE)	M (SE)	M (SE)	M (SE)	M (SE)	M (SE)
All CSI	1.52 (0.12)	**3.54 (0.15)**	0.57 (0.03)	**0.99 (0.03)**	0.73 (0.04)	**1.36 (0.04)**	2.25 (0.11)	**3.51 (0.15)**
Visual-Manual	1.52 (0.12)	**5.61 (0.22)**	0.57 (0.03)	**1.23 (0.06)**	0.73 (0.04)	**1.86 (0.07)**	2.25 (0.11)	**4.45 (0.21)**

Bold – significant difference; Mean (Standard Error)

Total EOCS

CSIs were examined using TEOCS. Results were significant [$F(1, 280.5) = 113.02$; $p < .0001$] and suggested TEOCS was longer for modern vehicles ($M = 3.54$; $SE = 0.15$) than for legacy vehicles ($M = 1.52$; $SE = 0.12$). To control for task type, visual interactions with modern center stacks were excluded to directly compare visual-manual CSIs across display types. Results were significant [$F(1, 203.4) = 271.04$; $p < .0001$], suggesting TEOCS was longer for manual interactions with modern vehicles ($M = 5.61$; $SE = 0.22$) than for legacy vehicles ($M = 1.52$; $SE = 0.12$).

Mean EOCS

CSIs were examined using MEOCS. Results were significant [$F(1, 327.7) = 93.17$; $p < .0001$] and suggested MEOCS was longer for modern vehicles ($M = 0.99$; $SE = 0.03$) than for legacy vehicles ($M = 0.57$; $SE = 0.03$). To control for task type, visual interactions with modern center stacks were excluded to directly compare visual-manual CSIs across display types. Results were significant [$F(1, 242.7) = 97.93$; $p < .0001$], suggesting MEOCS was longer for visual-manual interactions with modern vehicles ($M = 1.23$; $SE = 0.06$) than for legacy vehicles ($M = 0.57$; $SE = 0.03$).

Single Longest EOCS Glance

CSIs were examined using SLG. Results were significant [$F(1, 296.5) = 118.12$; $p < .0001$] and suggested SLG was longer for modern vehicles ($M = 1.36$; $SE = 0.04$) than for legacy vehicles ($M = 0.73$; $SE = 0.04$). To control for task type, visual interactions with modern center stacks were excluded to directly compare visual-manual CSIs across display types. Results were significant [$F(1, 231.7) = 185.59$; $p < .0001$], suggesting SLG was longer for visual-manual interactions with modern vehicles ($M = 1.86$; $SE = 0.07$) than for legacy vehicles ($M = 0.73$; $SE = 0.04$).

Number of EOCS Glances

CSIs were examined using NOG. Results were significant [$F(1, 184.10) = 48.89$; $p < .0001$] and suggested NOG was longer for modern vehicles ($M = 3.51$; $SE = 0.15$) than for legacy vehicles ($M = 2.25$; $SE = 0.11$). To control for task type, visual interactions with modern center stacks were excluded to directly compare visual-manual CSIs across display types. Results were significant [$F(1, 112.2) = 125.32$; $p < .0001$], suggesting NOG was longer for visual-manual interactions with modern vehicles ($M = 4.45$; $SE = 0.21$) than for legacy vehicles ($M = 2.25$; $SE = 0.11$).

Glances Over 2 Seconds

The frequency of center stack glances over 2 seconds in duration were calculated for the modern and legacy vehicle datasets. A chi-square test of independence was used to compare the occurrence of glances over 2 seconds across display type. Results suggest drivers with modern displays were more likely to have CSIs with glances over 2 seconds than drivers with legacy displays [$\chi^2(1,\ 1125) = 35.64$, $p < .0001$; OR = 4.96; 95% CI: 2.79, 8.81]. This pattern held when comparing visual-manual tasks by display type [$\chi^2(1,\ 581) = 113.51$, $p < .0001$; OR = 16.25; 95% CI: 8.70, 30.36)]. See Figure 2 for visual representations and Table 5 for frequency of CSIs with glances over 2 seconds by display type.

Table 5. Count of center stack interactions with glances over 2 seconds by display type.

	Overall		**Visual-Manual**	
	Yes	**No**	**Yes**	**No**
Legacy	14	426	14	426
Modern	96	589	55	103

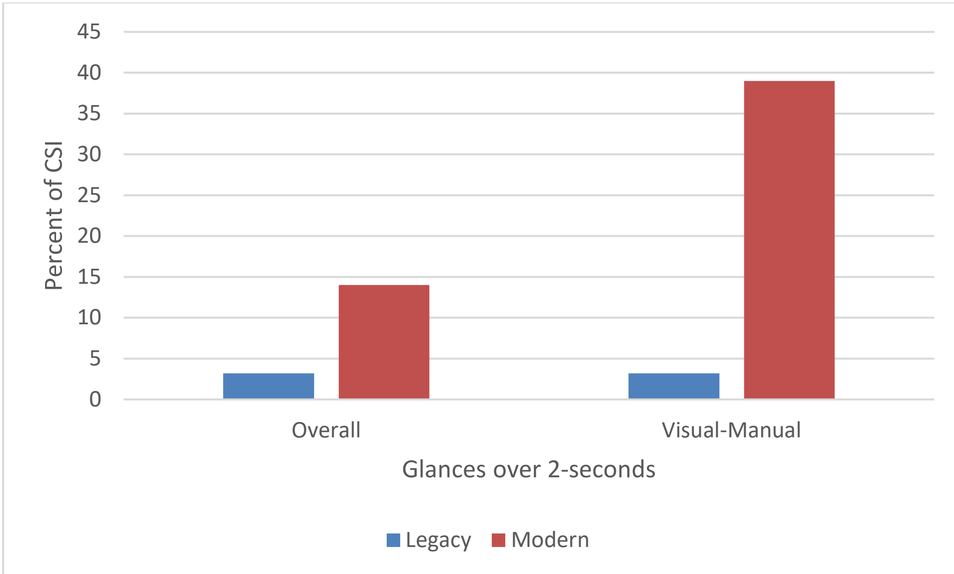


Figure 2. Chart. Percentage of glances over 2-seconds by display and task type.

RQ2: DOES DRIVING AUTOMATION INFLUENCE INTERACTIONS WITH THE CENTER STACK?

This research question examined the effect of L2 automation and task type on EOCS behavior, TOT, and glances over 2 seconds. Results suggest that EOCS, TOT, and glances over 2 seconds in duration are increased when L2 is active. See Table 6 for a summary of the effect of L2 activation status and CSI task type on EOCS and TOT.

Table 6. Summary of eyes on center stack results for RQ2.

	TEOCS M (SE)	MEOCS M (SE)	SLG M (SE)	Glances M (SE)	TOT M (SE)
L2 Active	**4.49 (0.23)**	**1.16 (0.06)**	**1.66 (0.07)**	3.99 (0.19)	**8.17 (0.45)**
L2 Inactive	3.93 (0.23)	0.98 (0.06)	1.38 (0.07)	3.93 (0.19)	7.10 (0.44)
Visual	2.78 (0.26)	0.90 (0.05)	1.19 (0.06)	3.01 (0.22)	5.42 (0.37)
Visual-Manual	**5.65 (0.19)**	**1.24 (0.07)**	**1.85 (0.08)**	**4.91 (0.17)**	**9.86 (0.51)**
Visual					
L2 Active	3.00 (0.34)	0.99 (0.06)	1.33 (0.07)	3.02 (0.20)	5.65 (0.45)
L2 Inactive	2.56 (0.21)	0.82 (0.05)	1.05 (0.07)	3.01 (0.19)	5.19 (0.42)
Visual-Manual					
L2 Active	5.98 (0.34)	1.33 (0.09)	2.00 (0.11)	4.97 (0.28)	10.70 (0.42)
L2 Inactive	5.31 (0.34)	1.14 (0.09)	1.71 (0.11)	4.86 (0.28)	9.02 (0.67)

Bold indicates significant difference of at least $p < .05$; Mean (Standard Error)

Total EOCS

CSIs were examined using TEOCS. Results were significant [$F(1, 643.1) = 4.99$; $p < .05$] and suggested TEOCS was longer when L2 was active ($M = 4.49$; $SE = 0.23$) versus inactive ($M = 3.93$; $SE = 0.23$). Regarding task type, visual CSIs were compared to manual CSIs. Results were significant [$F(1, 652.1) = 130.17$; $p < .0001$], suggesting manual CSIs had longer TEOCS ($M = 5.65$; $SE = 0.19$) than visual CSIs ($M = 2.78$; $SE = 0.26$). Finally, the interaction between L2 status and task type was not significant [$F(1, 656.7) = 0.24$; $p = 0.62$].

Mean EOCS

CSIs were examined using MEOCS. Results were significant [$F(1, 626.4) = 7.21$; $p < .01$] and suggested MEOCS was longer when L2 was active ($M = 1.16$; $SE = 0.06$) versus inactive ($M = 0.98$; $SE = 0.06$). Regarding task type, visual CSIs were compared to manual CSIs. Results were significant [$F(1, 634) = 23.64$; $p < .0001$], suggesting manual CSIs had longer MEOCS ($M = 1.24$; $SE = 0.07$) than visual CSIs ($M = 0.90$; $SE = 0.05$). Finally, the interaction between L2 status and task type was not significant [$F(1, 660.4) = 0.05$; $p = 0.82$].

Single Longest EOCS Glance

CSIs were examined using SLG. Results were significant [$F(1, 635.8) = 11.38$; $p < .001$] and suggested SLG was longer when L2 was active ($M = 1.66$; $SE = 0.07$) versus inactive ($M = 1.38$; $SE = 0.07$). Regarding task type, visual CSIs were compared to manual CSIs. Results were significant [$F(1, 644.8) = 61.91$; $p < .0001$], suggesting manual CSIs had longer SLG ($M = 1.85$; $SE = 0.08$) than visual CSIs ($M = 1.19$; $SE = 0.06$). Finally, the interaction between L2 status and task type was not significant [$F(1, 659) = 0.005$; $p = 0.94$].

Number of EOCS Glances

CSIs were examined using NOG. Results were not significant [$F(1, 656) = 0.09$; $p = 0.77$]. Regarding task type, visual CSIs were compared to manual CSIs. Results were significant [$F(1, 660.2) = 89.42$; $p < .0001$], suggesting manual CSIs had longer NOG ($M = 4.91$; $SE = 0.17$) than visual CSIs ($M = 3.01$; $SE = 0.22$). Finally, the interaction between L2 status and task type was not significant [$F(1, 651.9) = 0.06$; $p = 0.81$].

Time on Task

CSIs were examined using TOT. Results were significant [$F(1, 633.4) = 4.53$; $p < .05$] and suggested TOT was longer when L2 was active ($M = 8.17$; $SE = 0.45$) versus inactive ($M = 7.10$; $SE = 0.44$). Regarding task type, visual CSIs were compared to manual CSIs. Results were significant [$F(1, 645) = 76.67$; $p < .0001$], suggesting manual CSIs had longer TOT ($M = 9.86$; $SE = 0.51$) than visual CSIs ($M = 5.42$; $SE = 0.37$). Finally, the interaction between L2 status and task type was not significant [$F(1, 657.4) = 1.61$; $p = 0.21$].

Glances Over 2 Seconds

The frequency of center stack glances over 2 seconds in duration was calculated for the modern dataset. A chi-square test of independence was used to compare the occurrence of glances over 2 seconds across L2 status. Results suggest that when L2 was active drivers were more likely to have CSIs with glances over 2 seconds than when L2 was inactive ($\chi^2(1,\ 659) = 7.72$, p <.01; OR = 1.99; 95% CI: 1.27, 3.11). This pattern held when comparing visual $\chi^2(1,\ 518) = 10.79$, p <.001; OR = 3.34; 95% CI: 1.70, 6.58) but not visual-manual $\chi^2(1,\ 141) = 0.004$, p = .95) CSIs by L2 status. See Figure 3 for a visual representation of differences and Table 7 for the frequency of CSIs with glances over 2 seconds by L2 status.

Table 7. Count of center stack interactions with glances over 2-seconds.

	Overall		**Visual**		**Visual-Manual**	
	Yes	No	Yes	No	Yes	No
L2 Active	50	238	25	192	25	46
L2 Inactive	37	334	12	289	25	45

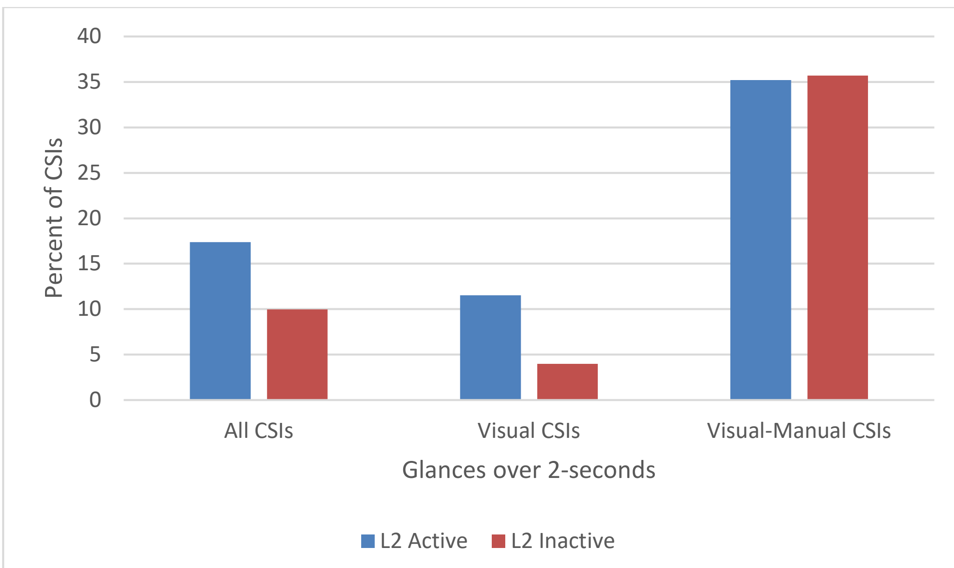


Figure 3. Chart. Percentage of modern center stack interactions with glances over 2 seconds.

CHAPTER 4. DISCUSSION

The current study examined data from three NDSs for the effect of center stack design on driver distraction during CSIs while driving. The effect of L2 activation status on CSIs and task type were also reviewed.

DISPLAY TYPE

CSIs with modern designs were shown to increase EOCS metrics compared to legacy designs, especially when comparing visual-manual CSIs. This is consistent with previous research showing driver performance is better (Crandall & Chaparro, 2012) and distraction is lowered (Wang et al., 2010) when performing a secondary task with a physical versus a touch-based interface. Results showed that drivers were more likely to have CSIs with glances over 2 seconds with a modern design than with a legacy design, and this difference increased substantially when comparing visual-manual CSIs. As established in Klauer et al. (2006), such glances at least double crash risk compared to normal driving, and the current study suggests they are more common with touchscreen designs. This is likely due to the differences in tasks that each design is capable of and the display design itself. Navigation tasks (i.e., destination input), a task that may be performed on modern but not legacy designs, have been shown to increase total eyes off road time by over 12 seconds when performed while driving (Ranney et al., 2013). The modern designs also invite longer visual dwell time by nature of the visual information being presented on a large display.

TASK TYPE

The legacy vehicle dataset did not have visual CSIs due to the nature of the physical center stack design. For the modern vehicle dataset, results suggest visual-manual CSIs were more distracting than visual CSIs across all dependent variables. This is consistent with previous research showing that visual-manual tasks are detrimental to driving performance (Dingus et al., 2016), increase crash odds (Dingus et al., 2019), and that other methods of in-vehicle infotainment system (IVIS) interactions are less impactful to driving (Strayer et al., 2019; Zhang et al., 2023). This also aligns with the theoretical framework proposed in multiple resource theory (Wickens, 2004) that performing a visual-manual secondary task will degrade driving performance due to shared resources between tasks. On average, TOT was over 9 seconds for visual-manual tasks (5.42 for visual), which exceeds the 8-second recommendation for IVIS task length from the Japan Automobile Manufacturers Association (JAMA, 2004). The National Highway Traffic Safety Administration (NHTSA, 2013) has design guidelines for IVISs with associated eye-glance metrics; however, they have specific requirements for evaluation that could not be applied in the current study (e.g., using a driving simulator). Previous research shows that complex IVIS tasks (i.e., destination input for navigation), such as those possible in modern center stacks, can exceed those guidelines under the prescribed testing conditions (Ranney et al., 2013). Overall, this suggests that touchscreen designs and the tasks that are possible on such displays can violate both JAMA and NHTSA IVIS design guidelines.

L2 AUTOMATION

EOCS was higher across all metrics (excluding NOG) when L2 systems were active. This pattern of higher distraction behavior with L2 systems active has been represented in previous research (Gaspar & Carney, 2019; Morando et al., 2021; Noble et al., 2021), and suggests that drivers are more distracted by secondary tasks when L2 systems are active. Specifically, Dunn et al. (2019) found that when L2 systems were active, engagement in visual-manual secondary tasks increased from 24% to 32%, drivers had higher total eyes off-road time, and drivers spent more time looking at non-driving-related tasks than when L2 systems were inactive. Drivers also engaged more with in-vehicle displays when automated systems were active compared to inactive (Miller & Boyle, 2019). The interaction between task type and L2 status was not significant for any metric, suggesting L2 status does not influence a specific task type's EOCS or TOT. This could be due to the nature of the task being performed. That is, visual-manual tasks may take longer to perform than visual tasks, regardless of L2 status, because they are more demanding (Strayer et al., 2019) and have more steps (Gupte & Askhedkar, 2018; Marinkov et al., 2022). For the current study, results suggest that EOCS and TOT stay consistent with task type regardless of L2 status; however, future research should investigate duration of CSIs as a function of L2 status. The current study was limited to 20-second windows and TOT represented the time engaged in a CSI during that window; however, the true beginning or end time of a CSI could be outside of that window. Drivers might be engaging in CSIs for longer periods of time, depending on L2 status.

LIMITATIONS

Over half of the current datasets have limited task-specific descriptions of CSIs that go beyond visual or visual-manual categorizations (e.g., adjusting climate control). As mentioned in Figure 1, the camera view for the VTTI L2 NDS does not show the center stack of the vehicle. For this reason, all CSIs across each dataset were coded as visual or visual-manual. Similarly, in VCC50, the center stack is shown in an over-the-shoulder camera view, but task-level details are hard to obtain (e.g., submenus are illegible) due to the brightness of the screen display (i.e., wash out). This further limits the ability to compare specific task interactions. The increases in distraction for touchscreen designs could be due to the more advanced tasks that can be performed on modern vehicle center stacks but are not possible on legacy vehicles. Because they require more steps, these advanced tasks require more interaction from the driver, (e.g., navigation; Gupte et al., 2018; Marinko et al., 2022), which could account for the increased distraction rather than the increase being due to the display design itself. Future research should perform a comparison of identical tasks across center stack designs to control for task complexity.

All drivers were monitored for behaviors in their personal vehicles. This suggests that they were experienced users of their center stacks, and this experience could affect driver distraction. For example, experienced drivers had fewer off-road glances of 3 seconds or longer compared to novices when performing visual-manual secondary tasks (Wikman et al., 1998). This suggests that novice users may need to look at the display for longer during interactions because they are not as familiar with the system. Further, studies show that novice drivers had higher manual interactions with in-vehicle displays when L2 systems were inactive than when L2 systems were active (He & Donmez, 2019). Future research should explore the effect of driving experience or experience with a display type on distraction.

For the modern vehicle dataset, only two makes were included for analyses (Subaru and Tesla). These vehicles represented all touchscreen designed center stacks; however, they do not represent the design approach of all OEMs. Future research should explore a broader range of vehicle makes and models to capture a wider representation of modern center stack software and hardware design. In addition, most participants for this study lived in major metropolitan areas (e.g., Northern Virginia, DC). This dense urban locality may not be representative of other driving environments (e.g., rural), and should be addressed in future research.

CONCLUSION

Modern vehicles with touchscreen center stacks are shown to be more distracting than legacy vehicles with physical controls. Although task-specific comparisons could not be made, visual-manual CSIs in modern vehicles were shown to substantially increase distraction over CSIs in legacy vehicles. Among modern vehicle CSIs, visual-manual CSIs were more distracting than visual CSIs, and drivers were more distracted when L2 systems were active compared to inactive. Overall, engineers need to consider downstream impacts on driver distraction of certain design decisions (i.e., replacing physical controls with software interaction).

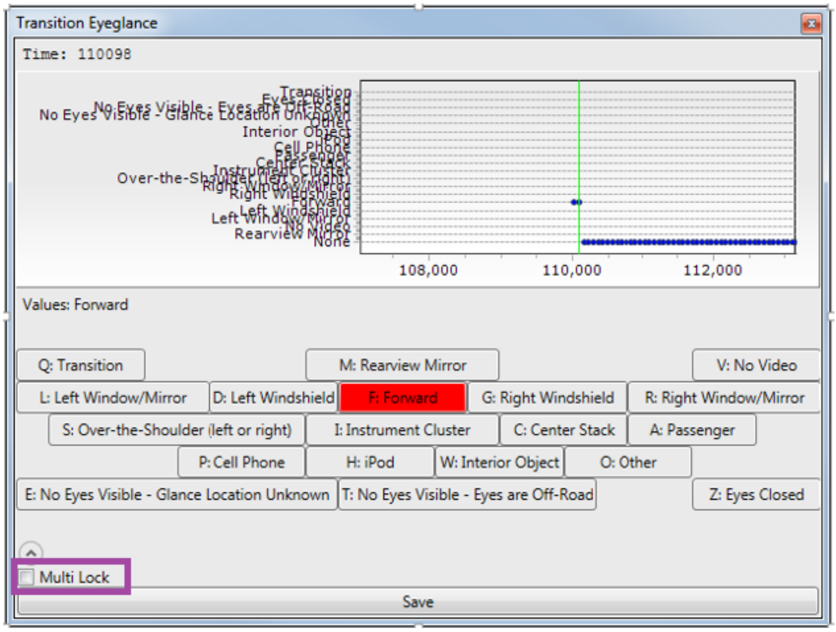
APPENDIX A. EYEGLANCE REDUCTION PROTOCOL

Origin Eyeglance General Protocol

Project Overview:
Origin eyeglance 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 version of eyeglance DOES NOT include "transition glances" which would be coded as part of the origin glance location.

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 eyeglance sequences (e.g. a new song comes on and driver looks over to XM radio to see title).
2. When ready to begin entering in eyeglance data, ensure that the cursor is located at the start of the event requiring reduction. The "Origin Eyeglance" video annotation will not let allow reduction outside of the event window.
3. With the "Origin Eyeglance" 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 (refer to Appendix A for glance location definitions and codes).
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 "Origin Eyeglance" video annotation (shown below).



Example image Hawkeye hightlighting the coded glance in red

7. If the "Multi Lock" check box is checked, further eyeglance 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 eyeglance 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: a glance is defined as the location a driver is fixated on for at least 2 consecutive video frames.

A glance that is coded following the origin eyeglance protocol begins the first frame that the eyes fixate on a location and ends the last frame before the eyes have fixated on a new location. Transitions are included in the origin glance location. For example, if the subject is looking forward and then transitions to right windshield, the transition would be included in the forward glance. Right windshield wouldn't begin until the first frame that the subject's eyes are fixated on right windshield.

Normal blinks (less than five consecutive video frames) are not recorded in eyeglance. Glance location should be coded straight through blinks. 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 eyeglance reduction should be undertaken or the event omitted.

	Glance Locati	**Standardized SHRP 2 Definitions**	**Additional Information and Tips**
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" (see Appendix C). "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. Eyeglance reduction should focus on the direction of their eyes, not the direction of their head. Therefore, this will be coded as "Forward".
M	Rearview Mirr	Any glance to the rear-view mirror or equipment located around it. This glance	For most studies, the camera has been placed right behind the rearview mirror. Therefore, any glance directly at the

	Glance Locati	Standardized SHRP 2 Definitions	Additional Information and Tips
		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.	camera will be a "Rearview Mirror" glance. Depending on the height of the driver, this glance might include a slight upward angle (see Appendix C). *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 Windshie	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 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).	
L	Left Window/ Mirror	Any glance to the left side mirror or window.	For most studies, the side mirror and side window glances have been merged into a single category.
R	Right Window/ Mirror	Any glance to the right-side mirror or window	For most studies, the side mirror and side window glances have been merged into a single category.
S	Over-The-Shoulder (left or right)	Any glance over either of the participant's shoulders. In general, this will require the eyes to pass the B-pillar.	B-Pillar is a vertical part of the vehicle frame providing support and separating

	Glance Locati	Standardized SHRP 2 Definitions	Additional Information and Tips
		If over the left shoulder, 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-the-shoulder 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.	the front doors from the rear doors of the vehicle (see Appendix B). 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 (see Appendix C).
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 eyeglance 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.

	Glance Locati	Standardized SHRP 2 Definitions	Additional Information and Tips
			Glances towards the steering wheel itself also go under this category (including glances associated with the use of steering wheel buttons and controls). Also includes gear shift, when located here.
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 (see Appendix B).
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).	
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	"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 (See Appendix B). The gear shift is often located in this area as well. 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.

	Glance Locati	Standardized SHRP 2 Definitions	Additional Information and Tips
		in this category. If the gear shift is located in the center console, glances towards it would also be coded as "Interior Object". 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 eyeglance 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.	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".
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 frames (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 eyeglance analysis, unless specified to do so by the project-specific protocol. A normal blink is anything up to 5 frames. 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	Some pre-approved uses of the "Other" option are listed below:

	Glance Locati	Standardized SHRP 2 Definitions	Additional Information and Tips
		this category, please inform a supervisor for appropriate follow-up.	- 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. NOTE: this sometimes occurs for 1-2 frames at a time. 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 "no eyes visible" period is longer than 2 frames OR it occurs during a transition, use the "no eyes visible" option.	"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.
T	No Eyes Visible – Eyes Are Off-Road	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. Video is present, but the driver's eyes and face are not visible due to an	"Eyes Are Off-Road" can be caused by several things. - The sun visor blocking a large portion of the face. - Hands blocking the face or camera view. Looking in the vehicle at an unknown object in the backseat.

	Glance Locati	Standardized SHRP 2 Definitions	Additional Information and Tips
		obstruction (e.g. visor, hand), head position, or due to glare. 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. NOTE: this sometimes occurs for 1-2 frames at a time. 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 "no eyes visible" period is longer than 2 frames OR it occurs during a transition, use the "no eyes visible" option.	
N	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 eyeglance 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 eyeglance 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 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 eyeglance 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.

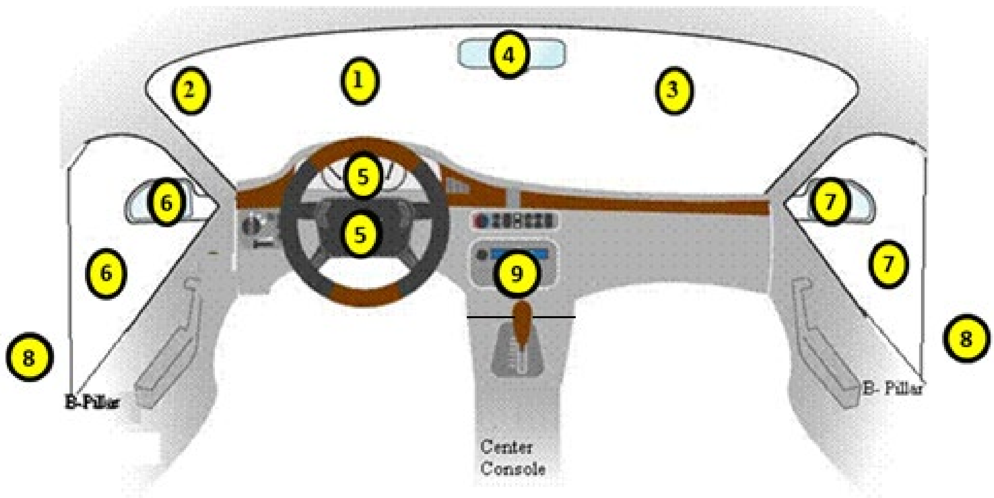
Sensitive Content: Reductionists should always refer to and abide by the Handling of Sensitive Video Content procedures listed in VTTI's DR Lab Policies.

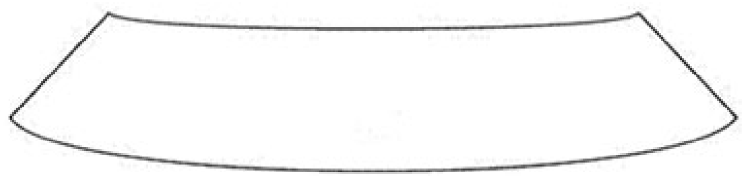
Typical Eyeglance Behaviors:

- 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 or Right Window, and/or Over-the-Shoulder.

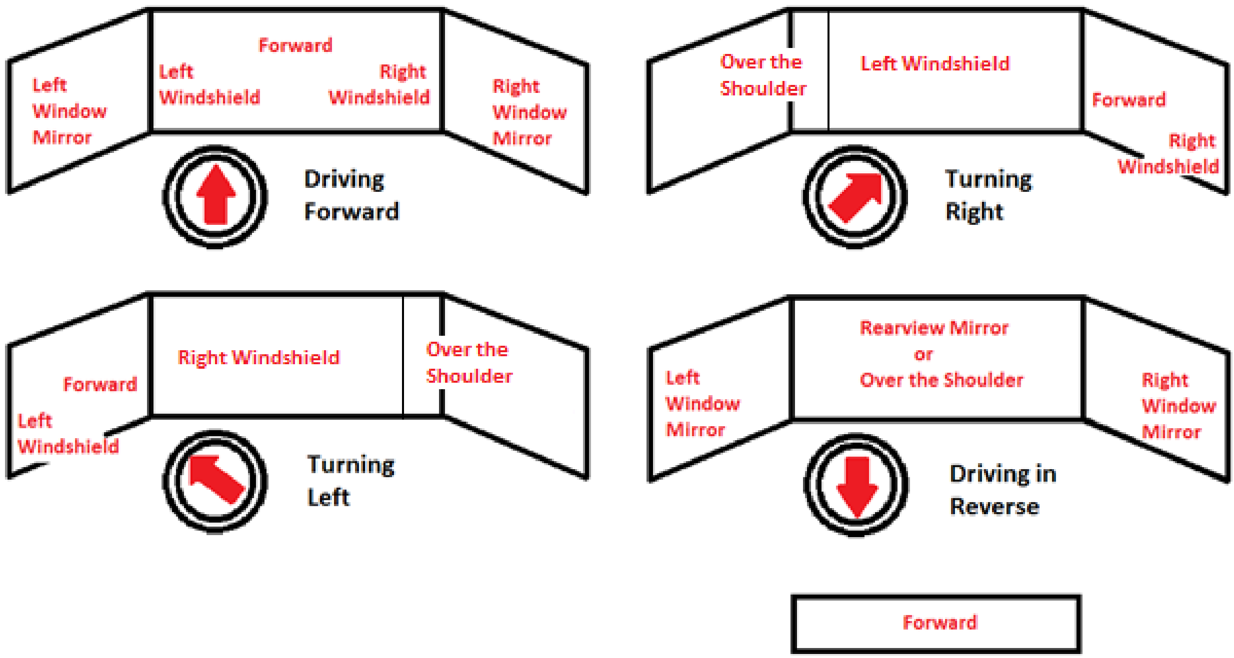
- Traffic Signals: When stopped at a traffic signal drivers will sometime glance from Forward, to the traffic signal (coded as "Other"), and then to an "Interior Object" like their hands or to a device like a "Cell Phone".
- Making a Turn: Before initiating the turn the driver will often glance to the "Right/Left Windshield" and/or the "Right/Left Window/Mirror" 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 (review Appendix C).
- 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



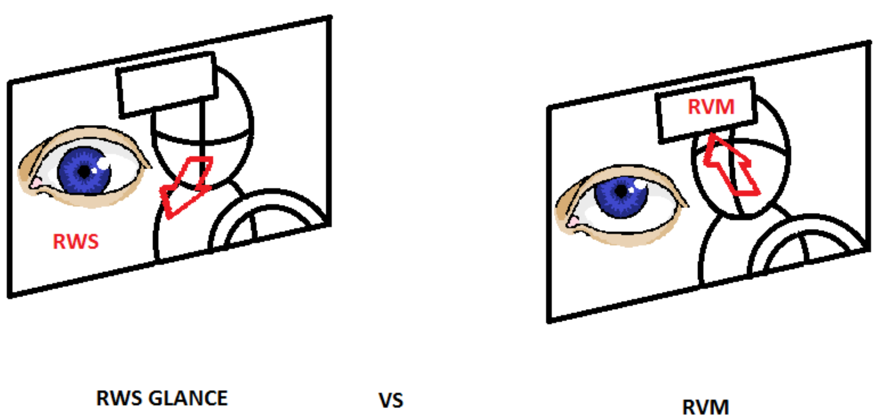


Number From Image Above	Corresponding Key	Glance Location
1	F	Forward
2	D	Left Forward / Left Windshield
3	G	Right Forward / Right Windshield
4	M	Rearview Mirror
5	I	Instrument Cluster
6	L	Left Mirror / Left Window
7	R	Right Mirror / Right Window
8	S	Over the Shoulder (Left or Right)
9	C	Center Stack (vertical)
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

Eyeglance 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.



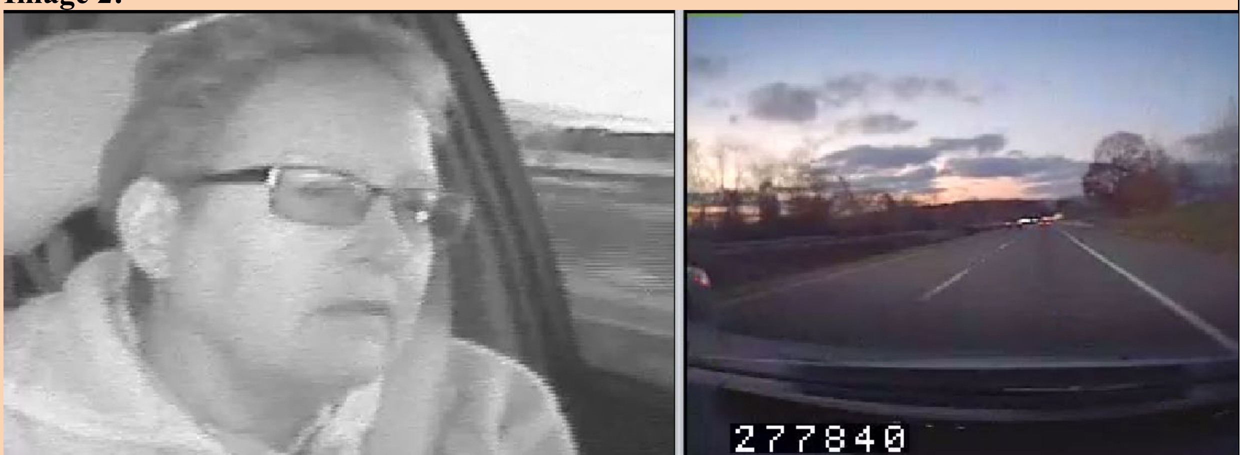
Eyeglance Right Windshield (RWS) vs. Rear View Mirror (RVM)



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)

<u>LEFT WINDOW/MIRROR:</u>

Image 1: (at intersection)

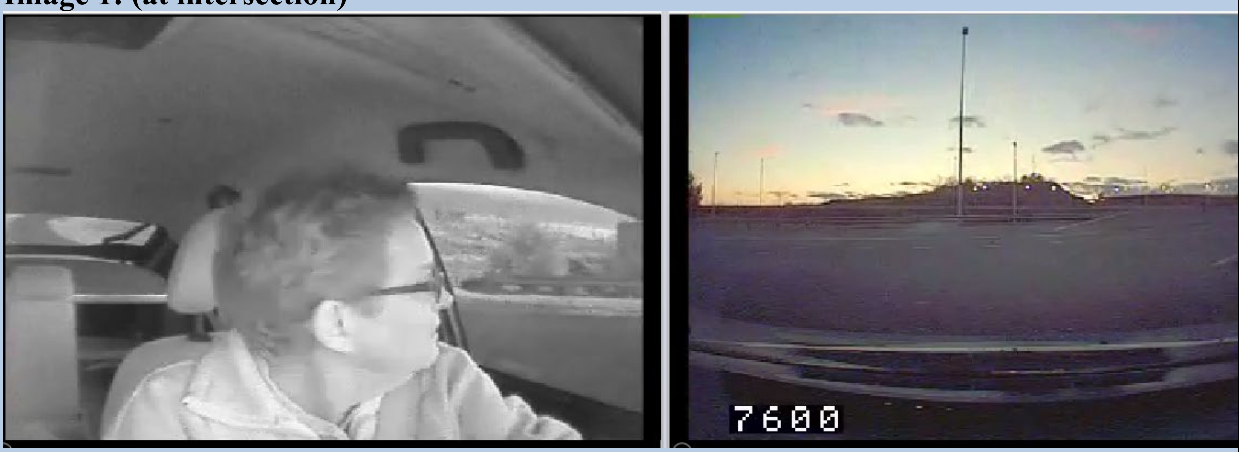


Image 2: (approaching intersection)

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

Image 1: (at intersection)

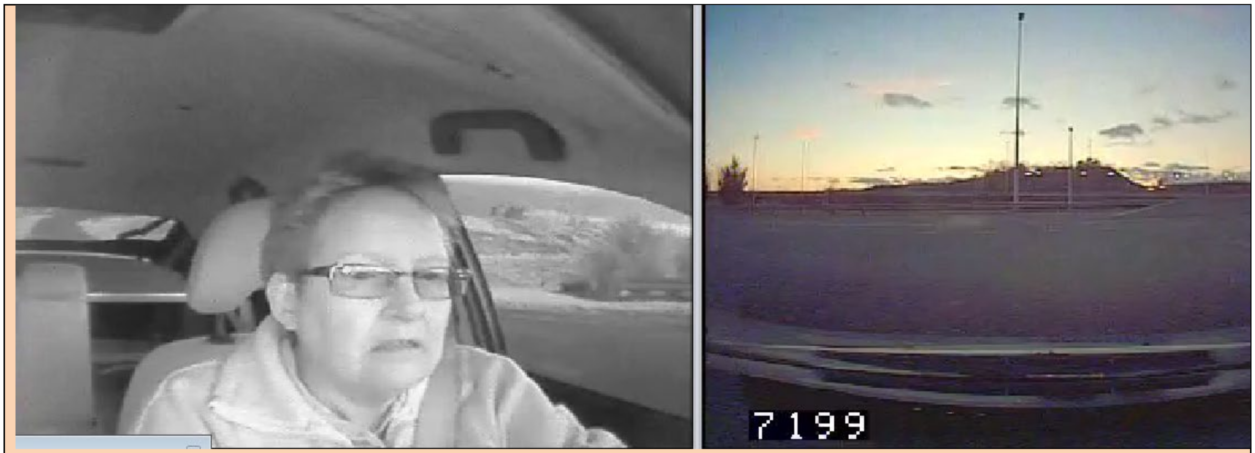


Image 2: (at intersection)

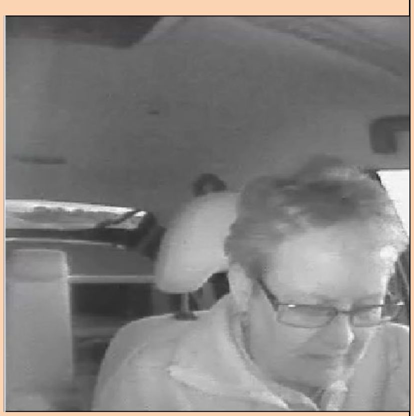
<u>RIGHT WINDOW/MIRROR:</u>

Image 1: (approaching intersection)

Image2: (at intersection)

REAR-VIEW MIRROR:
(Notice glance is to the right and up; looking directly at the camera.)

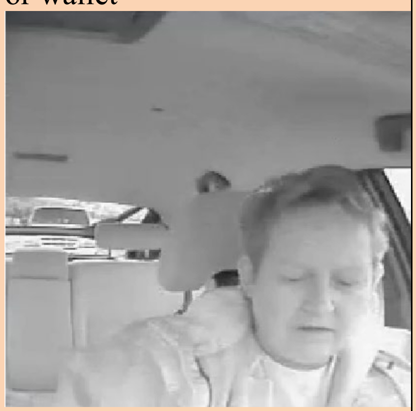
CELL PHONE:



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 B. VTTI L2 NDS REDUCTION PROTOCOL

Center Stack reduction uses a modified baseline annotation to answer researcher questions about changes in center stack secondary tasks as vehicle technologies have changed. Events were validated to determine times when center stack interaction was likely occurring, particularly times when it appeared that a secondary task involving both the eyes and hands occurred, or multiple center stack glances occurred. We will be reducing events with different PE times and Secondary Task Windows than our default baseline reduction. These events will be 20 seconds long, **the Secondary Task window is the full 20 seconds.** PE time will occur 14 seconds into the event, this time will be noted in the reduction log.

In addition to secondary tasks, attention will be given to the L2 automation state of the vehicle (adaptive cruise control + lane keeping/centering). Some of our events already have this identified and you can code what is documented in the reduction log. However, events where the vehicle is a Tesla have not had their L2 automation state determined beforehand and will need to be answered as an extra question in the annotation (replaces event severity in the default 4.2 dictionary).

Question Annotation: (uses standard 4.2 baseline dictionary with the following adjustments)

1. Subject number: Driver IDs should have been confirmed during validation but will need to be looked up during reduction. Use the CyberHEL driver ID tool.

2. L2Status: **What is the L2 Status?** - This is a determination of whether or not the vehicle has it's L2 automation systems active. These would consist of adaptive cruise control and either lane keeping or lane centering both being active. For more than half of the events we already have determined this and it's in the reduction log. For the Tesla events, reductionists will have to look at the IP video and determine whether the L2 systems are engaged. There will be a protocol appendix with training images to assist. For Tesla events L2 Status is determined at PE time.
    a. L2 Active
    b. L2 Inactive
    c. Unable to Determine

3. Secondary Task Adjustments: - Because this is a Center Stack focused reduction, particular attention should be paid to secondary tasks. We want to minimize "other" and "unknown" codings for what the driver is doing in the Center Stack area. However the collection we're using does not have a hands or over-the-shoulder video. During validation we used face video to determine when it was likely that such tasks occurred based off of eye glances or the subject reaching in that direction. For this reduction we will use those same guidelines. If it appears that some sort of Center Stack task is probably occurring, and there is no reliable evidence before, during, or after, that it was something else like a phone or interior object, then a center stack secondary task should be coded. Because we can't tell what the task is (radio, climate control, integral hands-free phone, automation-related, or display entertainment-related) rather than code a generic "other" or "unknown" task, we will select an option that reflects what sort of

center stack task is occurring. These will replace the adjusting radio and adjusting climate control options**. For Tesla events, the IP video can be very useful as it points toward the Center Stack display.**

a. Center stack, visual + manual Use this option when it seems apparent that the subject is interacting with the center stack by both looking in that direction (visually) and reaching for some part of the center stack display (manually). This can be any mix of visual and manual interactions.
b. Center stack, visual only Use this for times when the subject glances at center stack but does not ever use their hands to interact with it.
c. Center stack, manual only Use this for times the subject uses their hands to interact with the center stack but never looks at it.

In order to determine L2 status in a Tesla you have to use the IP video to take a look at the center stack display. There will be an application showing the vehicle and roadway ahead, toward the top of that display there are some icons which will appear when L2 automation is active. The first is a steering wheel icon that usually appears somewhere along the very top of the screen. The second is a maximum speed setting, however be aware that current speed and the posted speed limit for the road are also displayed.

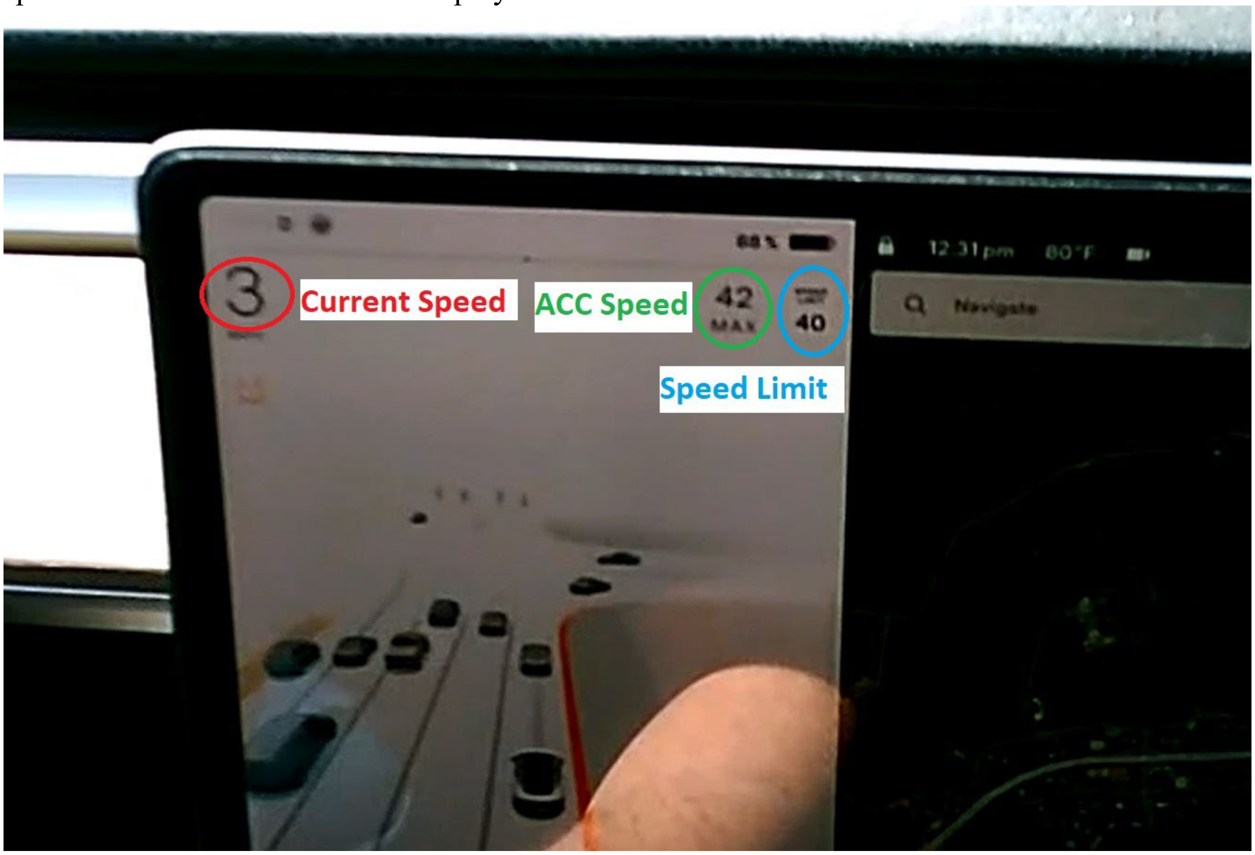


Figure 4. Photo. Tesla center stack display.

Figure 5. Photo. L2 Inactive (on standby) – has both the steering wheel and ACC speed setting but steering wheel is black.

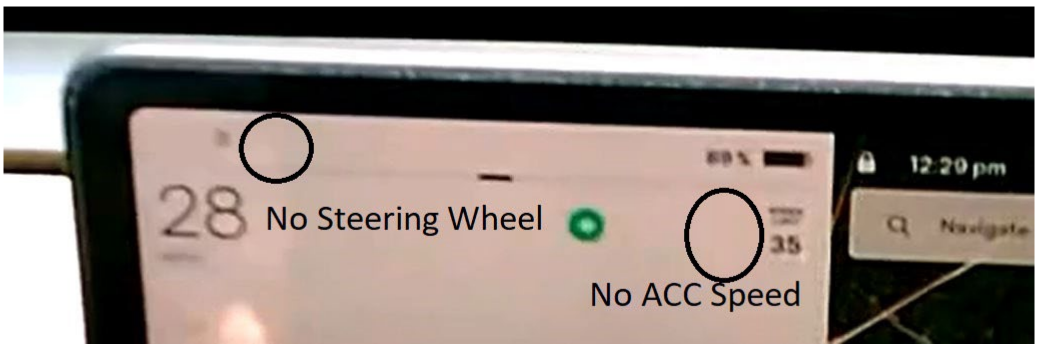


Figure 6. Photo. L2 Inactive – steering wheel and ACC speed icon have disappeared and only the vehicle speed and speed limit sign are shown.

Figure 7. Photo. L2 Inactive (on standby) – Steering wheel and ACC speed set but steering wheel is black.

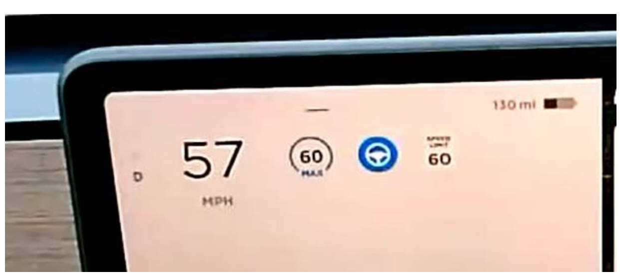


Figure 8. Photo. L2 Active – Steering wheel has turned blue.

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