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Changes in driver glance behavior when using a system that automates steering to perform a low-speed parallel parking maneuver

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A B S T R A C T

Drivers adapt their glance behavior when using automation, which may detract attention from their surroundings. Glance behavior during parallel parking maneuvers performed with and without automated steering was compared. Drivers directed a smaller proportion of their glances toward the parking space and spent less time looking at it when using automation than when not using automation. The proportion of glances and time spent looking at the instrument cluster containing information from the automation increased significantly. Drivers also spent a significantly larger proportion of time looking at the instrument cluster and a smaller proportion looking forward and rearward when using automation while approaching a parking space. The system selected the parking space in the approach phase, which may have drawn attention to the instrument cluster. In conclusion, when using automated steering during parallel parking drivers monitored their surroundings less and looked at system displays more presumably to supervise the automation. The safety implications of these changes in glance behavior should be explored in future research.

1. Introduction

Newer parking assistance systems use vehicle-based sensors to identify an open parking space and automatically control vehicle steering and sometimes the throttle and brake to precisely maneuver the vehicle into the identified space. Although these systems use vehicle-based sensors to detect surrounding objects and guide the vehicle into an open parking space, the driver remains responsible for monitoring the vehicle surroundings, detecting objects and events, and responding appropriately. The AutoPark system equipped to the 2018 Tesla Model S, for example, controls vehicle steering, throttle, and braking to maneuver the vehicle on a predetermined path into a detected available space, but, as described in the owner's manual, the system may not always detect objects in parking spaces and the driver must be prepared to apply the brakes to avoid vehicles, pedestrians, or objects (Tesla, 2018, p. 86). Whether drivers monitor their surroundings the same way when they are using automation to park as when they are parking unassisted is an open question.

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Technologies that augment the way information is acquired when performing the driving task can change visual scanning behavior. For instance, rearview cameras and parking sensors enhance visibility and detection in areas around the vehicle that are not visible using mirrors or glances through windows. Kidd and McCartt (2016) found that drivers performing low-speed parking maneuvers who used cameras, parking sensors, or both looked rearward over their shoulders for less time than drivers who did not use the technologies. Other studies have reported similar results (e.g., Kim, Rauschenberger, Heckman, Young, & Langem, 2012; McLaughlin, Hankey, Green, & Kiefer, 2003; Rudin-Brown, Burns, Hagen, Roberts, & Scipione, 2012).

There are several reasons to expect that parking assistance systems that steer the vehicle during a low-speed parking maneuver also would change driver glance behavior. Sequences of eye movements that make up glance behavior are tailored to current driving demands and where the driver needs to gather information to drive (Land & Lee, 1994; Land, 2006; Mourant & Rockwell, 1970; Shinar, 2008). Automating vehicle control can reduce driving demand (de Winter, Happee, Martens, & Stanton, 2014; Ma & Kaber, 2005; Stanton & Young, 2005) and also, in the case of lateral vehicle control, lead drivers to look at areas in the lateral direction less since they are no longer performing this aspect of the driving task.

Humans can sometimes rely too much on automation or pay less attention to the information automation is using to perform a task (Parasuraman & Wickens, 2008). In driving, past research has found that drivers using adaptive cruise control look at the forward roadway less (Reimer, Mehler, Dobres, & Coughlin, 2015). Instead, drivers redirect their gaze to other parts of the roadway (Tivesten, Morando, & Victor, 2015) or even to secondary activities unrelated to driving (Malta, Aust, & Faber, 2012). Similarly, drivers using parking assistance systems that control vehicle steering may withdraw attention from areas in the lateral direction and focus more on areas in the longitudinal direction to better support throttle and brake control or elsewhere.

Finally, drivers using automation must adapt their glance behavior to supervise it. Information about the status and operation of driving automation systems are typically found in in-vehicle displays. Information about adaptive cruise control systems is typically located in the instrument cluster. Tivesten et al. (2015) found that drivers looked at the instrument cluster more when using adaptive cruise control than when not using the feature.

Only one published study was identified that has examined glance behavior when drivers were using driving automation technology to perform a low-speed parking maneuver. Totzke (2010) examined the frequency of driver glances to different fields of view when using driving automation that controlled vehicle steering to reverse into a parking spot and when not using it. When using the automation, drivers made 22% of their glances to a center console display that contained system information, but only 1% of driver glances were to this area when the system was not being used. Drivers also made fewer glances through the rear window when using a parking assistance system that steered the vehicle. However, the study did not report any statistical comparisons of these data. Furthermore, glance behavior was characterized as a function of the fields of view that drivers used (e.g., mirrors, windows) rather than the areas around the vehicle that were being monitored. Thus, it is unclear how using driving automation during low-speed parking maneuvers affected the way drivers monitored and cross-checked information relevant to steering the vehicle.

The purpose of this study was to examine how using a parking assistance system that steered the vehicle during a parallel parking maneuver influenced driver glance behavior to different areas around the vehicle. Glance behavior was expected to be significantly different when drivers used the automation when parallel parking, compared with when drivers only used a rearview camera and parking sensor system. Drivers were expected to glance more frequently at the instrument cluster and spend significantly more time looking at it when using automation than when not using it in an effort to monitor system information and status. Additionally, drivers were expected to glance toward the right and left of the vehicle less frequently and spend less time looking at these areas when using the automation than when not using it. Instead, they were expected to redirect their attention to areas in front of and behind the vehicle to support longitudinal vehicle control.

2. Method

2.1. Participants

Data from 42 drivers who participated in a study evaluating driver stress and driving performance during the use of a semi-automated parallel parking system (Reimer, Mehler, & Coughlin, 2016) were used in this study. An equal number of men and women were recruited in three age groups (20s, 40s, 60s) from the greater Boston area using online, print advertisements, or referrals. Participants were in self-reported good health and were not taking medications that caused drowsiness or altered their psychological state (e.g., antipsychotics, antianxiety). Each driver had a valid driver's license for three or more years and did not report having a crash in the past year.

The current study focused on the frequency of glances toward different locations inside and outside the vehicle and the amount of time that drivers spent looking at each location when drivers parallel parked without and with the Lincoln Active Park Assist™ system, which automatically controlled vehicle steering. The timing and location of eye glances were coded from video recordings of the drivers' faces. The quality of video recordings from 11 of the original 42 participants was inadequate for coding eye glances. Glasses or poor lighting in these recordings resulted in an inconsistent, unclear picture of the driver's face. The final sample of 31 participants included 11 (six women) drivers in their 20s, 12 (six women) in their 40s, and 8 (three women) in their 60s.

2.2. Apparatus

Participants drove a 2010 Lincoln MKS equipped with a front and rear parking sensor system, rearview camera, and the Active Park Assist system. The rearview camera provided a view of the area directly behind the vehicle (Fig. 1). The camera image was displayed on an 8-inch diagonal-width screen in the center console. Guidelines superimposed on the camera image provided information about the proximity of objects behind the vehicle using a green (farthest), yellow, and red (closest) color scheme to indicate distance.

The ultrasonic front and rear parking sensor system identified objects up to 2 feet in front of the vehicle and 6 feet behind the vehicle (Ford and Motor Company, n.d., pp. 248–249). Distinct audible tones informed the driver about the distance between the front or rear bumper to the object. The rate of the tone increased as the vehicle moved closer to the object until it became continuous.

The Active Park Assist system controlled the steering wheel to parallel park the vehicle in an open space identified by sensors on the vehicle. The system was activated using a button near the gear shift. Once activated, the system displayed the text "ACTIVE PARK SEARCHING>>" on a two-line text display below the speedometer in the instrument cluster (Fig. 2); system status and instructions were always displayed in this location. Sensors on the vehicle searched for a parking space as the vehicle was driven past a line of parked vehicles or objects. A chime sounded when a parking space was found, and the text "SPACE FOUND >> PULL FORWARD" was displayed. After driving forward sufficiently past the parking space, the Active Park Assist system displayed the text "SPACE FOUND>>STOP" and a chime sounded. Then the system displayed "REMOVE HANDS PUT IN REVERSE" to instruct the driver to take their hands off the steering wheel and place the transmission in reverse. The system then displayed "BACKUP>>USE CAUTION," and drivers used the brake and accelerator to control the vehicle's speed and acceleration while the Active Park Assist system controlled the steering wheel to maneuver the vehicle into the parking space. The system prompted the driver to "PULL FORWARD USE CAUTION" and sounded a chime when the rear parking sensor system detected that the rear of the vehicle was close to the vehicle or object at the rear of the parking space. The same message was displayed if the driver placed the vehicle's transmission in drive before being prompted. Once placed into drive, the driver controlled the vehicle's forward motion using the brake and accelerator while the Active Park Assist system controlled the steering. The text "BACK UP SLOWLY USE CAUTION" was displayed and accompanied by a chime when the system detected that the vehicle had pulled forward far enough. The driver continued to move the vehicle

Fig. 1. Rearview camera image in the center console display.

Fig. 2. Two-line text display with Active Park Assist system status and instructions.

forward or in reverse until the system determined that the vehicle was parked. At this point the text "ACTIVE PARK FINISHED" was displayed and a chime sounded. The rearview camera and ultrasonic parking sensor system were active while drivers used the Active Park Assist system.

The vehicle was instrumented with a data acquisition system that recorded vehicle information from the controller area network bus at 10 Hz including the current gear, vehicle speed, brake input, accelerator input, and Active Park Assist system status. Vehicle data were time-synchronized with event flags manually triggered by a research associate in the vehicle, and video recordings from cameras mounted in the vehicle interior.

2.3. Procedure

Each participant was introduced to the parking technologies present in the study vehicle using short video clips produced by the manufacturer. Participants also were given an opportunity to review the relevant sections of the owner's manual. Sensors were then attached to participants to record heart electrical activity. Next, participants were led to the study vehicle where a research associate showed them the parking sensors and rearview camera on the exterior of the car. The participant sat in the front passenger seat and observed the research associate operating the parking sensor system, rearview camera, and Active Park Assist system. Participants then sat in the driver seat and drove a fixed route on local streets to become familiar with operating the vehicle. The familiarization drive lasted about 15 min.

Once familiar with the technologies and the vehicle, participants performed six practice parallel parking trials followed by six experimental parallel parking trials. All 12 parking trials were performed on an active two-lane street in Cambridge, Massachusetts, during the daytime. Participants were instructed to parallel park between two inflatable cars placed 24 feet apart and 9 in. from the curb (Fig. 3); the parking space provided adequate room for the 17-foot long Lincoln MKS. Each parking trial began when participants passed a fixed point approximately 75 feet from the rear bumper of the inflatable car at the rear of the parallel parking space. A research associate in the vehicle manually flagged the start of each trial in the data. Participants passed the open parking space, placed the vehicle in reverse, and began the parallel parking maneuver. Participants performed the necessary forward and reverse maneuvers to position the vehicle in the parallel parking space, and placed the vehicle in park, which defined the end of the parking trial. Then participants exited the parking space, drove around the block, and began the next parking trial upon returning to the starting location.

Participants alternated using and not using the Active Park Assist system between trials. Half of the sample used the Active Park Assist system in the first parking trial and the other half did not. The research associate instructed the driver whether to use the Active Park Assist system before each trial.

The original study examined driver stress levels when parallel parking with the Active Park Assist system. For this reason, participants self-reported their level of stress on a scale of 0 (not at all stressed) to 10 (very stressed) after every parking trial. They also completed two surveys before the parallel parking trials that captured information about their experience with, expectations of, and reactions to the vehicle technologies. The survey results, analysis of driver physiology and overall parking performance (e.g. use of turn signals, parking times, number of direction changes and distance to the curb) are discussed in a separate manuscript (Reimer et al., 2016).

2.4. Eye glance coding

Video of the driver's face was captured at 15 Hz during each of the six experimental parallel parking trials. Two trained data reductionists independently reviewed the video recordings and coded eye glances. Glances were coded per ISO 7()1500, 2002. A glance began at the first video frame where the driver's eye began moving to a new location until the last video frame prior to when the driver's eye began moving to a new location. Each reductionist manually coded the timing of movements in driver eye gaze to 11 possible locations: forward roadway, passenger-side mirror and window, over the right shoulder

Fig. 3. Study vehicle parallel parked between two inflatable cars.

toward the passenger-side blind spot, over the right shoulder toward the rear window, over the left shoulder, driver-side mirror and window, rearview mirror, instrument cluster, center console and rearview camera display, gear shift, or other coded area. Video frames where the driver's eyes were not visible also were coded. Discrepancies in the number, location and timing of glances (differences of greater than 200 ms) between reductionists were mediated by a third researcher. Using a third person to arbitrate disagreements between double-coded eye glance data significantly improves coding reliability (Smith, Chang, Glassco, Foley, & Cohen, 2005).

2.5. Dependent measures

Glance locations were combined into the following six categories based on the area observed from the field of view: forward; rearward (shoulder glance through rear window, rearview mirror, center console, or camera display); toward the parking space (passenger-side mirror/window, shoulder glance toward the passenger-side blind spot); away from the parking space (driver-side mirror/window, left shoulder glance); instrument cluster; and other coded locations (gear shift, other). Consecutive glances to different locations in the same category were counted separately. For example, if the driver glanced over his or her shoulder through the rear window followed by the rearview mirror, this would be counted as two rearward glances, not one.

The frequency and duration of glances to the six glance location categories were examined for two separate phases of the parallel parking maneuver with distinct vehicle control and visual demands: the approach phase and the maneuvering phase. Both glance frequency and glance duration were measured to form a comprehensive picture of glance behavior especially considering that a change in one measure does not necessarily correspond with a similar change in the other measure. The approach phase began when the parking trial started and ended when the participant placed the vehicle transmission in reverse to maneuver the vehicle into the parking space. During this phase, drivers drove forward while searching for an available parking space while monitoring their surroundings. The maneuvering phase started when the vehicle transmission was first placed in reverse and ended when the vehicle was placed in park at the end of the parking trial. In this phase, drivers maneuvered the vehicle longitudinally and monitored their position relative to the surrounding vehicles and environment.

Glance behavior was characterized by computing the frequency of glances to different glance location categories and the total duration of glances to each category separately for the approach and maneuvering phases. The approach and maneuvering phase of every trial took a different amount of time to complete, so these measures were normalized by computing the percentage of all glances made to each glance location category and the percentage of time spent looking at each glance location category during each phase for every parking trial.

2.6. Data analysis

A generalized linear mixed modeling approach was used to assess whether using the Active Park Assist system, when approaching a parallel parking space and maneuvering into it, was associated with changes in the percentage of glances drivers made toward each glance location category and the percentage of time drivers spent looking toward each one. Trial (2 vs. 1, 3 vs. 1), technology (Active Park Assist vs. Camera & Sensor), and an indicator variable for each glance location category (forward, rearward, toward the parking space, away from the parking space, instrument panel, other) were included as fixed effects. The two- and three-way interactions between these variables also were included as fixed effects in each model. Driver was included as a random effect to account for within-subject variance from repeated observations across trials and glance location categories. An exchangeable correlation structure was assumed for each model. Model parameters were estimated using the restricted maximum likelihood technique, and were considered statistically significant if the p-value of the associated t test for the hypothesis that the parameter is zero was less than 0.05. Separate models were constructed for the approach phase and maneuvering phase, resulting in four total models (2 dependent measures $\times$ 2 phases). Modeling was performed using the PROC GLIMMIX procedure in SAS 9.4.

Generalized score tests indicated that the set of parameters making up the main effect of trial and the two- and three-way interactions that included trial did not significantly improve model fit at the 0.05 level for any of the four full models that were constructed. Hence, these parameters were excluded from the final analysis. The final models included technology, an indicator variable for each glance location category, and the two-way interactions between technology and each glance location category as fixed effects, and driver as a random effect. The two-way interactions between technology and each glance location category indicated whether the Active Park Assist system was associated with a significant change in the percentage of glances made toward each glance location category or the percentage of time spent looking toward each. These two-way interaction terms were the effects of interest and are the focus of Section 3 below.

3. Results

3.1. Approaching the parallel parking space

Across trials, on average, each driver made eight glances (SD = 2.5) during the approach phase when they were not using Active Park Assist and 15 glances (SD = 4.7) when they were using the system. The average percentage of glances drivers made when approaching the parallel parking space that were directed toward each glance location category when the Active Park Assist system was used and when it was not used is shown in Table 1. The linear mixed model results indicated that, after controlling for other variables in the model, the percentage of glances directed rearward significantly decreased 11 percentage points ($b = -10.6$, $t(30) = -5.9$, $p < 0.001$), and the percentage of glances in the lateral direction toward the parking space significantly decreased 23 percentage points ($b = -22.5$, $t(30) = -12.5$, $p < 0.001$) when drivers used the Active Park Assist system while approaching the parking space, compared with when they did not use the system. In contrast, the percentage of glances made toward the instrument cluster when drivers used Active Park Assist significantly increased 31 percentage points ($b = 30.9$, $t(30) = 17.1$, $p < 0.001$), compared with when they did not use the system. The percentage of glances forward, in the lateral direction away from the parking space, and to other coded areas did not vary significantly with or without Active Park Assist.

On average across trials, each driver took 13.6 s ($SD = 3.0$) to approach the parallel parking space when they were not using Active Park Assist and 19.1 s ($SD = 4.1$) when they were using the system. The average percentage of time that drivers looked at each glance location category when approaching the parking space as a function of the Active Park Assist system is shown in Table 2. The linear mixed model results indicated that drivers spent a significantly smaller percentage of time looking forward ($b = -12.4$, $t(30) = -5.6$, $p < 0.001$), rearward ($b = -8.1$, $t(30) = -3.67$, $p < 0.001$), and in the lateral direction toward the parking space ($b = -21.1$, $t(30) = -9.6$, $p < 0.001$) when using the Active Park Assist system, compared with when they did not use it, after controlling for other variables in the model. The percentage of time drivers looked at the instrument cluster when using the system significantly increased 44 percentage points ($b = 43.5$, $t(30) = 19.7$, $p < 0.001$), compared with when they did not use the system, after controlling for other variables in the model. The percentage of time each driver looked in the lateral direction away from the parking space and at other coded areas when approaching the parallel parking space did not vary significantly when they were and were not using the Active Park Assist system. The results from the linear mixed models assessing glance behavior when drivers approached the parallel parking space are summarized in Table A1 of Appendix A.

3.2. Maneuvering into the parallel parking space

On average across trials, each driver made 34 glances ($SD = 14.3$) during the maneuvering phase when they were not using the Active Park Assist system and 30 glances ($SD = 12.2$) when they were using it. The average proportion of all glances

Table 1
Mean (SD) percentage of glances toward different glance location categories when approaching a parallel parking space, with the camera and sensor only and with Active Park Assist.

Glance location category	Technology	
	Camera & sensor only	Active Park Assist
Longitudinal direction		
Forward	31.16 (10.09)	34.57 (8.94)
Rearward	21.76 (14.20)	10.97 (8.02)
Lateral direction		
Toward parking space	26.28 (14.09)	3.57 (5.01)
Away from parking space	6.38 (8.46)	6.03 (7.24)
Instrument cluster	5.25 (7.65)	35.94 (8.09)
All other coded areas	8.49 (8.96)	8.45 (6.42)
Unknown (eyes not visible)	0.69 (2.78)	0.47 (1.84)

Table 2
Mean (SD) percentage of time spent looking toward different glance location categories when approaching a parallel parking space, with the camera and sensor only and with Active Park Assist.

Glance location category	Technology	
	Camera & sensor only	Active Park Assist
Longitudinal direction		
Forward	43.65 (15.50)	30.59 (11.54)
Rearward	17.49 (19.16)	8.78 (9.07)
Lateral direction		
Toward parking space	24.99 (17.39)	3.28 (6.39)
Away from parking space	3.92 (6.60)	4.83 (7.57)
Instrument cluster	3.08 (6.04)	45.91 (13.36)
All other coded areas	6.00 (6.86)	6.37 (4.56)
Unknown (eyes not visible)	0.87 (4.10)	0.24 (1.14)

Table 3
Mean (SD) percentage of glances toward different glance location categories when maneuvering into a parallel parking space, with the camera and sensor only and with Active Park Assist.

Glance location category	Technology	
	Camera & sensor only	Active Park Assist
Longitudinal direction		
Forward	30.95 (6.22)	29.01 (9.43)
Rearward	26.86 (9.81)	27.49 (9.67)
Lateral direction		
Toward parking space	20.34 (7.63)	13.65 (8.30)
Away from parking space	10.32 (7.54)	7.29 (6.42)
Instrument cluster	4.50 (5.66)	16.58 (8.43)
All other coded areas	5.22 (5.72)	5.52 (5.62)
Unknown (eyes not visible)	1.81 (4.68)	0.46 (1.32)

Table 4
Mean (SD) percentage of time spent looking toward different glance location categories when maneuvering into a parallel parking space, with the camera and sensor only and with Active Park Assist.

Glance location category	Technology	
	Camera & sensor only	Active Park Assist
Longitudinal direction		
Forward	34.96 (10.50)	25.65 (13.52)
Rearward	26.27 (12.66)	34.74 (17.21)
Lateral direction		
Toward parking space	21.69 (11.39)	14.25 (11.16)
Away from parking space	7.92 (7.18)	6.17 (6.55)
Instrument cluster	2.93 (4.85)	14.73 (10.27)
All other coded areas	3.71 (4.52)	4.08 (4.17)
Unknown (eyes not visible)	2.52 (7.23)	0.37 (1.19)

that a driver made toward each glance location category during the maneuvering phase is shown in Table 3. The linear mixed model results indicated that, after controlling for the other variables in the model, when using the Active Park Assist system to maneuver the vehicle into the parallel parking space the percentage of glances drivers made in the lateral direction toward the parking space significantly decreased 5 percentage points ($b = -5.3$, $t(30) = -3.6$, $p < 0.01$), and the percentage of glances made to the instrument cluster significantly increased 13 percentage points ($b = 13.4$, $t(30) = 8.9$, $p < 0.001$), compared with when they were not using the system. The two-way interactions between technology and all the other glance location categories were not statistically significant.

Across trials, on average, each driver took 46.2 s ($SD = 21.5$) to maneuver into the parallel parking space when not using the Active Park Assist system and 36.2 s ($SD = 10.4$) when using the system. The average percentage of time that drivers looked at each glance location category when maneuvering into the parallel parking space as a function of using the Active Park Assist system is shown in Table 4. The linear mixed model results indicated that when using the Active Park Assist system to maneuver the vehicle into the parallel parking space, the percentage of time drivers looked rearward significantly increased 11 percentage points ($b = 10.6$, $t(30) = 5.3$, $p < 0.001$), and the percentage of time they looked at the instrument cluster significantly increased 14 percentage points ($b = 14.0$, $t(30) = -6.9$, $p < 0.001$), compared with when they were not using the system after controlling for other variables in the model. In contrast, the percentage of time drivers looked forward significantly decreased 7 percentage points ($b = -7.2$, $t(30) = -3.6$, $p < 0.01$), and the percentage of time they looked in the lateral direction toward the parking space significantly decreased 5 percentage points ($b = -5.3$, $t(30) = -2.6$, $p < 0.05$). There was no significant difference in the percentage of time that drivers looked in the lateral direction away from the parking space or to other coded areas when they were using the Active Park Assist system and were not using it. The results from the linear mixed models assessing glance behavior when drivers maneuvered into the parallel parking space are summarized in Table A2 of Appendix A.

4. Discussion

The objective of this study was to examine how using driving automation that controls vehicle steering influenced the way drivers monitored different areas around the vehicle during a low-speed parallel parking maneuver. The percentage of glances and percentage of time that drivers glanced toward different areas around and inside the vehicle significantly changed when they used the Active Park Assist system. Automating parts of the driving task changes the driver's role from an operator performing the task to a supervisor monitoring automated performance (Parasuraman, Sheridan, & Wickens, 2000). As expected, drivers made proportionally more glances and spent more time looking at the instrument cluster where instructions and status information from the Active Park Assist system were located when using the system than when not using it. Totzke (2010) similarly found that the frequency of glances in the direction of the instrument cluster increased when steering was automated while drivers backed into a parking space. Comparable changes in glance behavior have been noted with adaptive cruise control, which automates longitudinal vehicle control (Reimer et al., 2015; Tivesten et al., 2015).

The Active Park Assist system steered the vehicle into a parking space, making the visual information in the direction of the parking space less relevant for controlling the vehicle in the maneuvering phase (e.g., Land, 2006; Land & Hayhoe, 2001; Land & Lee, 1994). As hypothesized, drivers made proportionally fewer glances in the lateral direction toward the parking space and spent proportionally less time looking at this area when using Active Park Assist to maneuver into the parking space than they did when not using it. When using the system, drivers were expected to shift their gaze from the parking space to the areas in front and behind the vehicle to support the longitudinal vehicle control task they continued to perform (e.g. Parasuraman & Manzey, 2010; Parasuraman, Molloy, & Singh, 1993). Drivers looked rearward for a significantly greater proportion of time when using the system to maneuver into the space, but this increase was offset by a significant decrease in the proportion of time drivers looked forward. The total proportion of time drivers looked forward and rearward when using the system to maneuver into the space was similar to when they were not using it. These findings suggest that drivers mainly reallocated glances from the parking space to the instrument cluster when using the Active Park Assist system during the maneuvering phase.

The information presented in the instrument cluster helped drivers use and supervise the Active Park Assist system, but, consequently, diverted visual attention from other areas around the vehicle. The findings of this study do not indicate if drivers were able to efficiently balance attention between the instrument cluster and the surrounding environment when using the automation. Ineffective monitoring and automation-induced complacency have contributed to accidents in other transportation domains (e.g., National Transportation Safety Board, 1997, 2014). Future research should investigate whether drivers using automation during low-speed parking maneuvers are less likely to notice and respond appropriately to unexpected hazards in the vehicle's path or detect driving automation technology failures.

Drivers spent a smaller proportion of time looking both forward and rearward when approaching the parallel parking space. The Active Park Assist system did not automate steering or any other driving functions during the approach phase, but it did identify an available parallel parking space and direct them to the appropriate starting point. Human operators are more likely to rely on automation with higher levels of decision-making authority without cross-checking sources of supporting information (Cummings, 2004; Parasuraman & Manzey, 2010; Parasuraman & Wickens, 2008). The system automated some aspects of decision-making during the approach phase, which may explain why drivers looked at the instrument cluster more and their surroundings less. Alternatively, task instructions to use the Active Park Assist system to park in a single, predetermined location may have caused drivers to look at the instrument cluster more than if they had been using the system in a more naturalistic setting. Still, designers of driving automation technology should consider how seemingly small changes to the driving task that are unrelated to automating vehicle functions can influence driver behavior.

The results of this study have practical implications for the design of driving automation technology. First, this study provides additional evidence that drivers direct visual attention to displays that support their use of driving automation technology and consequently reduce attention to other areas relevant to operating the vehicle and monitoring automated performance. Locating information displays within or near areas that the driver needs to monitor when using automation may encourage drivers to cross-check information. For instance, status information and instructions from automatic parking systems can be presented within or near the rearview camera image. However, display location has not been shown to reliably affect the incidence of automation-induced complacency (e.g., Singh, Molloy, & Parasuraman, 1997). Second, the findings indicated that drivers may rely more on automation when it chooses a course of action (i.e., selecting a parking space) than when drivers make this choice. Automating decision-making is beneficial when the probability of system failure is low but is not advisable when a failure can negatively impact safety since the failure may go undetected (Cummings, 2004; Parasuraman & Wickens, 2008).

There were several limitations in this study. First, participants were novice users of the Active Park Assist system. Participants received extensive instruction and six practice trials to familiarize themselves with the system, but the differences in glance behavior reported in this study may not reflect the actual changes observed following long-term use. It is also important to consider that drivers were required to use the Active Park Assist system to parallel park in a defined space rather than using the system to park in one of multiple available spaces. The study's demand characteristics may have pushed drivers to rely more on the system during the approach phase than they would have in a naturalistic setting. Another limitation is that glance behavior observed during the use of the Active Park Assist system may not generalize to comparable systems in other production vehicles. The interactions drivers have with vehicle technology can vary widely depending on how the technology is implemented in different vehicles and performs during actual use (Kidd, Cicchino, Reagan, & Kerfoot, 2017). Finally, like other driving tasks (Land & Lee, 1994; Mourant and Rockwell, 1970; Shinar, 2008), driver glance behavior is highly dependent on the demands of the parking maneuver (Huey, Harpster & Lerner, 1995). Drivers completed the parallel parking maneuver faster and with fewer changes in direction when they used the Active Park Assist system compared with when they did not use it (Reimer et al., 2016). The reversal in the proportion of time drivers looked forward and rearward when using the system and not using it may reflect differences in the number of times drivers changed directions and time they were moving in each direction. The size of the parking space in this study also was quite generous and driver glance behavior may be different when drivers use automation to park in smaller, more demanding spaces. Finally, motor control, body posture, and body movements may change when automation is used during parallel parking and could influence glance behavior, but these factors and their interaction with glance behavior were not considered.

4.1. Conclusion

In conclusion, driving automation technology that steers the vehicle during a low-speed parking maneuver significantly changed the way drivers monitored different areas around the vehicle and inside of it relative to when the technology was not being used. Drivers looked in the lateral direction toward the parking space significantly less frequently and for shorter periods of time when using the automation and redirected their visual attention to the instrument cluster where instructions and information related to using the automation was presented. Drivers also withdrew visual attention from areas in front of and behind the vehicle as they waited for the system to identify an available parking space even though vehicle control was not automated. Together, these findings suggest that automating a driving function changes the way drivers allocate attention around the vehicle and inside of it to support the driving task, and also may influence glance behavior in situations where the function is not automated depending on the way the system is implemented.

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Appendix A. Tables

Tables A1 and A2

Table A1
Results of two separate linear mixed models of the percentage of glances directed toward different glance location categories and the percentage of time spent looking at each when using the camera and sensor only and Active Park Assist while approaching a parallel parking space.

Parameter	Percentage of all glances made			Percentage of total glance duration		
	Estimate	95% Confidence Interval	p-value	Estimate	95% Confidence Interval	p-value
Intercept	0.69	[−1.15, 2.52]	0.45	0.87	[−1.53, 3.27]	0.46
Active Park Assist vs. camera & sensor only	−0.22	[−2.83, 2.38]	0.86	−0.63	[−3.81, 2.56]	0.69
Forward	30.47	[27.87, 33.07]	<0.001	42.78	[39.16, 45.95]	<0.001
Rearward	21.07	[18.47, 23.67]	<0.001	16.62	[13.45, 19.80]	<0.001
Toward parking space	25.59	[22.99, 28.19]	<0.001	24.12	[20.95, 27.29]	<0.001
Away from parking space	5.70	[3.10, 8.30]	<0.01	3.05	[−0.13, 6.22]	0.06
Instrument cluster	4.56	[1.97, 7.16]	<0.01	2.21	[−0.96, 5.39]	0.17
Other coded areas	7.80	[5.20, 10.40]	<0.001	5.13	[1.96, 8.31]	<0.01
Forward × (Active Park Assist vs. camera & sensor only)	3.63	[−0.05, 7.32]	0.05	−12.43	[−16.93, −7.93]	<0.001
Rearward × (Active Park Assist vs. Camera & sensor only)	−10.57	[−14.25, −6.88]	<0.001	−8.09	[−12.59, −3.59]	<0.01
Toward parking space × (Active Park Assist vs. Camera & sensor only)	−22.49	[−26.17, −18.80]	<0.001	−21.08	[−25.58, −16.58]	<0.001
Away from parking space × (Active Park Assist vs. Camera & sensor only)	−0.13	[−3.82, 3.56]	0.94	1.53	[−2.97, 6.04]	0.49
Instrument cluster × (Active Park Assist vs. Camera & sensor only)	30.91	[27.23, 34.60]	<0.001	43.46	[38.95, 47.96]	<0.001
Other coded areas × (Active Park Assist vs. Camera & sensor only)	0.19	[−3.50, 3.88]	0.11	0.99	[−3.51, 5.50]	0.66

Table A2
Results of two separate linear mixed models of the percentage of glances directed to different glance location categories and the percentage of time spent looking at each when using the camera and sensor only and Active Park Assist while maneuvering into a parallel parking space.

Parameter	Percentage of all glances made			Percentage of total glance duration		
	Estimate	95% Confidence Interval	p-value	Estimate	95% Confidence Interval	p-value
Intercept	1.81	[0.27, 3.34]	<0.05	2.52	[0.19, 4.85]	0.04
Active Park Assist vs. camera & sensor only	−1.34	[−3.52, 0.83]	0.22	−2.15	[−5.45, 1.16]	0.19
Forward	29.14	[26.98, 31.31]	<0.001	32.44	[29.53, 35.35]	<0.001
Rearward	25.05	[22.89, 27.22]	<0.001	23.75	[20.84, 26.66]	<0.001
Toward parking space	18.53	[16.36, 20.70]	<0.001	19.17	[16.26, 22.08]	<0.001
Away from parking space	8.52	[6.35, 10.68]	<0.01	5.40	[2.49, 8.31]	<0.01
Instrument cluster	2.69	[0.53, 4.86]	<0.05	0.41	[−2.50, 3.32]	0.78
Other coded areas	3.41	[1.25, 5.58]	<0.01	1.19	[−1.72, 4.10]	0.41
Forward × (Active Park Assist vs. camera & sensor only)	−0.60	[−3.67, 2.48]	0.69	−7.15	[−11.27, −3.03]	<0.01
Rearward × (Active Park Assist vs. camera & sensor only)	1.97	[−1.11, 5.04]	0.20	10.61	[6.49, 14.73]	<0.001
Toward parking space × (Active Park Assist vs. camera & sensor only)	−5.35	[−8.42, −2.27]	<0.01	−5.29	[−9.41, −1.17]	<0.05
Away from parking space × (Active Park Assist vs. camera & sensor only)	−1.69	[−4.76, 1.39]	0.27	0.40	[−3.72, 4.52]	0.84
Instrument cluster × (Active Park Assist vs. camera & sensor only)	13.42	[10.35, 16.50]	<0.001	13.95	[9.83, 18.07]	<0.001
Other coded areas × (Active Park Assist vs. camera & sensor only)	1.64	[−1.44, 4.71]	0.29	2.52	[−1.60, 6.64]	0.22

Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.trf.2018.07.002.

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