U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

NHTSA

DOT HS 813 565

April 2024

Older Drivers' Use of Rearview Video Systems

This page is intentionally left blank.

DISCLAIMER

Suggested APA Format Citation:

Staplin, L., Owens, J., Wotring, B., Mastromatto, T., Lococo, K. H., & Sifrit, K. J. (2024, April). *Older drivers' use of rearview video systems* (Report No. DOT HS 813 565). National Highway Traffic Safety Administration.

This page is intentionally left blank.

Technical Report Documentation Page

1. Report No. DOT HS 813 565	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Older Drivers' Use of Rearview Video Systems		**5. Report Date** April 2024 **6. Performing Organization Code**
7. Author(s) Loren Staplin[±], Justin Owens[¥], Brian Wotring[¥], Tia Mastromatto[±], Kathy H. Lococo[±], and Kathy J. Sifrit*		**8. Performing Organization Report No.**
9. Performing Organization Name and Address [±] TransAnalytics, LLC 336 West Broad Street Quakertown, PA 18951 [¥] Virginia Tech Transportation Institute 3500 Transportation Research Plaza Blacksburg, VA 24061		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** Contract No. DTNH22-16-C-00011
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Avenue SE Washington, DC 20590		**13. Type of Report and Period Covered** Final Report **14. Sponsoring Agency Code** NPD-320
15. Supplementary Notes *Dr. Kathy Sifrit was the NHTSA task order manager on this project.		

16. Abstract

This investigation examined older drivers' backing performance using a rearview video system (RVS) versus using inside and outside rearview mirrors alone. On a closed course, participants ages 60 to 69 and 70+ drove an instrumented late model sedan with center-console-mounted RVS display. Researchers tasked participants with backing, following a path defined by pavement markings as closely as possible, backing into a parking space, and completing a three-point turn; in some trials participants were to avoid a traffic cone while backing. Researchers added a single "surprise trial" at the end of the driving session in which they placed a traffic cone behind the test vehicle without the participant's knowledge. The study measured both the frequency and duration of drivers' eye glances to and away from the RVS display, along with performance errors.

The findings from the backing performance study supported development of an RVS training video that focused on preventing errors observed during that data collection effort and addressing study participants' difficulties using the technology. The backing performance study results show that instruction should be directed to drivers both experienced and inexperienced with RVS use, focusing not only on detecting/avoiding obstacles to the rear but also on improving the accuracy of backing movements by exploiting the overlay of RVS grid lines on pavement features. Researchers also developed a research plan and data collection protocol to evaluate the effectiveness of the training video in a later investigation. An increasing share of the U.S. passenger vehicle fleet is equipped with RVS technology, which offers safety and convenience benefits, particularly for older drivers whose neck/torso range of motion diminish with normal aging. However, to realize the full potential of their RVS, older drivers may benefit from training to become more proficient in RVS use.

17. Key Words Older driver, backup camera, backup video, rearview camera, rearview video, training		**18. Distribution Statement** This document is available to the public from the DOT, BTS, National Transportation Library, Repository & Open Science Access Portal, https://rosap.ntl.bts.gov.	
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 78	**22. Price**

Form DOT F 1700.7 (8-72) Reproduction of complete page authorized

This page is intentionally left blank.

Table of Contents

List of Figures

List of Tables

Acknowledgments

The authors are grateful to members of the Virginia Tech Transportation Institute (VTTI) team who provided valuable project assistance. Jon Antin provided input on experimental design and analyses, Lisa Eichelberger assisted with data collection, Christine Link-Owens led participant recruitment, and Julie McClafferty led data reduction. Hardware and software development and installation were led by Jared Bryson, Carl Cospel, Julie Rutledge, and Nicholus Sunshine.

Executive Summary

The National Highway Traffic Safety Administration (NHTSA) required that all new passenger vehicles under a gross vehicle weight rating (GVWR) of 10,000 pounds display rearview images meeting certain requirements by May 2018. Older drivers may benefit the most from proper rearview video system (RVS) use, as this technology may help compensate for age-related functional deficits including decreased neck/torso range of motion (ROM) and a narrowed useful field of view. These considerations were the premise for an investigation into how well older drivers with and without experience using an RVS could perform backing maneuvers encountered in everyday driving when using the RVS versus mirrors alone. Based on the findings, the research team developed an instructional video to address participants' performance errors and difficulties and a research plan for evaluating the effectiveness of the training video.

In this study, researchers obtained measures of backing performance using an RVS and using mirrors alone (the RVS display was blocked, so was unavailable during these trials) by cohorts of drivers aged 60 to 69 and 70 and older, seeking to identify specific maneuvers that were problematic for these drivers and that could be amenable to training. Researchers assessed participants' neck and torso ROM before beginning backing tasks as limitations in neck/torso flexibility may limit a driver's ability to turn their head to look behind the vehicle. Backing performance measures included binary outcomes (striking/avoiding rear hazard, use/nonuse of the RVS during a trial); continuous measures (number and duration of eye glances, deviation of the vehicle's path from a reference line on the pavement); and counts (of positioning and contact errors) as a function of categorical variables (e.g., age cohort, RVS experience). Positioning errors included vehicle tires touching or crossing a lane line, or vehicle misalignment, while contact errors included actual contact with a sign, obstacle, or a plastic barrier. These measures were applied across various backing tasks associated with everyday maneuvers—short backing (as if backing out of a parking space or garage); long backing; backing into a parking space (where there are potential conflicts with adjacent vehicles); and a three-point turn. A single "surprise trial" required participants to avoid an obstacle surreptitiously placed behind the parked test vehicle.

This study and associated data collection received clearance under the Paperwork Reduction Act (OMB Control No. 2127-0731) and approval by the Virginia Tech Institutional Review Board (IRB).

Analyses revealed statistically significant differences in driver performance on the short backing task as a function of frequency of glances to the RVS, level of driver familiarity/experience with an RVS, and age group. Specifically, a higher number (but *not* duration) of glances after beginning backing was associated with a decrease in contact errors (but with an *increase* in positioning errors). Drivers who were experienced with an RVS were significantly less likely to strike an obstacle (traffic cone) behind the vehicle when backing, and they also spent a significantly higher proportion of time glancing to the RVS both prior to and after initiating backing compared to drivers who were inexperienced with RVS. The drivers aged 60 to 69 spent a significantly greater amount of time glancing at the RVS display than the age 70 and older group before beginning backing, but this difference disappeared once the maneuver was initiated.

The long backing task included both straight and curved segments; performance was measured separately on each segment. Overall, drivers who looked at the RVS display longer, regardless of their experience level with an RVS, were significantly less likely to commit gross positioning errors. However, as in the short backing task, participants who looked away from the display more frequently tended to make more frequent positioning errors. More *time* spent using the RVS during the backing maneuver was associated with significantly *fewer* positioning errors. There was no association between the number of glances and positioning errors. There were also effects in task performance related to the level of RVS experience. Prior to backing, and during backing on both the straight and curved segments of this task, those with previous RVS experience allocated a significantly greater percentage of time than inexperienced participants looking at the RVS. There were no significant effects associated with driver age group on this task.

The RVS was available for some backing into a parking space trials and on other trials drivers relied on mirror views alone as the RVS display was blocked. Three-fourths of the contact errors were committed in this "mirrors a" condition; however, two drivers committed contact errors when the RVS was available. Both were inexperienced with the technology. Nearly every participant committed some form of positioning error, generally a vehicle misalignment; still, the older (70+) age group was significantly more likely to commit positioning errors than the younger (60 to 69) age group. A higher percentage of time looking at the RVS display during backing, as well as more glances to the display during backing, were both associated with significantly fewer errors. Further, drivers in the group experienced with an RVS allocated significantly more time to the rear camera display than those in the inexperienced group, but *only* after they began to back the vehicle. Also in this task, drivers struck an obstacle (a shopping cart) while backing significantly more often if their neck/torso ROM was limited, rather than being in the normal range, and if they were in the 70+ age group.

On the single "surprise event" trial, both the number of glances to the display prior to backing and the percentage of time spent looking at the RVS display while backing were associated with a significantly lower likelihood of error. Also, the level of driver familiarity with an RVS was associated with significant differences in task performance; 38% of drivers in the group with RVS experience struck the traffic cone in the surprise object trial, while 80% in the inexperienced group struck the traffic cone. There was no effect of age on errors in this task.

Researchers used the driver performance data, supplemented by (unsolicited) comments from participants, to develop priorities for instructional video content. These emphasized use of an RVS (a) where participants felt the information provided by the RVS would be most helpful to them; (b) where the RVS is the *only* source of information that allows the driver to avoid a conflict; and (c) where task performance depends on sharing/shifting attention between the RVS display, mirror views, and direct looks to the side and/or over the shoulder, to detect potential conflicts not visible with the outside mirrors. A further conclusion was that instruction should be considered regardless of a driver's RVS experience, focusing not only on detecting/avoiding obstacles behind the vehicle but also on improving the accuracy of backing maneuvers by using the grid lines on the RVS display to align the vehicle.

Introduction

Background

Crashes during backing maneuvers over a 25-year period from 1990 to 2014 resulted in 2,251 incidents and 1,232 deaths of children under 15 (Zonfrillo et al., 2018). A backing maneuver crash may occur when the driver is not aware of a hazard behind the vehicle. NHTSA's final rule in 2014 required all new vehicles under 10,000 pounds gross vehicle weight rating to provide a rearview image covering a specific area behind the vehicle by May 2018. This signified a major step toward the prevention of deaths and injuries from back-over crashes, but the ultimate safety gains depend in part on the driver understanding and using the technology as intended.

Older adults in particular may benefit from RVS technology. Age-related musculoskeletal limitations may impair a driver's ability to turn and scan behind the vehicle, while declines in visual search, visual information processing, and divided attention capacity may undermine an older driver's recognition of possible conflicts from cross traffic when backing from a driveway or a parking stall. RVSs have the potential to compensate for age-related functional deficits such as decreased flexibility and a narrower useful field of view (Meyer, 2009; Trubswetter & Bengler, 2013).

The acceptance and use of new technology among older adults rely on the perceived benefit—influenced by usability, functionality, and needs—relative to cost. Trubswetter and Bengler (2013) found that older drivers' most cited barrier to using advanced vehicle technology was *lack of perceived usefulness*, followed by *perceived system limitations*, often among participants who had never used the advanced vehicle technology. There is also evidence that some drivers of all ages do not use RVS technology effectively. Researchers observing visual sampling behavior of drivers during staged and naturalistic backing maneuvers concluded that, while an RVS offers a driver a useful tool for detecting obstacles behind the vehicle, drivers must learn to incorporate this new visual information source into their glance behavior (Mazzae et al., 2008; Llaneras et al., 2011).

The effective use of new in-vehicle technology may be particularly difficult for older drivers because it requires them to change their driving techniques and routines as well as acquire and incorporate new driving skills (Meyer, 2009; Trubswetter & Bengler, 2013). While older adults are less likely than their younger and possibly more tech-savvy counterparts to quickly learn to use new in-vehicle technology, they are often motivated to learn a new technology once they recognize its benefits (Yang & Coughlin, 2014). As advanced in-vehicle technology becomes more common, more driver education may be required on how and when to effectively use these systems, particularly for older drivers (Reimer et al., 2016).

Objectives and Scope

This project had three objectives. The first was to compare older drivers' backing performance using an RVS versus using inside and outside rearview mirrors alone. The second objective was to use the findings from the backing performance study to develop an RVS training video that focused on correcting errors observed during the first study segment and addressing study participants' difficulties using the system. A final objective was to develop a research plan and data collection protocol to evaluate the effects of RVS training on avoiding hazards while backing.

This study addressed the following research questions.

- How does the ability of older drivers to detect and avoid obstacles when backing using standard inside and outside rearview mirrors compare to that when using an RVS during different types of backing tasks?
- Are there significant performance differences in RVS use by drivers in their 60s versus those 70 and older?
- Which elements of RVS use are particularly difficult for older drivers?
- Can the results of the backing performance study be used to develop an RVS training video that addresses the errors that most affect drivers' safety and confidence in the technology when backing?

The project scope included:

- A literature review to identify studies that explored drivers' use of RVS, especially among older drivers;
- Obtaining measures of backing performance (using RVS versus mirrors alone) from 80 licensed drivers ages 60 to 69 and 70 and older, with half in each age group familiar with RVSs and the other half unfamiliar;
- Designing an RVS training video to address backing errors using an RVS, and drivers' lack of confidence in this technology; and
- Developing a plan for a training effectiveness evaluation study with participants age 60 and older with limited RVS experience or low confidence in RVS.

Literature Review

The researchers performed a limited review of studies conducted within the past 10 years that focused on older drivers' use of RVSs. The purpose was to identify similar or relevant studies to inform development of data collection designs for the current study.

The research team searched for articles published in 2006 and later in the following databases: TRID, PsycINFO, and Ageline. The team also performed searches in GoogleScholar, PubMed (which includes MedLine), and Science Direct. The main search strategy focused on the driving behavior of older people while using RVSs, and it included the following search terms:

Search Years: 2006 to 2016

aging OR old* OR elder* or senior
AND
backup camera OR backup video OR rearview camera OR rearview video

The researchers acquired 24 full-text reports as candidates for the literature review. Many of these reports did not include older drivers or included drivers 60 and older but did not do an age-related analysis. Several studies assessed the *effectiveness* of the RVS and were excluded as out of scope with the purpose of the task. A few articles simply synthesized or duplicated reports of full studies already acquired. Only 5 recent (2006 to 2016) studies focused on older drivers' use of the rear video or other backing system. Two on-road studies directly measured behavior of drivers using the system, and 3 relied on questionnaire data to assess older drivers' use and perception of such technology.

In-Vehicle Studies

Heckman et al. (2012) investigated the individual and combined effects of backing tasks, display location, and driver age on fixations to the RVS display by measuring driver gaze duration during a series of backing tasks on a closed course. The test course was a closed test track loop with six stations, each associated with a different forward or backing task. Backing tasks included (1) backing into a parking stall; (2) backing out of a garage; (3) parallel parking; and (4) backing down a driveway. A final backing task included one of the four backing tasks with the introduction of an unexpected obstacle that was hidden from view until the participant began to reverse. Gaze durations were longer for the parking stall task than for the other three tasks, and they were longer for the driveway task than for the parallel parking and garage tasks. The youngest age group (18 to 39) had significantly longer average gaze duration than those 40 to 59 and those 60 and older. There was no significant difference in gaze duration between the 40 to 59 and 60 and older age groups.

Overall, the results showed that the middle-aged and older drivers tended to use the RVS less than their younger counterparts. The authors suggested that this result may show age-related declines in visual search and divided attention, but it could also represent older and middle-aged drivers' reluctance to rely primarily on the RVS rather than the more familiar mirrors and head turns. Though drivers of all ages spent more time gazing at the RVS display than at mirrors, it was unclear if the reduction in RVS gaze seen among the middle-aged and older driver age groups was accounted for by gaze duration to the rearview and/or side mirrors or by turning around to look out the rear window.

Reimer et al. (2016) explored whether drivers could become comfortable with semi-autonomous parallel parking systems (as compared to manual parking) following comprehensive introduction to the technology under realistic field conditions. The researchers assessed comfort by measuring participants' heart rate as they performed a parallel parking task and by their self-reported retrospective stress ratings. A test vehicle was equipped with the manufacturer's forward and reverse proximity sensing systems, rearview camera, and active park assist (APA), and it was instrumented with a data acquisition system that could play recorded audio through the vehicle's sound system. The researchers briefed participants on the APA technology, rear sensor, and rearview camera; these briefings consisted of publicly available manufacturer-provided video clips supplemented by pre-recorded narrative and pictures developed by the research team. Participants were also encouraged to read relevant portions of the vehicle's owner's manual. Participants were then fitted with the physiological sensors, given a demonstration of the vehicle technologies, and administered a technology expectations questionnaire.

Overall self-reported stress ratings immediately after the parking tasks and the retrospective questionnaire stress ratings were significantly lower for APA-assisted parking than for manual parking. Heart-rate data were consistent with the self-reported data. Participants had higher mean heart rates throughout the manual parking trials than in the APA-assisted trials when controlling for age and sex. This finding was particularly evident during the parking maneuver (rather than immediately before and after parking). The mean heart rate for participants was significantly lower during the APA-assisted trials, with no significant interaction of age or sex. Data showed the same effect for the period immediately after the parking trial, again with no significant interaction of age or sex.

The analyses revealed a significant effect of repetition. Across both parking types, heart rate significantly decreased during the anticipatory (before) period from the first park to the second park. There was also a significant interaction between repetition and sex. Females showed a significant decrease in heart rate in the anticipatory period across repetitions, controlling for age. There was a significant interaction between repetition and age group, with the 20-year-old age group and females in the 60-year-old age group showing significant decreases in heart rate from the first to the second anticipatory period. Notably, these findings were consistent across both the manual and APA-assisted parking trials. Finally, pre- and post-questionnaires revealed that, while participants did not expect the APA to reduce stress compared to other parking technology (cross-traffic warning) and did not anticipate they would use the APA if it was available or choose to buy a vehicle with it compared to cross-traffic warnings, the likelihood of their using the APA technology and considering purchasing a vehicle with it increased significantly from pre- to post-experimental ratings.

Overall Reimer et al. (2016) showed that exposure can increase older drivers'—particularly older female drivers'—use and acceptance of advanced vehicle technology, while reducing stress when anticipating and performing difficult driving maneuvers.

Questionnaire and Survey Research

Cicchino et al. (2015) surveyed older drivers to evaluate the relationship between experiences with parking assist systems and characteristics such as vehicle model year and driver age. The system under study did not include a rearview camera but rather an ultrasonic rear parking assist system. Sensors on the rear bumper detected objects at least 10 in off the ground and up to 8 ft behind the vehicle when travelling in reverse at less than 5 mph. Researchers mailed questionnaires to 600 randomly selected owners of vehicles equipped with the systems. The 429 respondents included 184 owners of 2010 models and 245 owners of 2011 models. Nearly all (98%) participants were over 60, and 70% were over 70.

Results showed that 97% of respondents never turned the system off and approximately 75% heard beeping from the system at least a few times a week. Over half (56%) said the system alerted them to something behind the vehicle they were not aware of, most often a person or animal. Over 90% reported they understood the meaning of the beeps, and 97% found the system useful.

Twelve percent of respondents reported having crashes that involved backing into other vehicles or inanimate objects. Among those who had backing crashes, nearly half were alerted by the system prior to the crashes. Most respondents liked something about the system. Among these, just over half liked the general concept. A smaller percentage (19%) disliked something about the system. Of those with dislikes, some reported that the system was unreliable, some wanted a backup camera, and others reported too many false or unnecessary alerts. Nearly all respondents would want the system on their next vehicle.

Overall Cicchino et al. (2015) found high older-driver acceptance and understanding of the technology and increased driver confidence with exposure to the system.

Gish et al. (2016) interviewed older drivers about their perceptions and motivation for using advanced in-vehicle technologies (AVTs), focusing on AVTs in participants' own vehicles. The most common AVTs in participants' vehicles were backup camera (97%), GPS/navigation (84%), and proximity sensors (59%). Over half of participants bought their vehicles because of the AVTs. Three main themes emerged from the interviews:

1) <u>Counteracting changes in driving performance</u>: Some participants noted using RVSs, side cameras, and blind spot monitors to accommodate for changes in vision and perceptual awareness that affected their driving.
2) <u>Convenience</u>: Drivers said AVTs made them feel more comfortable by improving efficiency of driving performance (e.g., backing) and complex driving maneuvers (e.g., parallel parking).
3) <u>Enhancing safe driving</u>: Participants considered driving to be risky due to poorly designed roads, congestion, and other drivers' behaviors. They showed that AVTs improved safety by alerting drivers to vehicles in blind spots, decreasing driver error, and reducing distraction.

Overall the Gish et al. (2016) interviews revealed that older drivers tended to be aware of age-related deficits that could affect driving and how advanced vehicle technologies could counteract these changes.

Jenness et al. (2007) administered questionnaires to gauge the extent to which drivers believed that backing aid systems and RVSs enhanced or detracted from safety, particularly among older drivers. They also examined drivers' acceptance of and perceived effectiveness and usability of the systems as well as any behavioral adaptations associated with system use. The researchers mailed technology-specific questionnaires to backing aid and RVS owners selected by the

Automobile Club of Southern California from its insurance customer database. The researchers conducted brief telephone interviews with 42 backing aid respondents and 46 RVS respondents.

Older respondents generally cited more physical conditions that made driving difficult (e.g., vision or hearing limitations, and difficulty turning neck/torso) than younger respondents. Across age groups, significantly more drivers with sensor-based backing aids reported that they would want the system in their next vehicle compared to drivers with an RVS. Most of the older RVS users learned how to use the system via the owners' manual, whereas the younger RVS users were more likely to have learned from on-road experience. Significantly more of the younger drivers with RVSs stated that they had used the RVS without checking their mirrors or turning to look out the rear window within the last two weeks. Younger RVS drivers were more than twice as likely as older RVS drivers to say that they paid attention to the camera screen more than to their mirrors or glances out the rear window. Older drivers were significantly less likely than younger drivers to report that they were more willing to park in small or difficult parking spaces when using the RVS. Nearly all respondents showed that the RVS was either "very easy" or "somewhat easy" to use while backing out of a driveway, but younger drivers were significantly more likely than their older counterparts to respond with "very easy." Older drivers were more likely than younger drivers to report problematic sun glare and poor image contrast on the display.

Overall the results reported by Jenness et al. (2007) showed that older drivers found the RVS more difficult to learn, were less likely to park in more challenging spaces, and had more difficulty seeing images on the camera screen than their younger counterparts.

Backing Performance Study Methods

Office of Management and Budget and Institutional Review Board Approval

This study and associated data collection received clearance under the Paperwork Reduction Act (OMB Control No. 2127-0731) and approval by the Virginia Tech Institutional Review Board (IRB).

Participant Recruitment

The study was conducted by the VTTI with data collected from April to July 2021. VTTI's Participant Recruitment Group (PRG) recruited participants from the New River Valley area of Virginia where VTTI is located. PRG identified potential participants by placing advertisements in a local listserv inviting interested candidates to contact the research team (see Appendix A), as well as through an existing database of participants who previously consented to be contacted about participating in future research studies. A project assistant contacted interested candidates by phone to complete the 10-minute screen/driving habits survey.

Participants included 40 drivers aged 60 to 69 and 40 drivers 70 and older. Within each group, 20 were familiar with using RVS, and 20 were not. Participants assigned to the RVS-familiar group reported using this technology at least once each week, while those assigned to the RVS-unfamiliar group reported that they never used an RVS. Each participant had a valid driver's license and drove a minimum of three trips per week. Exclusion criteria included use of adaptive vehicle controls or having a medical condition of a level of severity that the research team, in consultation with NHTSA, felt could interfere with driving performance.

Rearview Video System

The study team surveyed the fleet of model year 2015 U.S. market vehicles with RVS as standard equipment. All manufacturers used in-dash or on-dash displays. The team elected to use an instrumented 2006 Infinity M35, which included an RVS built into the dash for data collection. Figure 1 shows the RVS screen size and the display. The display was equipped with a glare shield during data collection to afford an equal contrast image under all visibility conditions.

Figure 1. RVS screen size and glare shield

RVS Display Availability

On half of the trials (exclusive of the final "surprise" trial) the RVS display was blocked with a cover (RVS unavailable condition) as shown in Figure 2. On trials where the RVS display was available, drivers were free to use mirrors, the RVS, or over-the-shoulder glances as desired.

Figure 2. RVS display cover

Data Collection Protocol

A researcher trained in evaluating older drivers collected data in a controlled field experiment. Research assistants participated in various support roles, including placing and removing obstacles. The experimenter obtained informed consent and explained that the purpose of the research was to study drivers' scanning behavior, particularly the aids they used when backing in various situations. The experimenter also advised participants that they might encounter obstacles while backing.

The field experiment consisted of a partial factorial design with 12 trials. All combinations of *Backing Maneuver* (4 levels: short backing, long backing, backing into a parking space, and 3-point turn) and *RVS Display* (2 levels: with and without RVS) were included. However, the presence versus absence of an *Obstacle* was tested only for short backing and backing into a parking space. Table 1 illustrates the test conditions; trials were conducted in a circuit, and both object presence and RVS availability were counterbalanced across participants. The experimenter initiated the first trial by signaling the field crew. The total duration of the controlled field experiment was approximately 1 hour.

Table 1. Study Design

	RVS Available					**RVS Unavailable**			
Backing Task	Short	Long	Into Parking space	3-point turn	Surprise	Short	Long	Into Parking space	3-point turn
Trials (n = 12)	2	1	2	1	1	1	1	2	1
Obstacle?	Y / N	N	Y / N	N	Y	N	N	Y / N	N

Backing Maneuvers

This study included five different backing maneuvers.

- Short backing, which simulated backing out of a parking space or a garage.
- Long backing, which simulated backing out of a long driveway.
- Backing into a parking space, which simulated backing into a space in a parking lot, bounded by vehicles.
- Three-point turn, which simulated a multipoint turn.
- Surprise trial (unexpected obstacle detection).

The study incorporated both static and dynamic obstacles. The static obstacle was a standard traffic cone, covered with a matte grey tape to reduce conspicuity. The dynamic obstacle, used only during the *backing into parking space* trials, consisted of a full-size shopping cart made from a lightweight, impact-resistant plastic and equipped with padding to resist damage from inadvertent bumps. The researchers equipped the cart with a remote trigger activating a small electric motor that moved it behind the parking space the participant was using. A differential GPS (dGPS) signal threshold activated the trigger as the participant's vehicle entered the space.

For the *short backing* task, also referred to as *backing out of parking space*, participants backed straight out of a standard-width parking space delineated by pavement markings with vehicles parked in the adjoining spaces protected by plastic barriers. The experimenter asked participants to back up to a temporarily positioned stop sign. On one of the trials with RVS available, a research assistant placed a low-contrast obstacle (a traffic cone wrapped in grey tape, shown in Figure 3) between the vehicle and the stop sign such that it could only be seen using the RVS. Each of the 80 participants completed the backing out trial three times, twice with the RVS and once without the RVS. On every trial, a partition blocked the driver's line of sight to the rear to prevent the driver from seeing the research assistant place the obstacle. Thus, the protocol prevented participants from seeing whether a researcher placed an obstacle behind the car.

Figure 3. Modified low-contrast cone

The researchers designed the *long backing* task to simulate backing along a long, curving driveway and to assess the participant's ability to accurately steer the vehicle while driving in reverse. There was no obstacle for this task as vehicle control was the primary behavior of interest. Participants reversed for 264 ft on an irregularly shaped road course following a pavement marking reference line. The backing course included an initial straight segment followed by two changing-radius curves. Each participant completed the long backing task two times, once with the RVS available and once without the RVS available. The experimenter instructed the participant to use the pavement marking for guidance but not to cross it. Researchers scored encroachments on this path boundary as backing errors (event counts); they also scored lateral deviations that diverged substantially away from the reference pavement marking (as recorded by the on-board side-view cameras) as errors.

The trial for the *backing into parking* space task began with the test vehicle placed perpendicular to and behind the same parking space used for the backing-out-of-space trials, delineated by standard-width pavement markings with vehicles parked in adjoining spaces protected by plastic barriers. The experimenter asked participants to back into the space until the rear of the car aligned with the back of the space. During two trials (one with RVS available, one without) a dGPS sensor automatically triggered a remote-controlled shopping cart when participants were midway into the parking space. This cart moved at a walking pace directly behind the rear line of the parking space, where it would appear to be a hazard while minimizing the risk of a collision. The cart stopped midway across the space such that participants could not avoid it by slowing or pausing. This was the only trial that included a moving obstacle, as participants would have seen a stationary obstacle when they made their initial glance into the space. Each participant completed the backing task four times, twice with the RVS available and twice without the RVS available. Figure 4 illustrates this obstacle's position at the beginning of the maneuver in relation to the backing vehicle, and at maneuver completion.

Figure 4. Position of automatically triggered shopping cart obstacle at the beginning and end of parking space backing trials

In what the experimenter described to the participant as the final task, the participant completed a *three-point turn*. The participant performed the task without using a parking place or driveway, in an 'open' section of roadway bounded only by curbs, i.e., to emulate the need for a U-turn where the road is too narrow for such a maneuver, and it requires a three-point turn. This task did not have an obstacle, as vehicle control throughout the maneuver was the behavior of interest.

After completion of all permutations of these four trials, the experimenter instructed the participant to drive forward into a parking space for debriefing. As the participant was occupied, a research assistant surreptitiously placed a final stationary obstacle behind the vehicle for a single “*surprise trial*,” to capture behavior in a less scripted context. The research assistant positioned the obstacle, the same low-contrast cone that was used for the *backing out of parking space* task, 2 ft behind the rear of the vehicle at the centerline, such that it was visible only via the RVS and likely to be hit if the participant began backing before checking the display. The RVS was available in all cases.

After all trials were completed, researchers provided participants with more information if they so desired. Any discussions occurred on the completion of all data collection to prevent discussion with others who also served as participants.

Test Site

The study was conducted on VTTI’s Smart Road Surface Street (SRSS), a 9-acre, flat, paved, closed road course that allowed for simultaneous setup of four “backing stations” and a rapid transition between experimental trials. Figure 5 shows where the participants performed the various backing tasks within the closed course, including close-ups of each maneuver trajectory (shown in yellow).

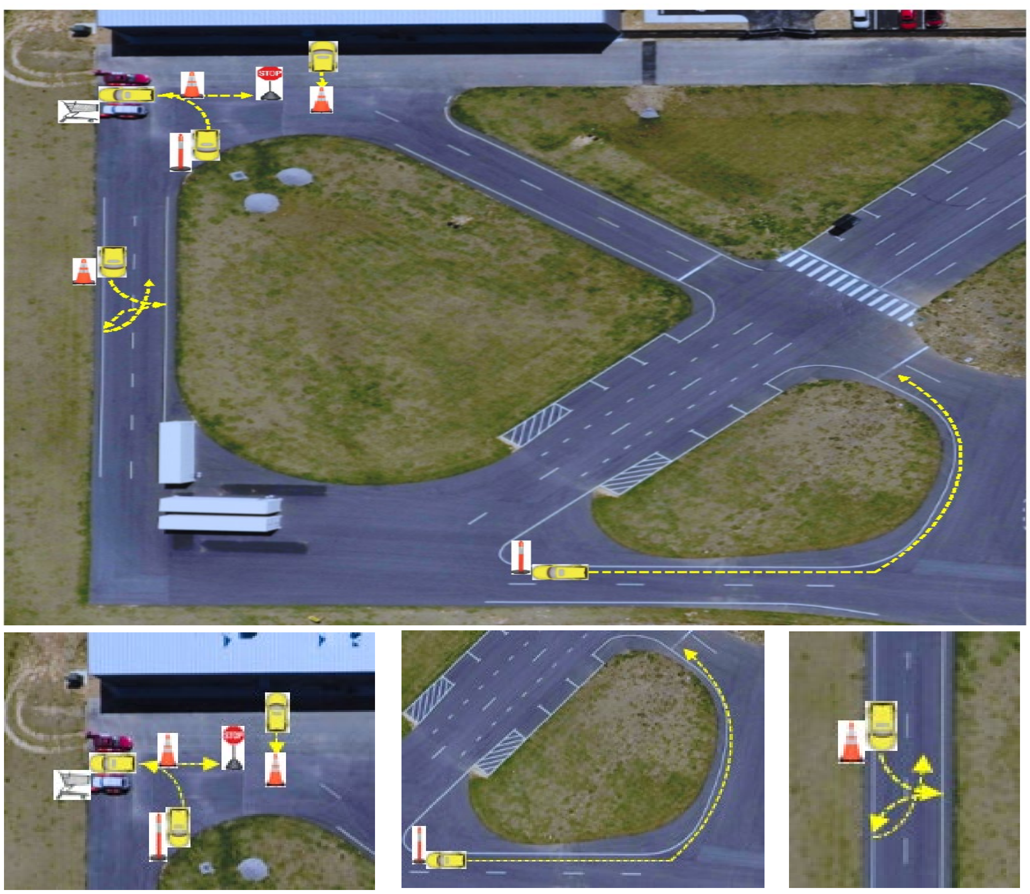

Figure 5. Locations of backing tasks on SRSS closed course

Data Collection Platform

The data collection platform consisted of a full-size sedan from VTTI's instrumented vehicle fleet with a passenger-side secondary brake that the experimenter could use to stop the vehicle if necessary to ensure safe vehicle operation. VTTI mounted its data acquisition system (VTTI DAS) securely and inconspicuously in the test vehicle, and the VTTI DAS provided the following sources of data.

1. Five video camera views, including the driver's face, forward roadway, rear roadway/parking space, and vehicle left and right sides (see Figure 6);
2. Precise vehicle (and target) location using dGPS;
3. Multi-axis accelerometers enabling identification of hard braking or acceleration events; and
4. Timing information at the millisecond level.

Figure 6. Video camera views

VTTI imported both video and vehicle data into a secure database, allowing the following analyses.

- Event manual video data reduction conducted in the VTTI Data Reduction Lab enabled the following for each trial from the synchronized video and vehicle/kinematic data:
    - Trial start and stop time for each trial;
    - Successful avoidance of obstacles;
    - Error counts (i.e., line crossings or exceeding maximum lateral distance) in the long backing maneuver; and
    - Driver glance behavior to determine number of glances and glance allocation among mirrors, RVS, and over-the-right-shoulder.
- GPS enabled determination of proximity to obstacles that participants avoided.
- Accelerometer data allowed analyses of hard braking events that could show last-moment identification of obstacles.

Researchers conducted multivariable analyses across groups and conditions, allowing comparisons to be made on performance metrics between age and experience groups, RVS presence or absence, and maneuver type. The researchers also analyzed within-group differences, particularly differences among participants' glance behaviors.

This page is intentionally left blank.

Backing Performance Study Results

Sample Characteristics

A total of 80 participants completed the study, with 10 in each age/gender/RVS experience group (see Table 2).

Table 2. Participant Demographics

Age Group	RVS Experience	# Male/Female Participants	Age		Total ROM (deg)	
			M	*SD*	*M*	*SD*
60–69	Yes	10/10	64.4	3	200.5	20
	No	10/10	64.7	3	194.6	30
70+	Yes	10/10	73.7	3	189.65	32
	No	10/10	74.5	4	186.6	34

Researchers captured participants' ROM using a compass mounted to the top of a hard hat along two dimensions, neck-only, and torso-and-neck (Figure 7). In the neck-only ROM assessment, participants were instructed to look left and right as far as possible while keeping their back against the back of the chair (limiting the opportunity to engage the torso). For the torso-and-neck assessment, participants were instructed to turn as far as possible each direction while not allowing their hips to rotate on the chair. Researchers collected values twice for both the left and right directions to ensure consistency.

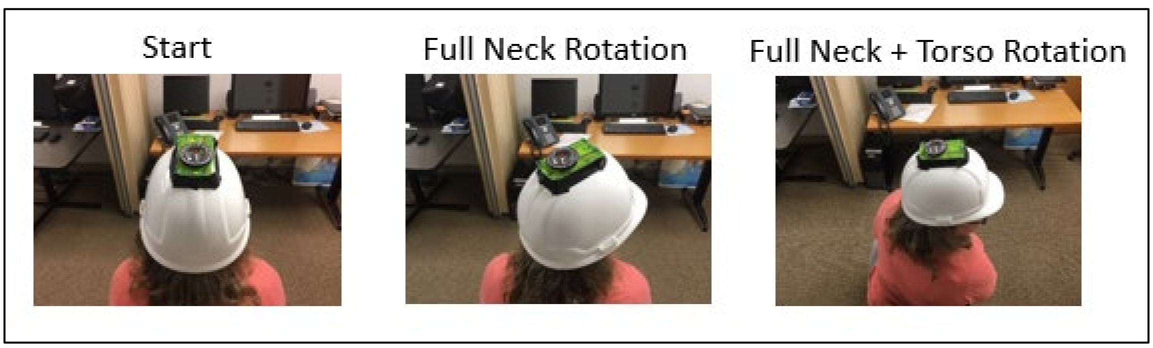

Figure 7. ROM testing showing starting, neck rotation, and neck plus torso rotation

Mean and standard deviation (SD) ROM values are presented separately for each age group in Table 3; a t-test of the younger versus older group showed a statistically significant difference of 9.4° between the age groups on this measure ($t = 2.06$, $p = .043$). Researchers converted continuous (left plus right) ROM values into categorical values for analyses and categorized participants whose ROM value were within .5 SD of the group mean as "normal," those with lower values as "limited," and those with higher values as "good."

Backing Task Performance Analyses

Researchers used chi-square or Fisher's exact tests to analyze performance for binary backing task outcome measures (striking/avoiding rear hazard and use/nonuse of the RVS during a trial); analysis of variance (ANOVA) where continuous outcome data were recorded (eye glance behavior and deviation of the test vehicle's path from a reference line on the pavement); and Poisson regression where the analysis goal was to predict counts of position and contact errors as a function of categorical variables (e.g., age cohort and RVS experience). For selected maneuvers, as identified below, the sample size (number of participants) for a given condition may be less than 80 when an analysis excluded participants, such as those where an RVS was available but not used at any point during the maneuver.

Short Backing

Each of the 80 participants completed the short backing trial three times, twice with the RVS and once without the RVS. Almost all participants (97% with RVS experience and 91% without) used the RVS at some point during the 160 trials when it was available. For this task, positioning errors included vehicle tires touching or crossing a lane line, or vehicle misalignment. Contact errors could include bumping the stop sign, obstacle, or one of the plastic barriers.

Figure 8 shows an overall summary of the performance during this task for the 80 trials in which the RVS was available, and an obstacle was present. Participants with experience made fewer contact errors than those who had no prior RVS experience; in all cases, contact errors involved hitting the low-contrast obstacle (gray traffic cone).

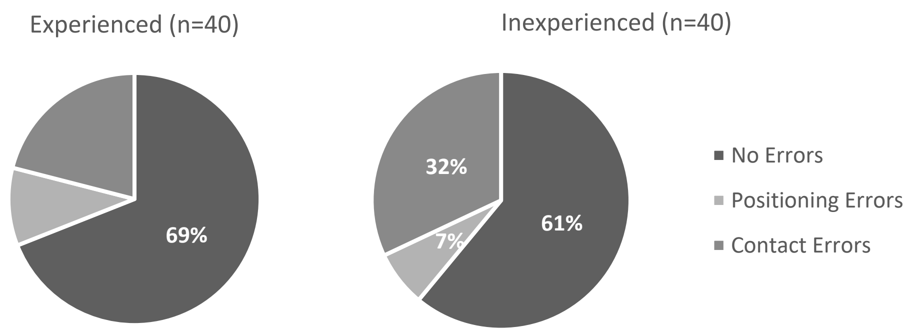

Figure 8. Overall task performance by prior experience for short backing task.
Note: RVS available, obstacle present

Figure 9 summarizes the performance for the 80 trials in which the RVS was not available. The protocol did not present obstacles in any of the trials in which the RVS was not available, as the obstacle would have been invisible without the RVS, and all participants would be expected to hit it. As hypothesized, there were no performance differences between participants who had or did not have prior experience using RVS. The single contact error committed in this condition was a participant who hit the stop sign.

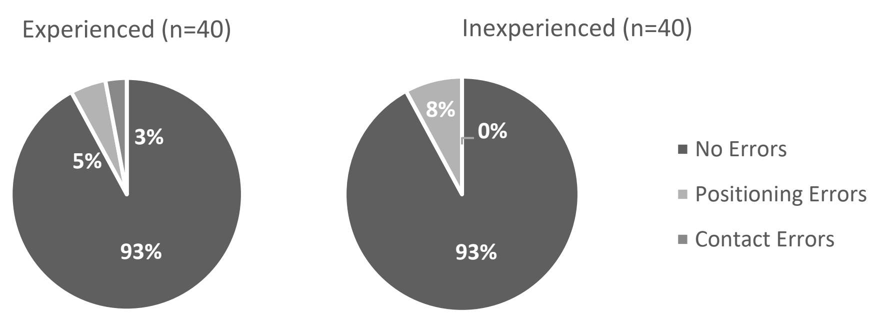

Figure 9. Overall task performance by prior RVS experience for short backing task.
Note: RVS unavailable, no obstacle present

The researchers conducted a series of generalized linear models with Poisson regressions for both contact and positioning error count data. As shown in Table 3, there was a statistically significant relationship between the number of contact errors and for the number of glances to the RVS after movement initiation when the RVS was available.

Table 3. Poisson Regression Results for Contact Errors During Short Backing Task

Variable	**Contact Errors**	
	z-value	*p*-value
Range of motion[a]		
Normal	-0.108	.914
Limited	0.841	.401
RVS experience[b]		
Inexperienced	1.335	.182
Age group[c]		
70+	0.113	.910
Percentage of time prior to initiation	0.018	.985
Percentage of time after initiation	-0.198	.843
Number of glances prior to initiation	1.481	.139
Number of glances after initiation	-2.812	**.005**

Note: Bold text indicates statistical significance. [a] 0 = Good range of motion.
[b] 0 = Experienced with RVS. [c] 0 = 60 to 69 years old

Table 4 shows regression results for positioning errors; there were statistically significant relationships between the number of positioning errors and glances to the RVS, both before and after movement initiation. However, these effects were in opposite directions. Prior to movement, more glances was associated with a decrease in errors; this may reflect participants' seeking more visual information before executing a decision to begin backing, which can only enhance safety. However, after movement was initiated, more glances was associated with an *increase* in errors; this may reflect participants' behavior where their eyes are moving back and forth between the display and another location, suggesting a division of attention that could be detrimental to safety.

Table 4. Poisson Regression Results for Positioning Errors During Short Backing Task

Variable	**Positioning Errors**	
	z-value	*p*-value
Range of motion[a]		
Normal	0.935	.351
Limited	1.118	.264
RVS experience[b]		
Inexperienced	-0.835	.404
Age group[c]		
70+	1.656	.098
Percentage of time prior to initiation	-1.377	.169
Percentage of time after initiation	0.556	.578
Number of glances prior to initiation	-2.301	**.021**
Number of glances after initiation	4.237	**<.001**

Note: Bold text indicates statistical significance. [a] 0 = Good range of motion.
[b] 0 = Experienced with RVS. [c] 0 = 60 to 69 years old

Chi-square and Fisher's exact tests examined the likelihood of avoiding the unexpected traffic cone by participants' range of motion, experience, age group, and use of the RVS. Figure 10 shows that statistically significant effects (denoted by asterisk) were found for RVS experience. Twenty-six percent more of the inexperienced group struck the traffic cone than the experienced group. One participant struck the stop sign included for task guidance, but that object strike is not included in the analyses below as the analysis focused on the surprise object placed behind the test vehicle. No other statistically significant effects were found (see Table 5).

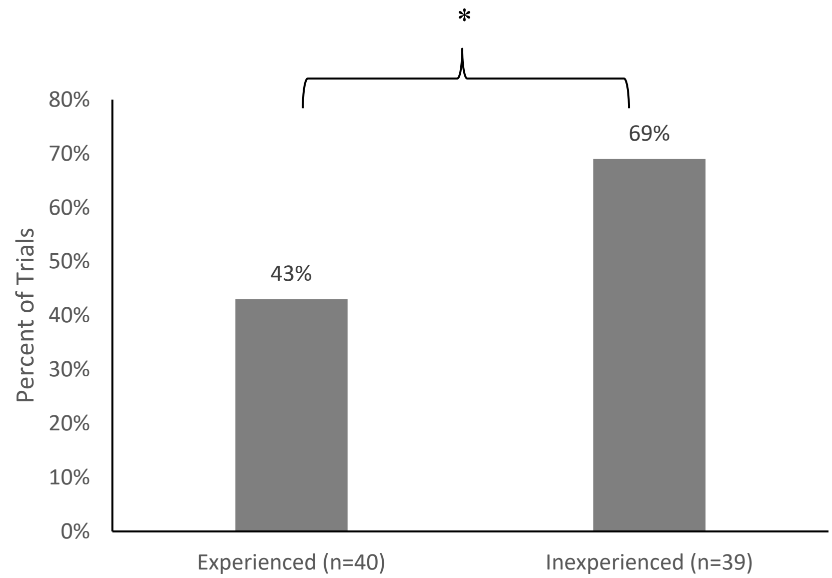

Figure 10. Percentage striking object by RVS experience for short backing task.
Note: Asterisk (*) indicates p < .05

Table 5. Chi-Square and Fisher's Exact Test Summary Results for Object Avoidance

Independent Factor	**% Hit Object**	**X^2 Value**	***p*-value**
Range of motion			
Good	52.4%	5.57	.062
Normal	44.1%		
Limited	75%		
Experience			
Experienced	42.5%	5.72	**.017**
Inexperienced	69.2%		
Age group			
60–69	52.5%	0.33	.563
70+	59%		
RVS use			
Use	53.4%	Fisher's exact test	.126
No use	100%		

Note: Bold text indicates statistical significance

Table 6 presents the results of two ANOVAs to test for differences in the proportion of time glancing to the RVS prior to and after initiating backing, by age group and RVS experience level.

Table 6. ANOVA Results Table for Short Backing Task Glance Analyses

Independent Factor	***M***	***SD***	***F*- Value**	***p*-value**
RVS use prior to initiation x experience				
Experienced	0.34	0.30	5.69	**.018**
Inexperienced	0.23	0.26		
RVS use after initiation x experience				
Experienced	0.64%	0.28	9.17	**.003**
Inexperienced	0.49%	0.33		
RVS use prior to initiation x age group				
60-69	0.34%	0.31	5.06	**.026**
70+	0.23%	0.26		
RVS use after initiation x age group				
60-69	0.59%	0.29	0.81	.371
70+	0.54%	0.33		

Note: Bold text indicates statistical significance

The ANOVAs demonstrated a statistically significant difference in time spent glancing to the RVS by experience, both prior to and after initiating the backing maneuver (see Figure 11 where asterisks denote significant differences). Also, those in the experienced group allocated significantly more time glancing to the RVS than those in the inexperienced group.

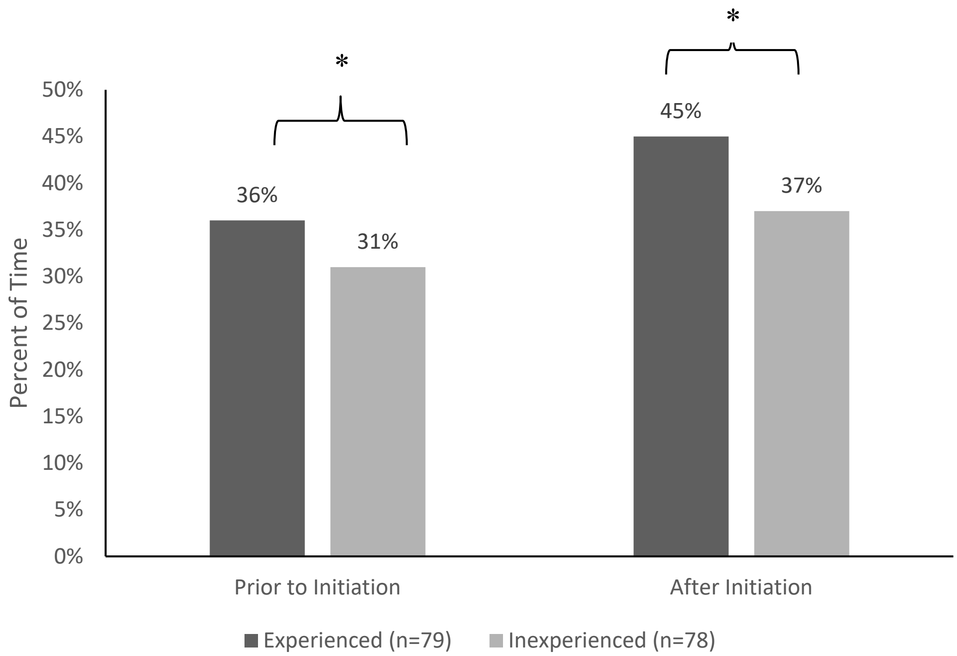

Figure 11. Proportion of time glances were directed to RVS by experience level, before and after initiating backing in short backing task.
Note: An asterisk (*) indicates p < .05

The amount of time participants allotted to glancing at the RVS display also varied by age group, with younger participants spending significantly more time looking to the display prior to initiating backing (see Figure 12 where asterisk denotes a significant difference). This effect disappeared once the maneuver was initiated.

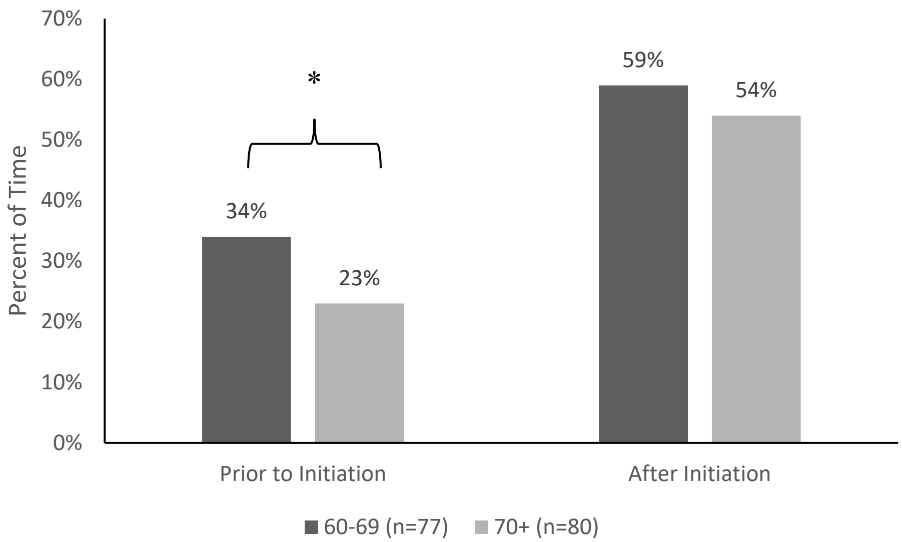

Figure 12. Proportion of time glances were directed to RVS by age group, before and after initiating backing in short backing task.
Note: An asterisk (*) indicates p < .05

Researchers also evaluated glance behavior according to what proportion of participants looked to the right mirror, over their right shoulder, and to the RVS (when available). As shown in Figure 13, participants in both RVS experience groups tended to use the RVS when it was available (over 80% in both cases, with nearly 100% usage for the experienced group) when backing out of the parking space. These are descriptive analyses; no significance tests were conducted. This coincided with a reduced likelihood of glances to both the right mirror and over the shoulder when the RVS was available.

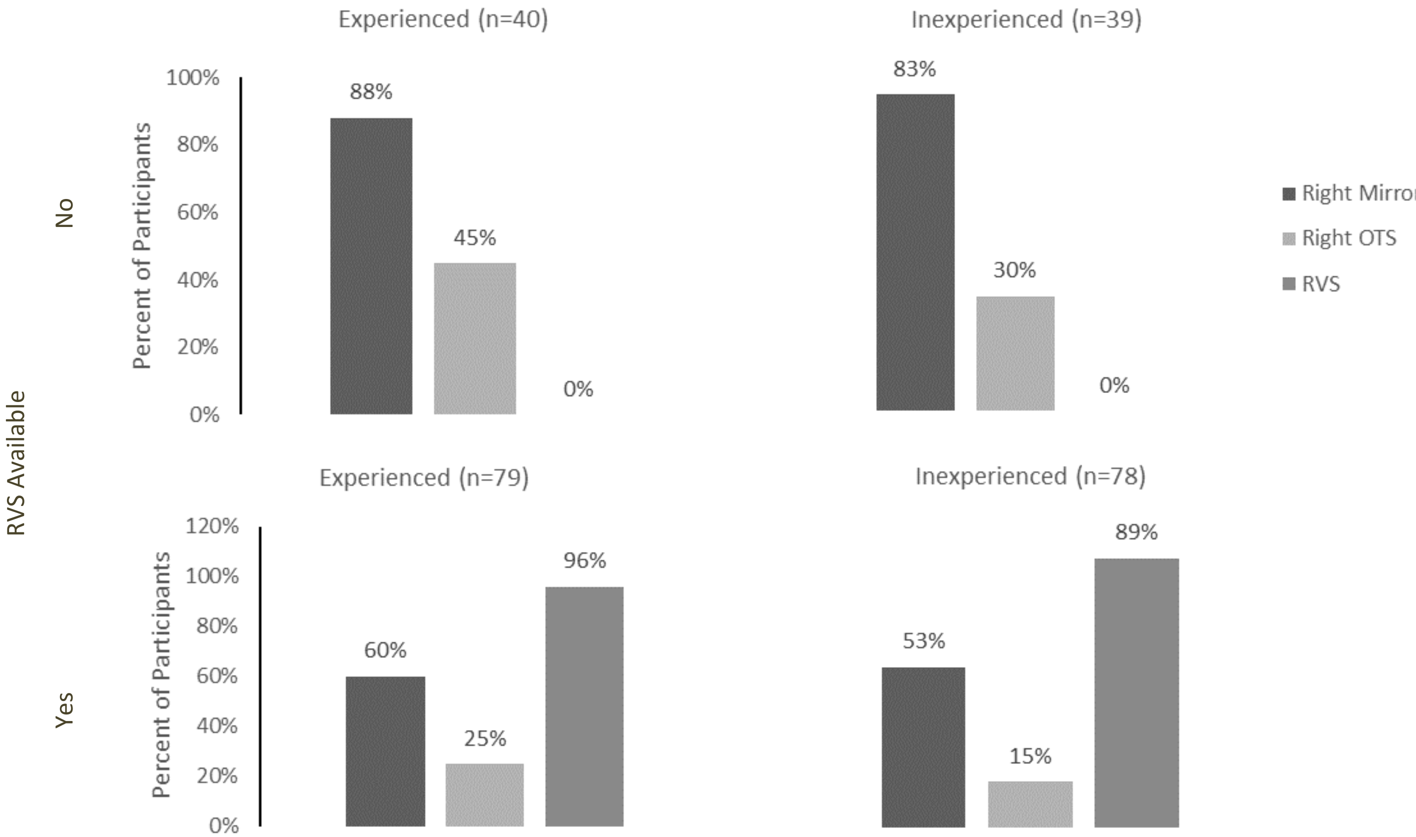

Figure 13. Glance behavior to targeted areas during short backing task

Finally, the mean number of glances per participant to each of three target locations—to the right mirror, over the shoulder, and to the RVS—are displayed in Figure 14. When the RVS was *not* available (top graphs), the most frequent glances were to the right mirror (two or three glances). When the RVS *was* available (bottom graphs), it was the most-frequently-glanced-at location, with a mean of about five or six glances. These are descriptive analyses; no significance tests were conducted. Glances to both the mirror and over the shoulder were reduced when the RVS was available.

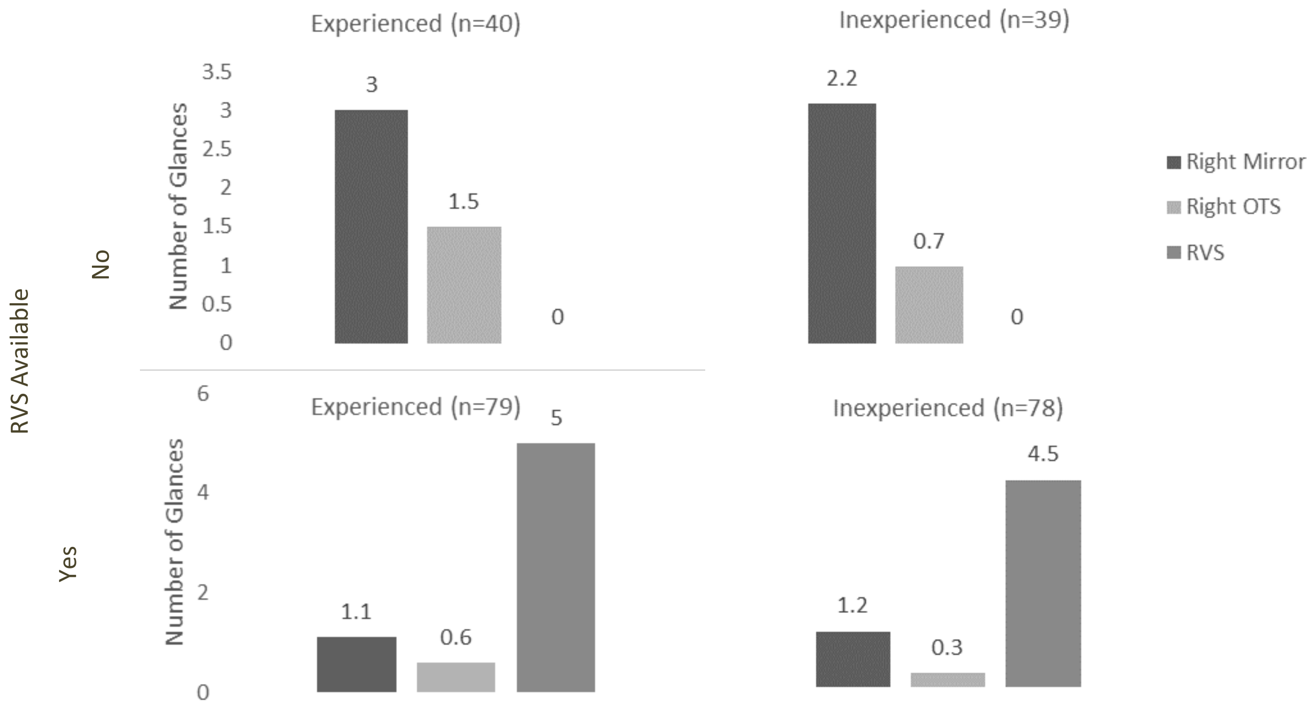

Figure 14. Mean number of glances to selected locations during short backing task

Long Curved Backing

Each participant completed this backing task once with and once without the RVS available. It included an initial straight segment followed by two changing-radius curves. A total of 97% of experienced participants glanced to the RVS at some point during the maneuver when it was available, compared to 87% of inexperienced participants. Researchers analyzed performance on this task separately for segments labeled *pre-backing, straight backing, curve 1,* and *curve 2*, and aggregated across the entire trial. Errors on this task were reflected by the degree of divergence from the optimal backing path, either *gross* or *slight*; these terms are defined below.

A total of 46 participants committed at least one gross divergence error, defined as a tire leaving the roadway or the vehicle diverging substantially from the guidance line. During the straight backing segment, gross divergence was defined as the left tire crossing the center line; on curved segments, this was defined as the right tires diverging approximately 4 ft away from the reference line on the pavement. Of these 46 participants with gross errors, 31 committed more than one. Nearly all participants with multiple gross errors committed the errors while navigating the route's two curves.

Figure 15 shows how the overall performance differed for the long-curved backing task. Note that the participant counts for the RVS-Yes cells are lower than 40, as they do not include participants who had access to the system but did not use it. Fisher's exact tests found no significant differences in error distribution.

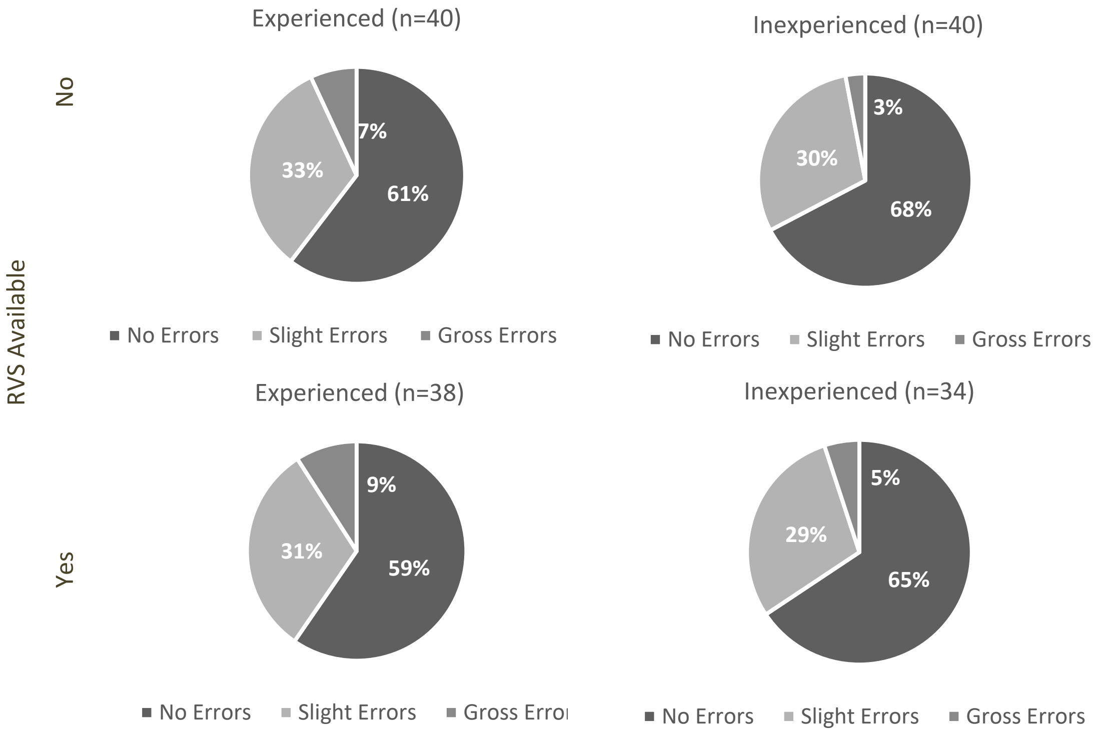

Figure 15. Overall long curved backing performance by RVS experience and availability (only including those participants who used RVS when available)

Table 7 presents the results of a series of generalized linear models with Poisson regressions conducted for the gross error count data. Results showed a statistically significant relationship between the percentage of time using the RVS after initiation of the trial and the number of gross errors. People who looked at the display longer, regardless of their experience level with an RVS, were less likely to commit gross errors. However, the *number* of glances after movement initiation was *inversely* correlated with performance on this task; more frequent glances to the RVS was associated with an increase in gross errors.

Table 7. Poisson Regression Results for Gross Divergence Errors During Long Curved Backing

Variable	**Gross Divergence Errors**	
	z-value	*p*-value
Range of motion[a]		
Normal	0.832	.405
Limited	-1.325	.185
RVS experience[b]		
Inexperienced	0.023	.981
Age group[c]		
70+	0.780	.435
RVS use[d]		
No RVS available	-0.344	.730
Percentage of time prior to initiation	1.145	.252
Percentage of time after initiation	-2.584	**.001**
Number of glances prior to initiation	-1.273	.203
Number of glances after initiation	-2.284	**.022**

Note: Bold text indicates statistical significance. [a] 0 = Good range of motion.
[b] 0 = Experienced with RVS. [c] 0 = 60 to 69 years old. [d] 0 = RVS used

A Poisson regression model explored the relationship between number of slight divergence errors and range of motion, experience, age group, and whether the driver glanced at the RVS at any point during the backing task. A second model explored the relationship between slight errors and the percentage of time spent looking at the display, both prior to and during the backing maneuver. Like the results for the number of gross divergence errors, a statistically significant relationship was found between the percentage of time using the RVS after initiating the backing maneuver and the number of slight errors (Table 8); specifically, more time spent using the RVS during the backing maneuver was associated with fewer slight errors. There was no statistically significant association between the number of glances and number of slight divergence errors.

Table 8. Poisson Regression Results for Slight Divergence Errors During Long Curved Backing

Variable	**Slight Divergence Errors**	
	z-value	*p*-value
Range of motion[a]		
Normal	1.156	.248
Limited	0.196	.844
RVS experience[b]		
Inexperienced	1.061	.289
Age group[c]		
70+	-0.215	.829
RVS use[d]		
No RVS available	0.731	.464
Percentage of time prior to initiation	0.912	.362
Percentage of time after initiation	-4.116	**.001**
Number of glances prior to initiation	-0.115	.908
Number of glances after initiation	0.700	.484

Note: Bold text indicates statistical significance. [a] 0 = Good range of motion. [b] 0 = Experienced with RVS. [c] 0 = 60 to 69 years old. [d] 0 = RVS used

The researchers conducted two ANOVAs to test for differences in the percentage of time spent glancing to the RVS (prior to backing initiation and after backing initiation) by age group and experience. As shown in Figure 16 and Table 9, there were statistically significant differences in the percentage of time using the RVS between experience groups for all four segments of this task (*pre-backing, straight backing, curve 1,* and *curve 2*). In all cases, those with previous RVS experience allocated a greater percentage of time than inexperienced participants to the RVS.

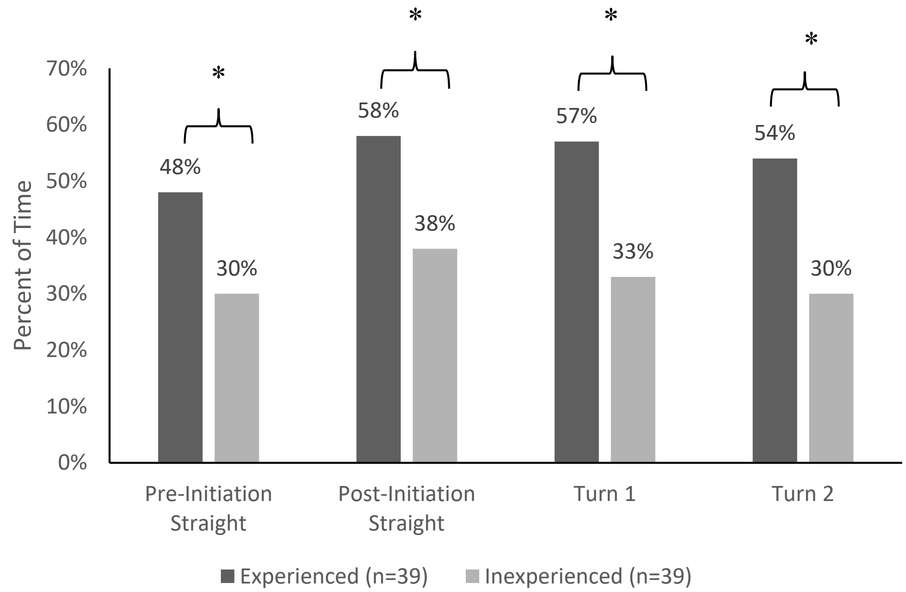

Figure 16. Proportion of time glances were directed to RVS by experience and segment during long curved backing.
Note: An asterisk (*) indicates $p < .05$

Table 9. ANOVA Summary Table for Long Curved Backing Glance Analyses

Independent factor	***M***	***SD***	***F*- Value**	***p*-value**
RVS use prior to initiation x experience				
Experienced	0.48	0.35	5.75	**.019**
Inexperienced	0.30	0.34		
RVS use during straight x experience				
Experienced	0.58	0.37	4.90	**.031**
Inexperienced	0.38	0.41		
RVS use during Turn 1 x experience				
Experienced	0.57	0.37	8.46	**.005**
Inexperienced	0.33	0.36		
RVS use during Turn 2 x experience				
Experienced	0.54	0.38	7.77	**.007**
Inexperienced	0.30	0.38		
RVS use prior to initiation x age group				
60-69	0.44	0.35	1.71	.195
70+	0.33	0.37		
RVS use during straight x age group				
60-69	0.54	0.40	2.09	.153

Independent factor	*M*	*SD*	*F*- Value	*p*-value
70+	0.41	0.39		
RVS use during Turn 1 x age group				
60-69	0.49	0.37	0.95	.333
70+	0.41	0.39		
RVS use during Turn 2 x age group				
60-69	0.45	0.38	0.33	.566
70+	0.40	0.41		

Note: Bold text indicates statistical significance

Researchers also analyzed glance behavior according to what proportion of participants looked to the right mirror, over their right shoulder out the back side or rear window, and to the RVS (when available). As shown in Figure 17, glances were primarily directed to the right mirror and the RVS (when available), to which nearly all participants looked at least once. These are descriptive analyses; no significance tests were conducted. Fewer glances were directed over the drivers' shoulders, and this proportion was relatively consistent across participant groups.

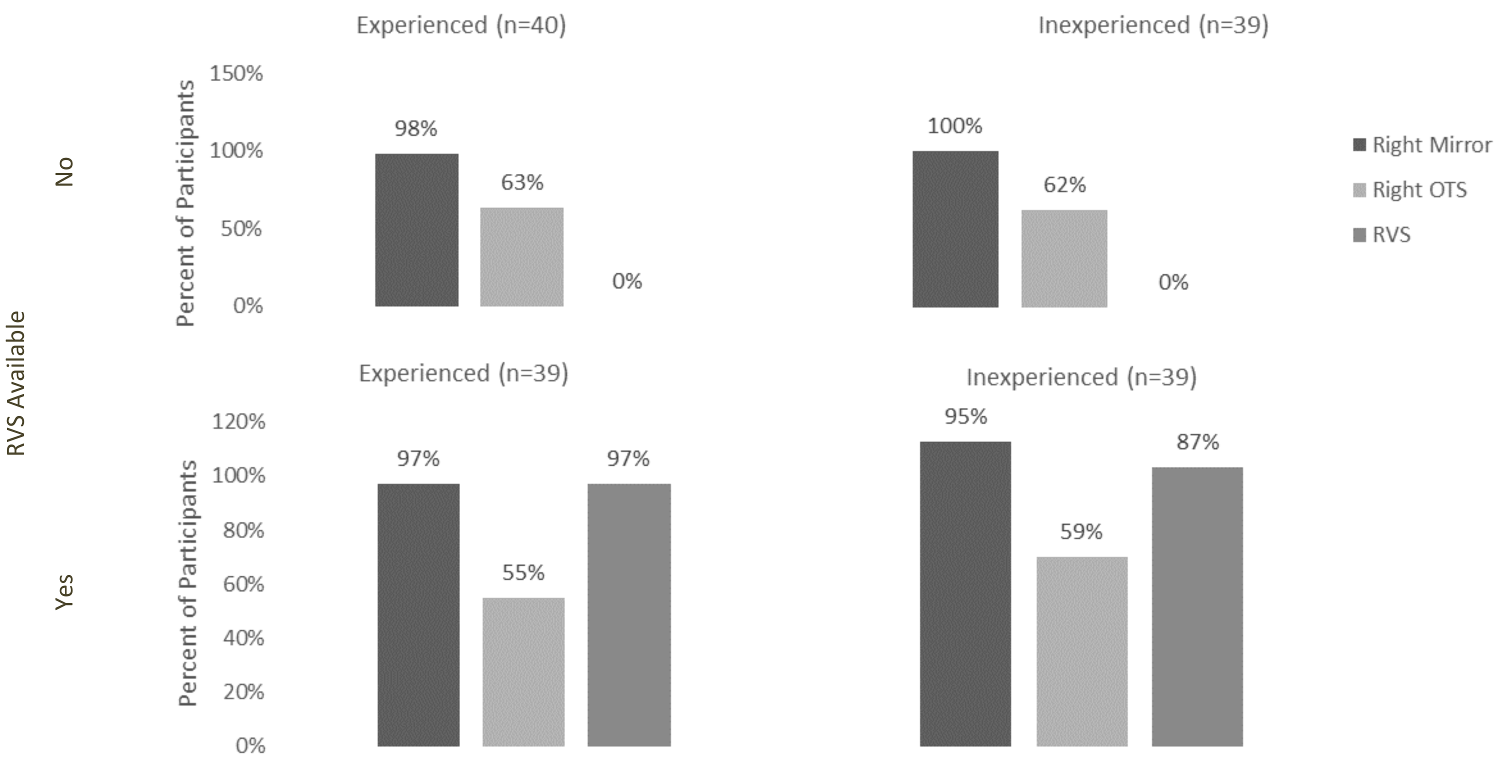

Figure 17. Proportion of participants glancing to specific target areas when performing long-curved backing task

Finally, researchers calculated the mean number of glances per participant to each of three target locations—to the right window/mirror, over the shoulder, and to the RVS. Results are shown in Figure 18. When the RVS was unavailable (top graphs), participants tended to glance most often to the right mirror (on average 10 to 12 times per trial) and much less frequently over their shoulders (on average about twice per trial). These are descriptive analyses; no significance tests were conducted. When the RVS was available, participants with RVS experience glanced most frequently at it, with fewer glances to the right mirror, while inexperienced participants glanced about equally to both locations.

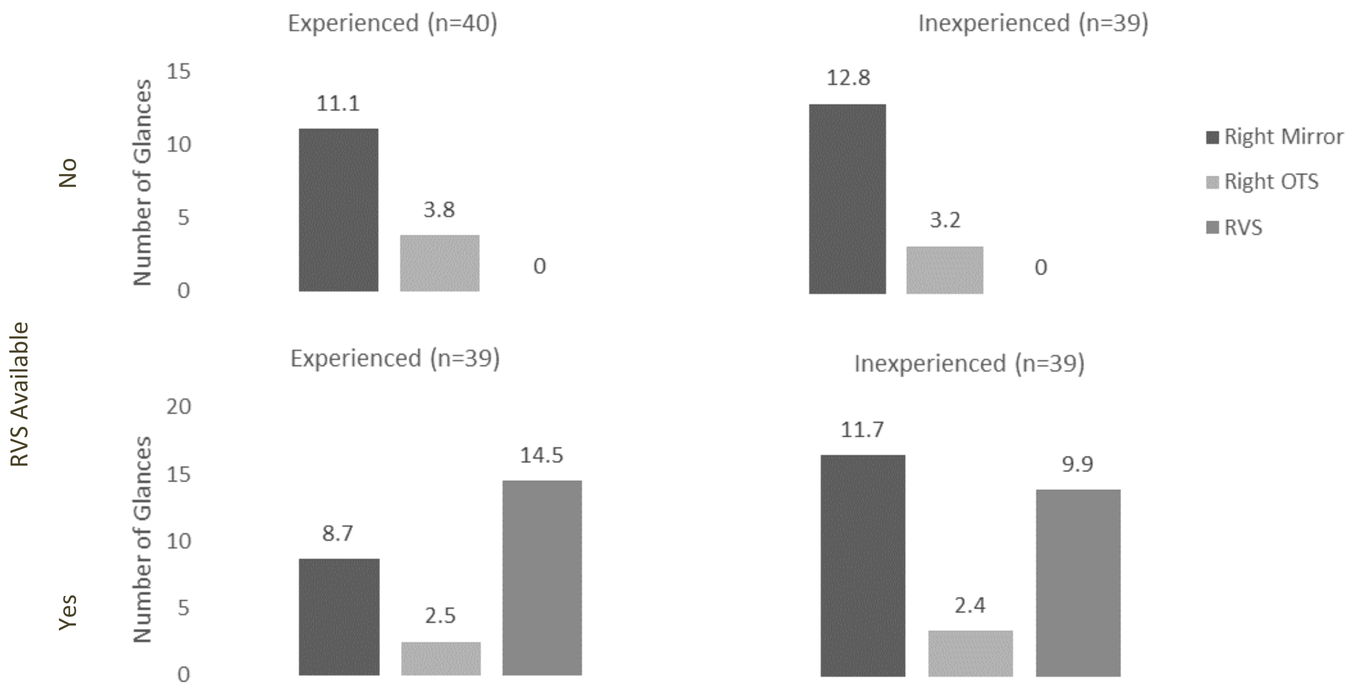

Figure 18. Mean number of glances to target locations for long curved backing task

Backing Into Parking Space

Each participant completed this backing task four times, twice with and twice without RVS available. Nearly all participants used the RVS at some point during this task (100% in the experienced group and 95% in the inexperienced group).

Eight of the 80 participants committed a contact error (going beyond the parking space and contacting the shopping cart) while completing this task. Six of the participants who struck the obstacle did not glance to the RVS display at any point during the maneuver. In four of these cases, the RVS was not available for use (no-RVS trial). In two, the RVS was available, and the participant had no RVS experience.

Figure 19 shows the overall task performance for the backing into parking space task with the number of participants in each condition. As noted earlier, participant numbers for a given condition—in this case RVS-Yes cells—are lower than 80 because this analysis includes only participants who *used* the RVS at some point during the backing maneuver, while the RVS was available.

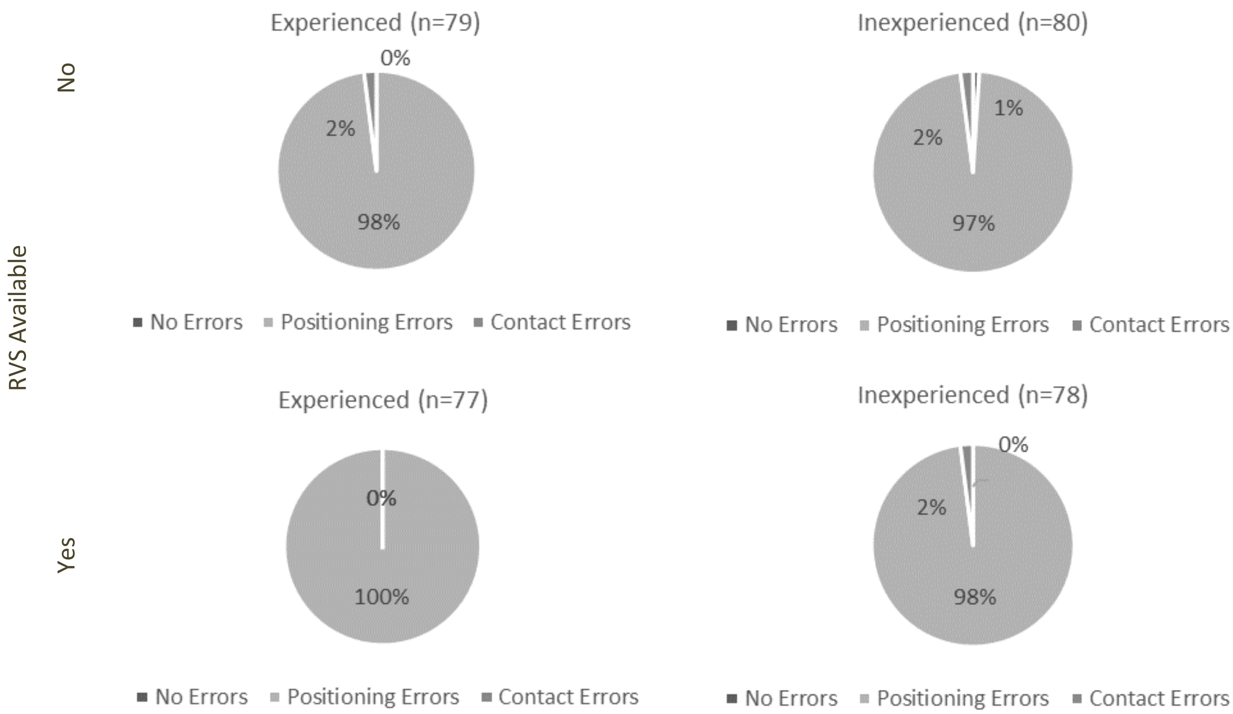

Figure 19. Overall performance by age and RVS experience level for backing into space task

The backing into parking space task demonstrated a ceiling effect for the prevalence of positioning errors. Regardless of RVS use, nearly every participant committed some form of positioning error (Figure 19), generally a vehicle misalignment in the space or a shift into forward gear for realignment.

Table 10 presents the results of a series of generalized linear models conducted for both contact and positioning response error count data. Only age group and the percentage of time that participants looked at the display *during trial movement* were statistically significant predictors of number of positioning errors. While not statistically significant at the .05 level, the number of glances to the display during trial movement was statistically significant at the .10 level. While nearly all participants made at least one positioning error, the older age group was more likely to commit positioning errors than the younger age group. Also, a higher percentage of time looking at the RVS display after movement initiation was associated with fewer errors. Given few contact errors, a logistic regression was not conducted for that error category.

Table 10. Poisson Regression Results for Positioning Errors While Backing Into Space

Variable	Positioning Errors	
	z-value	*p*-value
Range of motion[a]		
Normal	0.268	.789
Limited	0.732	.464
RVS experience[b]		
Inexperienced	0.428	.669
Age group[c]		
70+	2.191	**.029**
RVS use[d]		
No RVS available	0.556	.578
Percentage of time prior to initiation	0.939	.348
Percentage of time after initiation	-2.616	**.009**
Number of glances prior to initiation	0.745	.457
Number of glances after initiation	-1.941	.052

Note: Bold text indicates statistical significance. [a] 0 = Good range of motion. [b] 0 = Experienced with RVS. [c] 0 = 60 to 69 years old. [d] 0 = RVS used

Participants with limited ROM were more likely to strike the shopping cart obstacle (13% of participants) than those in the normal ROM group (3%). Figure 20 and Figure 21 show the contact errors by range of motion and age group respectively; an asterisk denotes a significant difference. For the range-of-motion analysis, the 'good' group performed significantly better than the limited group at the .05 level of statistical significance. Table 11 summarizes the testing results. Both results were statistically significant using Fisher's exact test (Table 11). As participants only committed a total of eight contact errors during this task, the results below should be interpreted with caution. It may also be noted that the numbers on the abscissa reflect two trials per participant, one when the RVS was available and one when it was not.

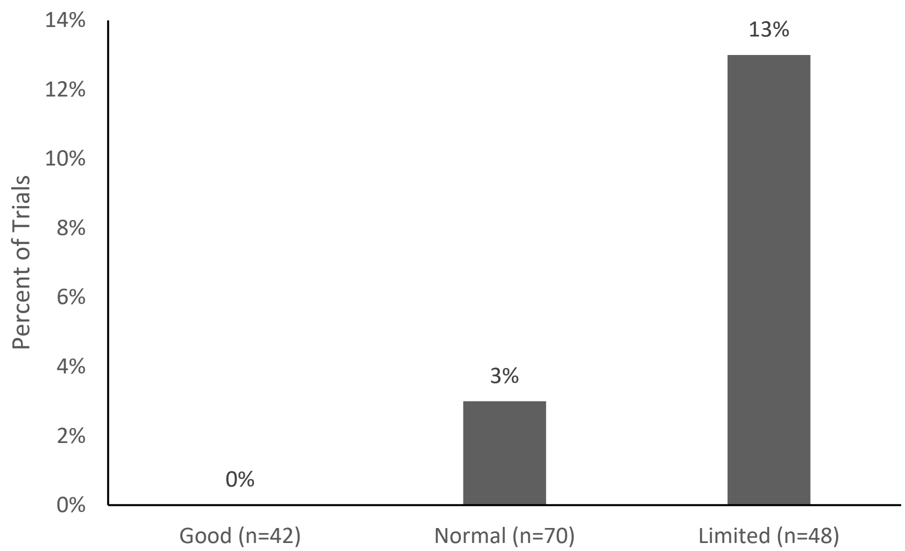

Figure 20. Percentage of participants who struck the shopping cart obstacle by range of motion for backing into space task

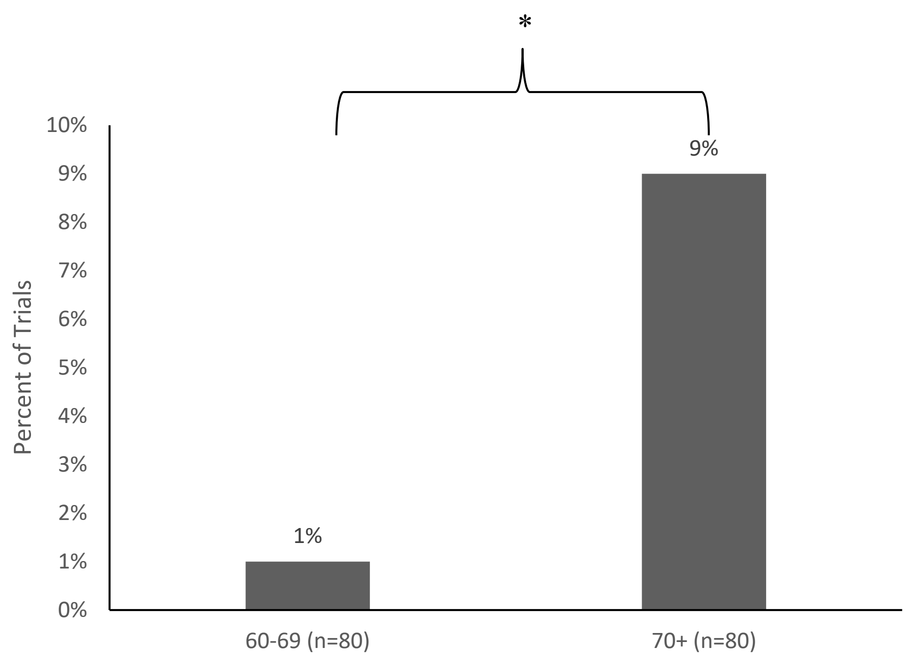

Figure 21. Percentage of participants who struck the shopping cart obstacle while backing into space by age group.
Note: An asterisk (*) indicates p < .05

Table 11. Chi-Square and Fisher's Exact Test Summary Results for Contact Errors While Backing Into Space

Independent Factor	% Hit Object	X^2 Value	*p*-value
Range of motion			
Good	0.0%	Fisher's exact test	**.016**
Normal	2.9%		
Limited	12.5%		
Experience			
Experienced	3.8%	0.58	.446
Inexperienced	6.4%		
Age group			
60–69	1.3%	Fisher's exact test	**.033**
70+	9.0%		
RVS use			
Use	53.4%	Fisher's exact test	1.000
No use	100%		

Note: Bold text indicates statistical significance

Two ANOVAs explored differences in the proportion of time spent glancing to the RVS (*prior* to backing initiation and *after* backing initiation) by age group and RVS experience level. As shown in Table 12, those in the experienced group allocated more time to the RVS than those in the inexperienced group, but *only* after participants began to back the vehicle (Figure 22).

Table 12. ANOVA Results Table for Backing Into Space Glance Analyses

Independent factor	*M*	*SD*	*F*- Value	*p*-value
RVS use prior to initiation x experience				
Experienced	0.27	0.21	0.61	.436
Inexperienced	0.24	0.26		
RVS use after initiation x experience				
Experienced	0.54	0.17	30.62	**<.001**
Inexperienced	0.36	0.23		
RVS use prior to initiation x age group				
60-69	0.27	0.23	1.35	.247
70+	0.23	0.25		
RVS use after initiation x age group				
60-69	0.47	0.17	0.73	.394

Independent factor	*M*	*SD*	*F*- Value	*p*-value
70+	0.44	0.26		

Note: Bold text indicates statistical significance

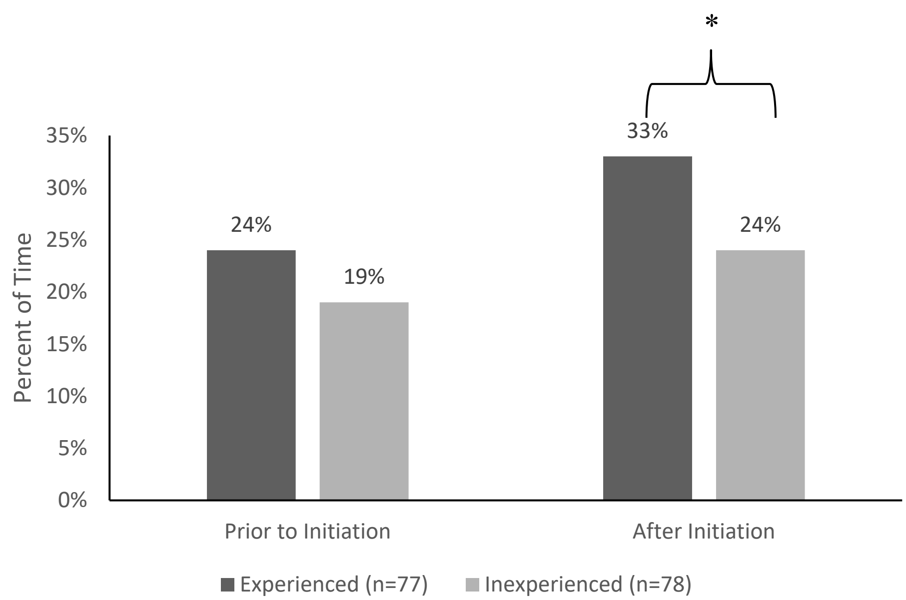

Figure 22. Proportion of time glances directed to RVS by experience and timing when backing into space.
Note: An asterisk (*) indicates p < .05

Researchers also analyzed glance behavior to examine what proportion of participants looked to the right mirror, over their right shoulder out the back side or rear window, and to the RVS (when available). As shown in Figure 23, there were only small differences across participant groups. These are descriptive analyses; no significance tests were conducted. Most participants checked the right mirror, over their shoulder, and used the RVS when it was available.

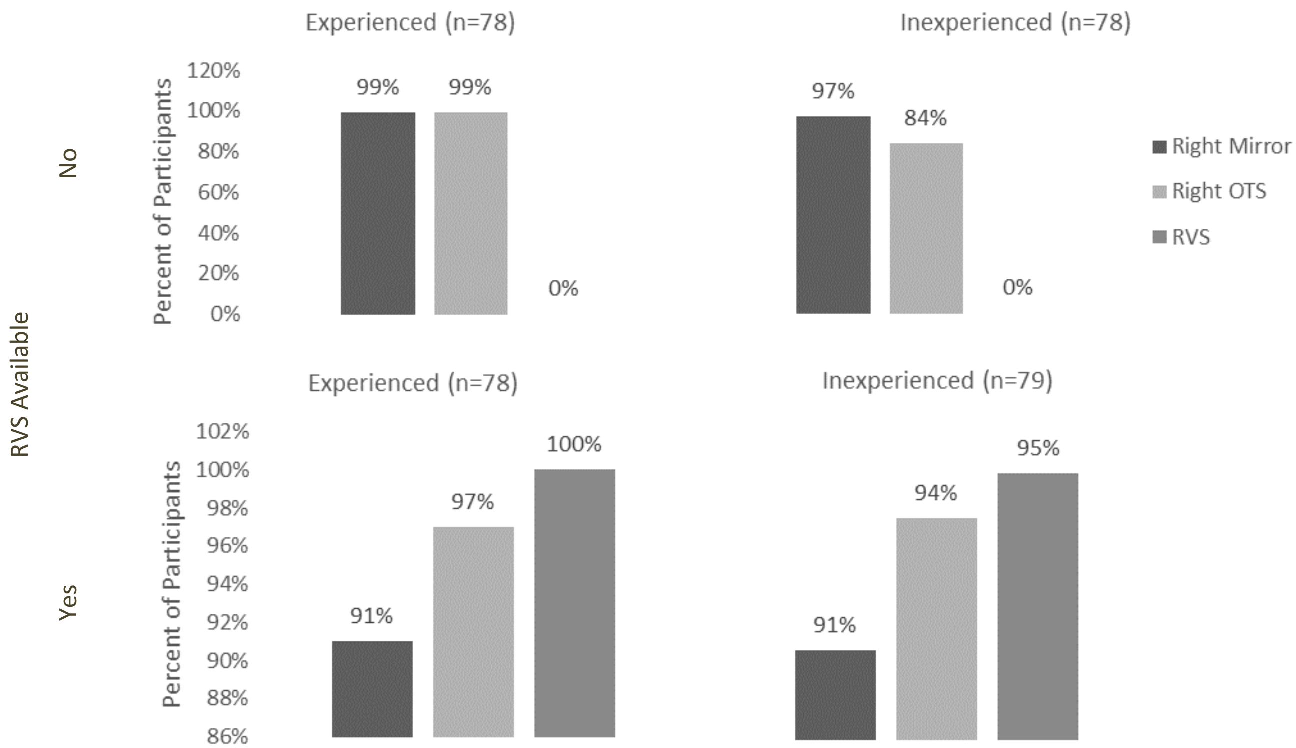

Figure 23. Glance behavior to target areas when backing into space

Finally, the researchers calculated the mean number of glances per participant for each of three target locations—to the right mirror, over the shoulder, and to the RVS. As shown in Figure 24, when the RVS was unavailable (top graphs), participants tended to glance to the right mirror most frequently, about six glances on average. When the RVS was available (bottom), participants glanced most frequently to the display, although on average people with RVS experience glanced there more than twice as often (about eight glances) as inexperienced participants. These are descriptive analyses; no significance tests were conducted. Participants with RVS experience glanced less frequently to the right mirror (about four glances), while inexperienced participants made about six glances to both the display and right mirror.

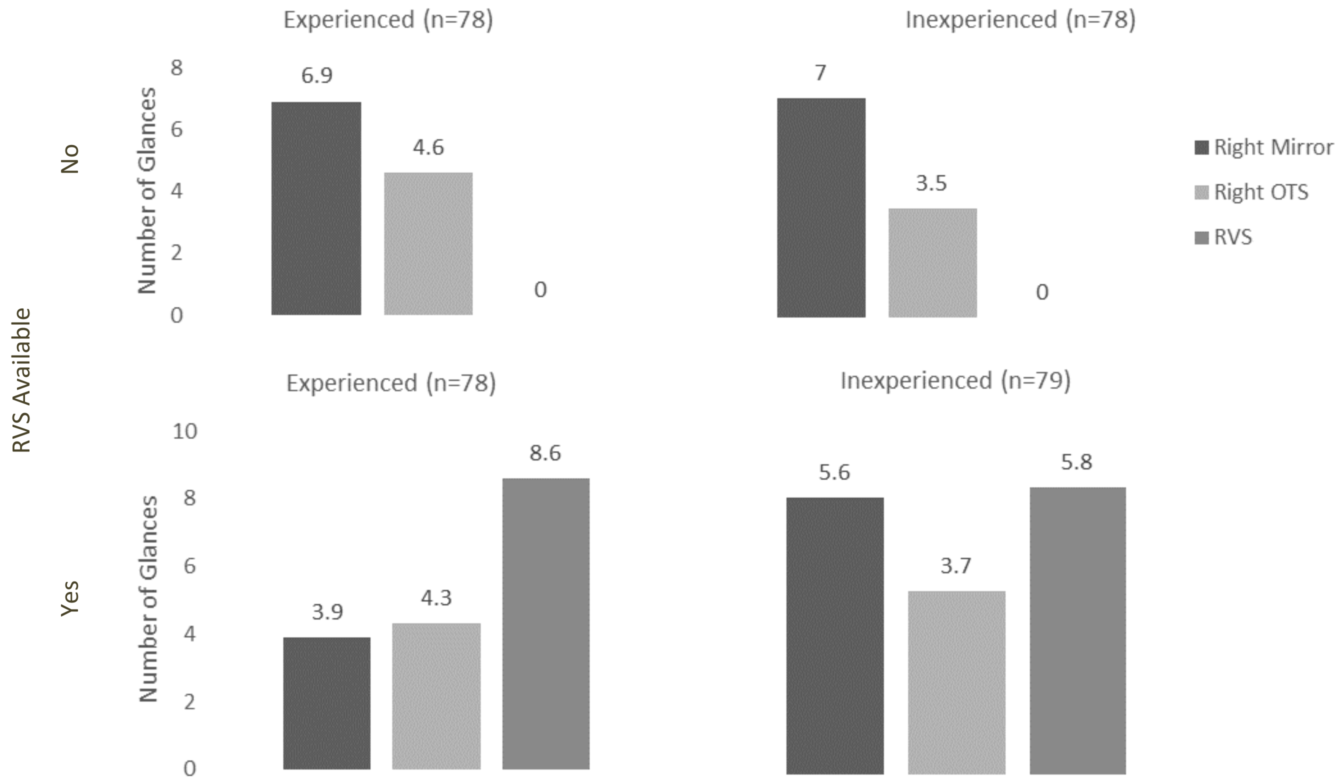

Figure 24. Mean number of glances to selected locations in backing into space

Three-Point Turn

Each participant completed this task once with the RVS available and once without the RVS. Eighty-five percent of participants in the experienced group used the RVS at some point during the maneuver, while only 69% of the inexperienced group did so. No participant in any group committed an error during this task; consequently, there was no need for regression analyses.

As shown in Table 13, an ANOVA on proportion of time allocated to the RVS by experience and by age group revealed no statistically significant differences.

Table 13. ANOVA Results Table for Three-Point Turn Glance Analyses

Independent factor	Proportion of Time		*F*- Value	*p*-value
	M	***SD***		
RVS use prior to initiation x experience				
Experienced	0.15	0.12	0.98	.326
Inexperienced	0.12	0.12		
RVS use prior to initiation x age group				
60-69	0.14	0.12	0.48	.491
70+	0.12	0.12		

Surprise Obstacle Event

Researchers first measured hazard avoidance as a function of participant age cohort and RVS experience. Each participant completed the surprise event task only once, and the RVS was available in all cases. Figure 25 and Figure 26 illustrate the breakdown of object avoidance for the surprise event task. No positioning errors were possible during the task, only the single error of hitting the object. Overall, participants without RVS experience were much more likely to hit the object than those with prior experience; 38% of drivers in the group with RVS experience hit the surprise object, compared to 80% of those in the inexperienced group. Participants who used the RVS during the trial were much less likely to commit an error; 95% of those who did not use the RVS hit the surprise object in contrast to the 46% of drivers using the RVS. A single driver who did not use the RVS and did not strike the surprise obstacle avoided it by chance as they angled the vehicle to the side when reversing.

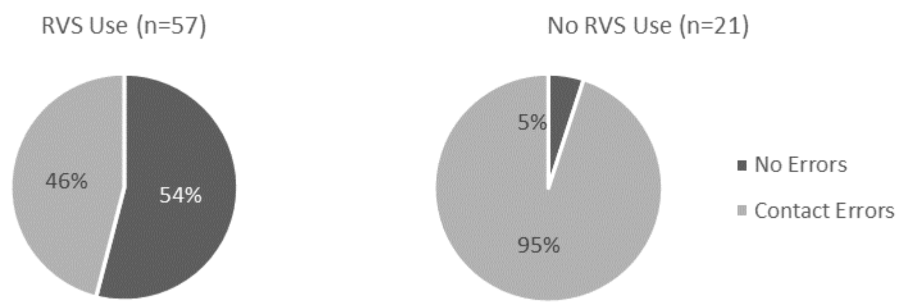

Figure 25. Overall performance by RVS use for surprise trial

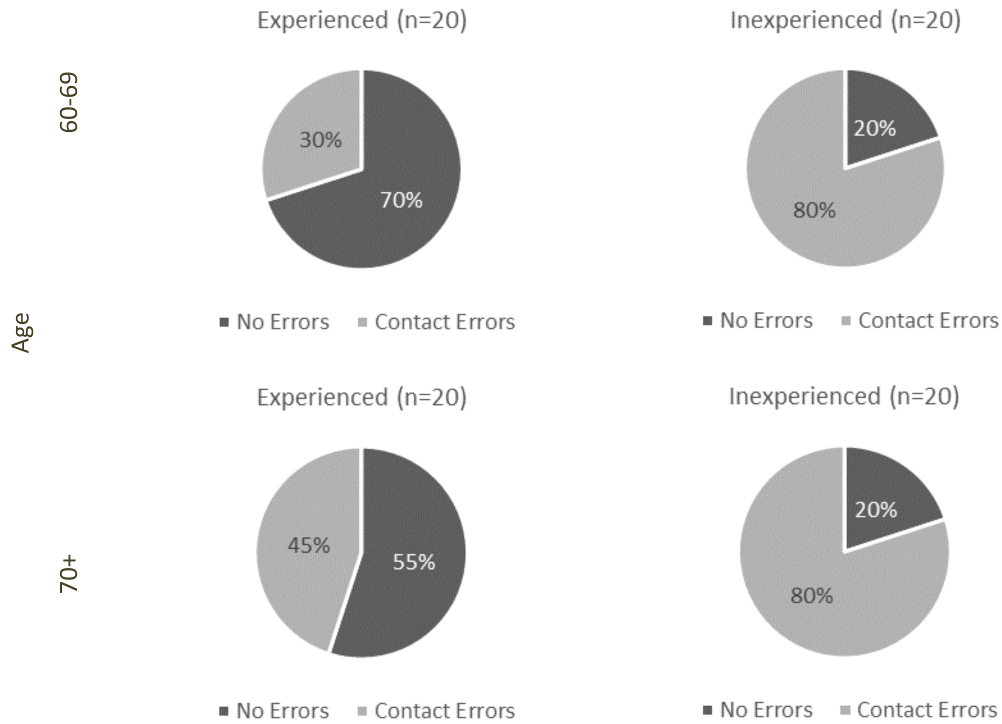

Figure 26. Overall performance errors for the surprise trial by experience and age group

A series of chi-square tests confirmed statistically significant differences for both experience and RVS use during the trial (Table 14). A Fisher's exact test was used for the RVS use test due to a low cell count.

Table 14. Chi-Square Summary Results for Surprise Trial

Independent factor	**% hit object**	**X^2 Value**	**p-value**
Range of motion			
Good	57.1%	0.20	.905
Normal	57.1%		
Limited	62.5%		
Experience			
Experienced	37.5%	14.91	**<.001**
Inexperienced	80%		
Age group			
60-69	55%	0.46	.496
70+	62.5%		
RVS use			

Independent factor	% hit object	X^2 Value	p-value
Use	45.6%	Fisher's exact test	**<.001**
No use	95.2%		

Note. Bold text indicates statistical significance.

Table 15 presents the results of a series of generalized linear models conducted for errors during the surprise trial. Confirming the ANOVA results, experience was associated with significantly fewer object hits. Further, both the number of glances to the display prior to movement and the percentage of time spent looking at the RVS display after initiation of movement were significantly associated with decreased likelihood of errors at the .05 level of statistical significance.

Table 15. Poisson Regression Results for Errors During Surprise Trial

Variable	Errors	
	z-value	*p*-value
Range of motion[a]		
Normal	0.225	.822
Limited	0.117	.907
RVS experience[b]		
Inexperienced	2.422	**.015**
Age group[c]		
70+	0.453	.651
Percentage of time prior to initiation	-1.450	.147
Percentage of time after initiation	-2.887	**.003**
Number of glances prior to initiation	-2.569	**.010**
Number of glances after initiation	-1.382	.167

Note. Bold text indicates statistical significance. [a] 0 = Good range of motion.
[b] 0 = Experienced with RVS. [c] 0 = 60 to 69 years

ANOVAs (Table 16) explored differences in the proportion of time spent glancing to the RVS (prior to backing initiation and after backing initiation) by age group and experience. Table 16 presents the results of these analyses. Those in the experienced group reliably allocated more time to the RVS than those in the inexperienced group, both prior to initiating the backing maneuver and after beginning backing (Figure 27).

Table 16. ANOVA Results Table for the Surprise Trial Glance Analyses

Independent factor	***M***	***SD***	***F*- Value**	***p*-value**
RVS use prior to initiation x experience				
Experienced	0.26	0.31	7.04	.010
Inexperienced	0.10	0.20		
RVS use after initiation x experience				
Experienced	0.54	0.41	20.09	**<.001**
Inexperienced	0.17	0.31		
RVS use prior to initiation x age group				
60-69	0.16	0.23	0.40	.531
70+	0.20	0.31		
RVS use after initiation x age group				
60-69	0.41	0.43	2.13	.149
70+	0.28	0.37		

Note. Bold text indicates statistical significance.

The researchers also evaluated targeted glance behavior by comparing the proportion of participants glances to various locations during the task, including to the right mirror, over their right shoulder out the back side and rear window, and to the RVS (see Figure 28). Participants with RVS experience were more likely to use the RVS at some point during the trial (over 80%), while inexperienced participants were more likely to look to the side mirror or rear window than to the RVS. These are descriptive analyses; no significance tests were conducted.

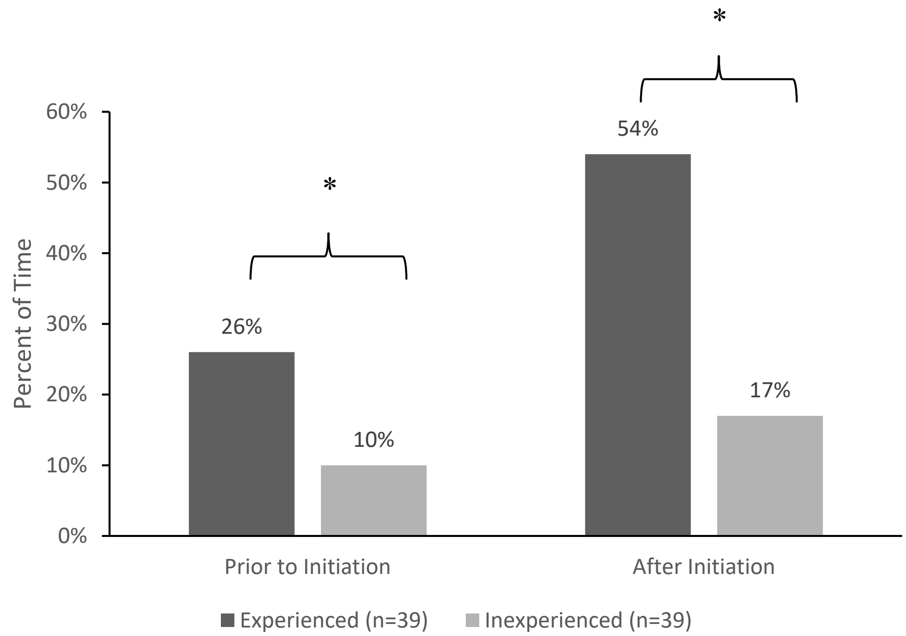

Figure 27. Proportion of time glances directed to RVS by experience and timing during the surprise trial.
Note: An asterisk (*) indicates p < .05

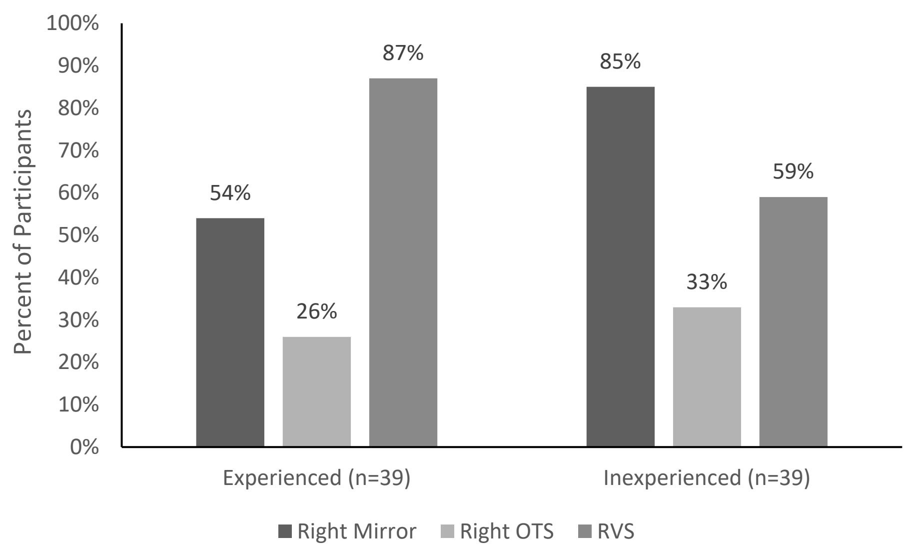

Figure 28. Glance locations by participant experience group

Finally, the researchers calculated the mean number of glances per participant to each of three target locations—to the right mirror, over the shoulder, and to the RVS. As shown in Figure 29 participants with RVS experience glanced about twice on average to the RVS, with about one glance to the side mirror, while inexperienced participants reversed this glance prioritization (these are descriptive analyses; no significance tests were conducted).

Figure 29. Mean number of glances to target locations for surprise trial

Participant Comments

During data collection, researchers documented participants' spontaneous comments and questions as they related to the experimental session or the RVS. These comments were categorized into those about the vehicle's RVS display and those about a task. Vehicle-related comments focused on the RVS display as it differed from the display in the participant's personal vehicle in terms of screen size, clarity, or alert system. Specific remarks are paraphrased below:

- "Does this vehicle also have a beeping/alert system?"
- "The screen in my car is larger and easier to see."
- "I'm used to how the screen on my car looks (with respect to clarity or lines)."
- "I'm used to having an alert system to tell me when I get close to something."
- "The lines on the display are too dim."
- "How far do those lines on the display represent?"

Task-related comments either expressed confusion about what was displayed, or were performance related, mainly participants' failure to use the RVS when beneficial. During the long-curved backing task, the reference line on the pavement was clearly visible in the RVS display; however, multiple participants noted they could not see the line. In these cases, the participant was looking over their shoulder or out of a side window toward the mirror and did not glance to the RVS. Similarly, participants who struck the low contrast cone placed behind the vehicle (either in the backing out of space task, or the surprise event), commented that they were unable to see the cone in any of their mirrors or over the shoulder. However, in these cases participants generally failed to glance to the RVS display where it was clearly visible. Specific remarks are paraphrased below.

- "I thought I was doing really well." (After poor performance on long curved backing).
- "I can't see the road lines." (During long curved backing – regardless of RVS availability).
- "I don't use the RVS because I don't know how."
- "Was I supposed to be able to see the cone? How was I supposed to see the cone?" (After surprise event/backing out of space—with RVS available).

In general, participants in the no-experience groups did not own a vehicle with an RVS at the time of the study, whereas those in the experience groups did. Participants who owned a vehicle with an RVS tended to also have experience with rear cross-traffic alerts (RCTA) as well as general backing alerts. About half the participants with an RVS had one with predictive lines and RCTA. As would be expected, those who did not own a vehicle with an RVS were less likely to have experience with any of the advanced alert systems.

Participants with RVS experience were more likely to say they felt comfortable using the RVS in this study and to state that backing is easier when using the RVS. However, most participants offered that they felt safe using the RVS that it would be most helpful when backing into and out of parking spaces and for use in parking lots, and in the garage or driveway. No participants singled any situations where the system would be dangerous. When the broader topic of learning to use new technologies in vehicles arose, participants clearly voiced their preferred method of learning how to use technology like an RVS. Most preferred video instruction, followed by instruction by a salesperson or dealer representative, and finally, trial and error.

Implications for Training

Two major findings of this backing performance study have clear implications for training. First, experience with RVS was found to be associated with improved obstacle detection. Training could allow an inexperienced RVS user to detect and avoid obstacles more reliably than they would without such training, including potentially avoiding back-over crashes. These findings suggest an initial training focus on getting unfamiliar drivers comfortable with the features, display and capabilities of an RVS, and encouraging them to practice in a controlled environment to learn to use the system. This training should also include explicit instruction and practice/exposure to both the capabilities and limitations of the RVS to enable new users to take full advantage of their benefits—such as identifying objects directly behind the vehicle—while complementing this with glances to the surrounding environment to identify potential hazards such as a pedestrian approaching from the side outside the field of view of the RVS.

Secondly, as discovered in the backing-into-parking space and long-curved-backing tasks, experience alone is not sufficient to improve performance on tasks where exact vehicle guidance is required. The present results suggest that directed training may improve performance beyond what is accomplished simply through exposure, both for inexperienced and experienced users. Further, as RVS displays have a variety of static and curving lines, it would make sense for training to provide instruction in the best use of these when performing different backing tasks. Training should not, however, ignore the need for drivers to continue to use mirrors to identify hazards outside the field of view of the RVS.

Training Video Development

This study found that to the extent participants voiced preferences about their preferred method of learning how to use technology like an RVS, most preferred video instruction. Additional participant feedback, plus observations of participant behavior, also provided guidance for the development of instructional video content. Researchers determined that:

- To benefit the widest possible user population, training results should be generalizable across different vehicles/devices. Accordingly, training should be *task-specific*, not *device-specific*. Promoting generalizability also pointed to the use of a centrally (dash/console) located RVS in the training video.
- The instructional video should focus on (a) where participants felt the information provided by the RVS would be most helpful to them; (b) where the RVS is the *only* source of information that allows the driver to avoid a conflict; and (c) where task performance is dependent on efficiently sharing/shifting attention between the RVS display, mirror views, and direct looks to the side and/or over the shoulder to detect potential conflicts beyond the field of view of the outside mirrors.
- The instructional video should potentially benefit experienced RVS users as well as inexperienced users. This suggested an emphasis on not only the detection/avoidance of static objects and increased awareness of conflicts with moving targets behind the vehicle (e.g., pedestrians, cyclists, or rear cross traffic) but also on how to improve the accuracy of backing movements—for example, how to highlight the use of RVS grid lines on pavement features while backing into a parking space.

In consultation with NHTSA, researchers developed a video storyboard with four scenes featuring an actor ('Peter') as an older driver, who delivered a script detailing proper use of an RVS in three different scenarios plus a summary of key points covered in the video. A professional video production company filmed the scenarios. The scenarios were (a) backing a vehicle out of a space in a row of cars in a parking lot; (b) backing a vehicle into a space in a row of cars in a parking lot; and (c) backing a vehicle a long distance, including a curved segment, staying close to but not crossing the edge of the path (in this case, a curb). The storyboard is presented in Appendix A.

This page is intentionally left blank.

Training Evaluation Study Plan

Introduction

The data collection and analysis plan described below represents a second phase in this study. This phase seeks to develop a test protocol to assess the effectiveness of a training program intended to increase knowledge and familiarity with RVS. The specific backing tasks and maneuvers proposed in the test protocol reflect situations where proper RVS use is emphasized in the training video and are designed to answer the following research questions:

1. To what extent does an evidence-based training program improve older drivers' backing performance when using an RVS?
2. How does vehicle guidance and obstacle detection performance differ between participants who have experienced RVS-specific training and a control group that has experienced unrelated training?
3. Is the training equally effective among drivers in their 60s and those 70 and older?

Sample Characteristics

The proposed test protocol would start by recruiting 120 drivers across two age groups (60 to 69 and 70+), who will be randomly assigned to a Training (RVS training) or Control (unrelated training) group. The four groups will each have 30 participants.

Participants will be sought who have minimal-to-no experience using RVS devices. If too few such drivers can be recruited to meet sample size requirements, drivers who have an RVS in their vehicle but report that they do not use it or express dissatisfaction or dislike for the technology may also be included. If the sample includes mixed RVS experience levels, the researchers will categorize by experience with RVS, then randomly assign to groups from each category. People who participated in the first phase, as well as their spouses, will be excluded from participation in phase two to reduce the likelihood of expectancies for surprise event trials. Additional inclusion criteria include a current, valid driver's license, and a minimum of three driving trips per week. Candidate participants with a visual or medical condition or limitation that the research team feels could interfere with driving performance will be excluded, as will those who are required to use any adaptive vehicle. Medical inclusion criteria will be consistent with phase one.

Participant Recruitment

Potential participants will likely include those who have responded to prior advertisements and have consented to be contacted about research opportunities. If sufficient participants cannot be recruited via this database, additional recruitment will target the senior population in general such as senior living communities and other locations with a high concentration of senior activity, including community and fitness centers. Advertisements in local newspapers, as well as social media that may be frequented by seniors including Facebook, also may be used. The research team will endeavor to ensure sex equity across groups by ensuring similar portions of males and females in all four groups. In addition, the plan will specify recruiting participants from a wide cross-section of the population in the study area to ensure people of all demographics (e.g., race, ethnicity, sex, and socioeconomic status) have equal opportunity to volunteer to participate. Potential participants who have contacted the recruitment team will be requested to provide the following information: date of birth; driver license status; number of trips per week (at least three trips per week required); if they have medical conditions consistent with those used for screening in the first phase; and their level of familiarity with confidence in, and frequency of use of RVSs. Recruits who pass all screening criteria and are interested in participating will be scheduled for participation and will be sent consent information in advance.

Consent and Participant Protection

Before any phase two data collection, the researchers will obtain clearance under the Paperwork Reduction Act as well as approval from an Institutional Review Board. Before the experiment begins, the researcher will administer an informed consent procedure. Participants will be told that the purpose of the research is to study their scanning behavior, in particular what aids they use when backing in various situations; and that they may encounter obstacles while backing.

In addition to expanded consent information, additional behavioral and protocol protections may be incorporated for participants if necessary to address any continuation of the pandemic. These may include the required use of face masks and the implementation of a clear partition (like those seen in taxicabs) in the research vehicle. The research team will comply with all recommended practices related to the pandemic at the time of data collection to ensure the safest possible research experience for both participants and experimenters.

Training Video Presentation

Prior to the beginning of the test-track portion of the study, each participant in both the Control and Training groups will individually view a training video. Viewing will be conducted in a private research room with a suitable viewing environment, and an experimenter will be present to start the video and ensure participant comfort. Participants in the Training group will view the RVS training video described above, whereas participants in the Control group will view a video of equal duration about an unrelated vehicle/driving safety topic such as driving in inclement weather or changing a flat tire. The experimenter will not elaborate on the videos beyond basic questions of clarification to ensure as consistent a training experience across participants as feasible. Each participant will be offered a brief break following the training video presentation, then will be escorted to a closed course where they will be guided to the test vehicle.

Evaluation Data Collection Platform

The test vehicle will be a full-size sedan. This affords significant advantages over the use of personal vehicles, including installation of a passenger-side secondary brake (which can be operated from the front or back seat) that the experimenter can use to stop the vehicle as needed to ensure safety.

Each participant will be afforded a brief interval (of equal duration across participants) driving the test vehicle to become familiar with its handling characteristics and controls before data collection begins. This will include practice (i.e., not scored) maneuvers using the RVS; specifically, during this familiarization period each participant will be asked if they have questions about any of characteristics or features of the display. If so, the experimenter will answer them at this time.

The DAS (Figure 30) that will be installed into the test vehicle will provide the following sources of data:

1. Five video camera views, including the following:
   a. Driver face.
   b. Forward roadway.
   c. Rear roadway/parking space.
   d. Vehicle left and right sides.
2. Precise vehicle (and target) location using dGPS.
3. Multi-axis accelerometers enabling identification of hard braking or acceleration events.
4. Precise timing information at the millisecond level.

Figure 30. VTTI DAS main unit, mounted securely and inconspicuously

RVS

Consistent with phase one, the researchers will use an OEM-integrated RVS built into the dash of t test vehicle. Key features of the RVS will include an approximately 8-in. diagonal display with moving guidance lines.

Evaluation Data Collection Protocol

Data collection will be conducted by a trained researcher who has completed specific training on working with senior drivers, including the operation of the secondary vehicle brake. This training will be based on a curriculum used to gain certification as a certified driving rehabilitation specialist (CDRS), although it should be noted that the experimenter will not be a CDRS. The experimenter will be assisted by one or more research assistants who will serve in various supporting roles, including surreptitious object placement and removal, as needed.

Backing Maneuvers

A partial factorial design including eight backing trials is planned for the field experiment. As illustrated in Table 17, all backing tasks [backing out of a garage (twice); long backing with curve; backing into and out of a parking space (twice each maneuver); and experiencing a surprise trial] will be completed by all participants. However, the presence versus absence of an obstacle will be tested only for three of the four maneuvers; no obstacles will appear in the long backing with curve task. The final surprise trial will also include an obstacle. The long backing, backing-in, and backing-out of space trials will be counterbalanced across participants, as all participants will start by backing out of the garage and finish with a surprise trial after they believe the experiment has concluded. The experimenter will initiate the first trial by signaling the field crew after the pre-experiment survey has been completed. The total duration of the controlled field experiment will be approximately 40 minutes.

Table 17. Experimental Design

	RVS Trials				
Backing Task	From Garage	Long	Out of Parking Space	Into Parking Space	Surprise
Obstacle?	Y N	N	Y N	Y N	Y

Garage Backing

This condition simulates backing out of a garage. Here, researchers will install a single-bay carport on the test track that is enclosed on three sides. A researcher will ask the participants to back out of the garage, and in half the trials the participant will experience a low-contrast obstacle placed surreptitiously by the experimenter. Errors will consist of impacting either the garage entrance/walls or the obstacle. For trials in which there is an obstacle, a research assistant will surreptitiously place the obstacle—tentatively a traffic cone—in the backing path. This cone will be covered in a grey cloth or tape material that will make it less conspicuous than a standard orange traffic management cone. An example is shown in Figure 31. The driver's attention will be diverted while cones are being placed prior to trial initiation, and neither the in-vehicle researcher or field crew will provide cues to the driver.

Figure 31. Low-contrast cone in surprise trial

Long Backing With Curve

For this task, participants will be asked to back around a grass island like Figure 32, which simulates backing along a curb or driveway, including a curved segment, and will assess the driver's ability to accurately control the vehicle while driving in reverse. There will be no obstacle for this task, as the primary behavior of interest is vehicle control. The long backing path will be delineated with a temporary pavement marking that the driver will be instructed to use for guidance but not to cross. As in phase one, encroachments on or significant deviations from this path boundary will be scored as backing errors (event counts).

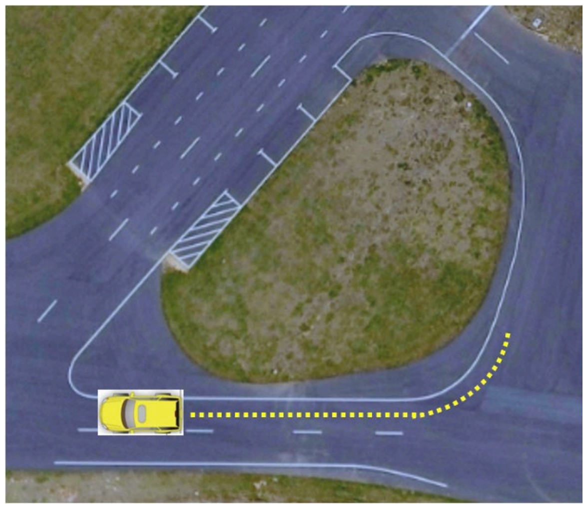

Figure 32. Overhead view of long backing with curve task

Backing Into a Parking Space

This task involves backing into a parking space that will be bounded by a stationary vehicle (or plastic barriers) and the garage. The trial will begin with the test vehicle placed perpendicular to and behind the open parking space (Figure 33-1), and will involve the participant pulling beyond the space (Figure 33-2), then backing into it (Figure 33-3).

While the phase one *back-into-space* task involved the use of a moving shopping cart obstacle (to avoid participants' noticing it during the initial alignment), phase two will use a larger garage to allow an experimenter to surreptitiously insert a stationary yet rollable obstacle such as a child's wagon into the space during the backing maneuver (Figure 34). This method has the advantage of an increased potential for actual conflict, which was impossible with the obstacle moving perpendicularly behind the end of the parking space in Experiment 1.

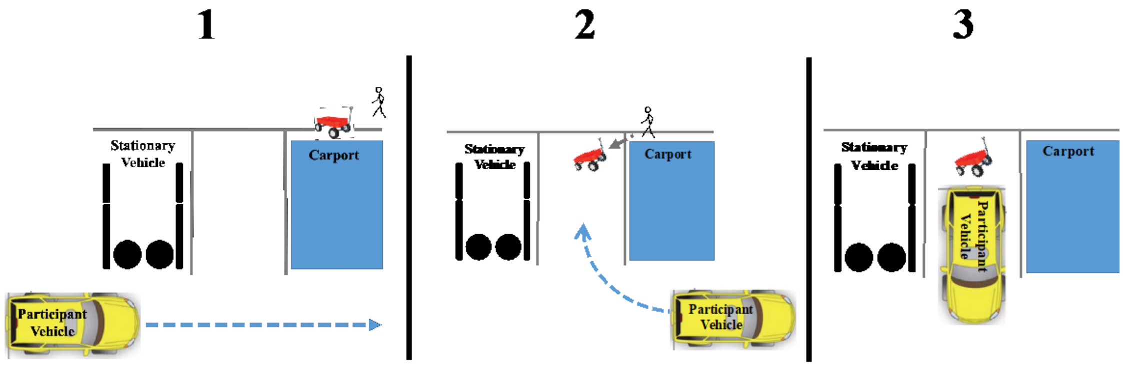

Figure 33. Backing into parking space

Backing Out of a Parking Space

This task simulates the case of a person backing out of a space in a crowded parking lot. Here, participants will back straight out of a parking space two spaces to the left of the space used in the *backing into a parking space* trial, bounded by two stationary vehicles, toward a goal post (Figure 34). In half the trials participants will encounter a shopping cart moving across the vehicle's path from the right. This cart will be like the cart used previously, with additional padding and breakaway wheels since it is more likely to come into conflict with the participant vehicle. The garage will serve to initially obscure the cart from participants' views.

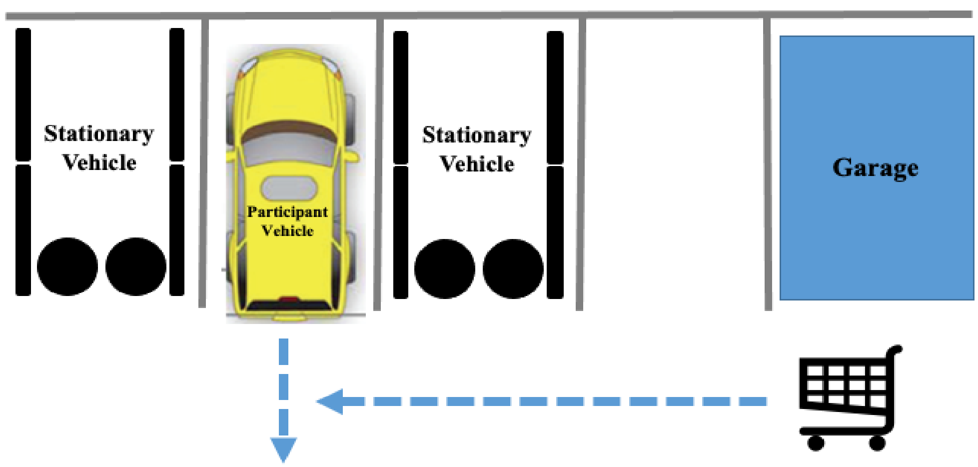

Figure 34. Backing out of parking space

Surprise Trial

After the final counterbalanced trial, the participant will be instructed to pull front-first into a parking space to receive debriefing. As in phase one, as the participant is occupied with this debriefing, another experimenter will surreptitiously place a final stationary obstacle behind the vehicle for a final "surprise" trial, to capture behavior in a less scripted context. The surprise trial will be initiated by the experimenter asking participants to use the test vehicle to return to the location where they parked their car on arrival.

For each participant, after all trials have been completed, the researcher will administer a post-experimental survey including, but not limited to, the following questions:

- What is your opinion of the rear-vision system?
- How comfortable were you with using the rear camera display?

After responding, the researchers will provide a full debrief to those participants wishing to receive one upon completion of all data collection (i.e., to prevent them from discussing such with other people who may also serve as participants).

Obstacle Presentation

Phase two will use three types of obstacles: matte grey cones, a padded motorized shopping cart, and a padded toy such as a child's wagon. As described above, cone objects will be standard traffic cones, but they will be covered with a matte grey cloth or tape to be less conspicuous than the standard orange. The shopping cart used in the *backing-out-of parking-space* trials is the same as used previously, with additional padding and a revised powertrain to improve reliability. The obstacle used only during the *backing-into-parking-space* trials will consist of a toy like a standard wagon that has received additional padding to prevent damage to either wagon or test vehicle should a collision occur. An experimenter will wheel this wagon to a predetermined location inside the parking space during the trials.

Planned Data Analyses

Data will include five camera views providing a complete picture of events in and around the vehicle, precise vehicle position via dGPS, throttle position, brake status, gearshift position, multi-axis acceleration data, and digital inputs (event markers). Researchers will import both video and vehicle data into a secure database. Analyses will parallel those presented above, although comparisons will focus on between-subjects (training and age) groups instead of between RVS and no-RVS trials. Specific dependent measures will include:

- Successful avoidance of obstacles versus collisions or positioning errors,
- Counts of errors in the long backing maneuver,
- Driver glance behavior—number of glances and glance allocation among RVS, mirrors, and over-the-shoulder, in the aggregate and for each included backing task/maneuver.

These variables will be subject to multivariable analyses across groups and conditions, allowing comparisons to be made on performance metrics between age and experience groups, RVS presence or absence, and maneuver type. We will also analyze within-group differences, particularly differences in glance behavior among participants.

This page is intentionally left blank.

Conclusions and Discussion

This research addressed a problem that many drivers may experience, but one that is exaggerated for many older drivers due to age-related musculoskeletal deficits that restrict neck/torso mobility: detecting objects and maintaining a safe path to avoid conflicts when backing. Compared to their younger counterparts, older drivers are more likely to have difficulty turning to look over their shoulders. In addition, drivers' vision is blocked for the area on or near the ground immediately behind the vehicle. RVS technology offers the promise of a disproportionate benefit for older drivers. However, a literature review revealed that using an RVS is more difficult to learn for this group and they are less confident in this technology for backing into small or difficult parking spaces. Consequently, researchers obtained measures of backing performance using an RVS versus mirrors alone, by drivers in their 60s and those 70 and older, seeking to identify specific maneuvers that were most problematic for these drivers and that may be amenable to training. They applied the results to develop and produce an RVS training video and design a training effectiveness evaluation study to be carried out in a second phase.

The data analyses included binary outcomes (striking/avoiding rear hazard, and use/nonuse of the RVS during a trial); continuous measures (eye glance behavior, and deviation of the test vehicle's path from a reference line on the pavement); and counts of position and contact errors as a function of categorical variables (e.g., age cohort, and RVS experience). Position errors included vehicle tires touching or crossing a lane line, or vehicle misalignment, while contact errors included actual contact with a sign, obstacle, or one of the plastic barriers. These measures were applied as appropriate across various backing tasks associated with everyday maneuvers—short backing (as if backing out of a parking space or garage); long backing; backing into a parking space (where there are potential conflicts with adjacent vehicles); and a three-point turn. A single "surprise trial" required avoidance of an obstacle surreptitiously placed behind the test vehicle.

The backing performance study found some statistically significant effects. In the short backing task, drivers who were experienced with an RVS were significantly less likely to strike the obstacle (traffic cone) when backing and spent a significantly higher proportion of time glancing to the RVS both prior to and after initiating backing compared to drivers who were inexperienced with RVS. The drivers in their 60s spent a significantly greater amount of time glancing at the RVS display than those 70 and older before beginning to back, but this difference disappeared once backing was initiated. Across age groups, a higher number (*not* duration) of glances after beginning backing was associated with a decrease in contact errors, but with an *increase* in position errors—which, it should be noted, were inconsequential, typically just the vehicle being slightly off-angle (not perfectly aligned) in the parking space. Researchers concluded that these findings may indicate that participants were seeking more visual information *before* executing a decision to begin backing, which arguably will enhance safety; but when participants' eyes were moving more frequently back and forth between the display and another location *after* beginning backing, this suggested a division of attention that could be potentially detrimental to safety.

In the long (curved) backing task, drivers who looked at the display longer, regardless of their experience level with an RVS, were less likely to commit gross divergence errors; again, participants who looked away from the display more frequently tended to have higher error rates. Similarly, more time spent using the RVS during the backing maneuver was associated with fewer slight divergence errors. There was no statistically significant association between the *number* of glances and slight errors. There were also statistically significant effects in driver glance behavior related to the level of RVS experience. Prior to backing, and during backing on both the straight and curved segments of this task, those with previous RVS experience allocated a greater percentage of time to glancing at the RVS display. There were no statistically significant effects associated with driver age group on this task.

When backing into a parking space on trials when the RVS was available, two drivers committed contact errors; both were inexperienced with the technology. Nearly every participant committed some form of position error, generally a vehicle misalignment; still, the older (70 and over) age group was more likely to commit position errors than the younger (60 to 69) age group. A higher percentage of time looking at the RVS display after beginning backing, as well as more glances to the display during backing, were both associated with fewer errors. Drivers in the group experienced with an RVS allocated more time to the rear camera display than those in the inexperienced group, but *only* after they began to back the vehicle. Also in this task, drivers struck the shopping cart while backing more often if their neck/torso range of motion was limited, rather than in the normal range, and if they were in the older (70 and over) age group.

Finally, on the single "surprise event" trial, only 38% of drivers in the group with RVS experience hit the traffic cone, while 80% of those in the inexperienced group struck the traffic cone across both age groups, which was a statistically significant difference. Not surprisingly, both the number of glances to the display prior to backing and the percentage of time spent looking at the RVS display after initiating the backing movement were associated with a lower likelihood of an error on this task.

Incidental/unsolicited participant comments provided an additional and useful perspective for the takeaways from this study. These focused on (a) where participants felt the information provided by the RVS would be most helpful; (b) where the RVS was the *only* source of information that allowed the driver to avoid a conflict; and (c) where task performance was dependent on sharing/shifting attention between the RVS display, mirror views, and direct looks to the side and/or over the shoulder, to detect potential conflicts not visible with the outside mirrors.

The driver performance data from the backing performance study, plus participant comments, shaped the design of the instructional video as well as the data collection plan to evaluate its effectiveness. In brief, these emphasized situations defined by the three points noted above. Researchers also concluded that instruction and evaluation should be directed as much to experienced as to inexperienced RVS users, focusing not only on detecting/avoiding obstacles to the rear but also on improving the accuracy of backing movements by highlighting use of the overlay of RVS grid lines on pavement features. Further, assuming the primacy of the visual information a driver acquires from an RVS, and how it supports the tasks prioritized in the evaluation study plan, our team concluded that the generalizability of training study results should not be compromised by the specific physical characteristics (e.g., size, placement) of the RVS.

An increasing share of the U.S. passenger vehicle fleet is equipped with RVS technology, which offers safety and convenience benefits, particularly for older drivers whose neck/torso range of motion diminish with normal aging. However, to realize the full potential of their RVS, older drivers may benefit from training to become more proficient in RVS use.

References

Cicchino, J. B., Eichelberger, A. H., & McCartt, A. T. (2015). Buick Lucerne drivers' experiences with rear parking sensors. *Traffic Injury Prevention, 16*, 196–201.

Gish, J., Vrkljan, B., Grenier, A., & Van Miltenburg, B. (2016). Driving with advanced vehicle technology: A qualitative investigation of older drivers' perceptions and motivations for use. *Accident Analysis and Prevention*, *106,* 498–504.

Heckman, G. M., Kim, R. S., Lin, S., Rauschenberger, R., Young, D. E., & Lange, R. (2012). Drivers' visual behavior during backing tasks: Factors effecting the use of rearview camera displays. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *56*(1), 2236–2240.

Jenness, J. W., Lerner, N. D., Mazor, S., Osberg, J. S., & Tefft, B. C. (2007, August). *Use of advanced in-vehicle technology by young and older early adopters. Results on sensor-based backing sytems and rear-view video cameras* (Report No. DOT HS 810 828). National Highway Traffic Safety Administration. www.nhtsa.gov/sites/nhtsa.gov/files/dot-hs-810-828rev.pdf

Kidd, D. G., Hagoski, B.K., Tucker, T.G., & Chiang, D.P. (2015). The effectivenes of a rearview camera and parking sensor systme alone and combined for preventing a collision with an unexpected stationary or moving object. *Human Factors, 57*(4), 689–700.

Llaneras, R. E., Neurauter, M. L., & Green, C. A. (2011). Factors moderating the effectiveness of rear vision systems: What performance-shaping factors contribute to drivers' detection and response to unexpected in-path obstacles when backing? *SAE 2011 World Congress & Exhibition.* SAE International.

Mazzae, E. N., Barickman, F., Baldwin, G. H. S, & Ranney, T. (2008). *On-road study of drivers' use of rearview video systems (ORSDURVS)* (Report No. DOT HS 811 024). National Highway Traffic Safety Administration. www.nhtsa.gov/sites/nhtsa.gov/files/811024.pdf

Meyer, J. (2009). Designing in-vehicle technologies for older drivers. *The Bridge, 39*(1), 21–26. www.nae.edu/File.aspx?id=12500

Reimer, B., Mehler, B., & Coughlin, J. F. (2016). Reductions in self-reported stress and anticipatory heart rate with the use of a semi-automated parallel parking system. *Applied Ergonomics, 52*, 120–127.

Trubswetter, N., & Bengler, K. (2013, June 17-20). Why should I use ADAS? Advanced driver assistance systms and the elderly: Knowledge, experience, and usage barriers. *7th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*, Boltan Landing, NY, 495–501.

Yang, J., & Coughlin, J. F. (2014). In-vehicle technology for self-driving cars: Advantages and challenges for aging drivers. *International Journal of Automotive Technology, 15*(2), 333–340. https://dspace.mit.edu/bitstream/handle/1721.1/105917/12239_2014_Article_34.pdf?sequence=1&isAllowed=y

Zonfrillo, M. R., Ramsay, M. L., Fennell, J. E., & Andreasen, A. (2018). Unintentional non-traffic injury and fatal events: Threats to children in and around vehicles, *Traffic Injury Prevention, 19(2)*, 184–188. www.congress.gov/116/meeting/house/109548/witnesses/HHRG-116-IF17-Wstate-FennellJ-20190523-SD004.pdf

Appendix A: Storyboard for Training Video

- Scene 1 – Peter backing vehicle out of a space in row of cars in a parking lot.
- Scene 2 – Peter backing vehicle into a space in a row of cars in a parking lot.
- Scene 3 – Peter backing vehicle a long distance, including a curved segment, staying close to but not crossing the edge of the path.
- Scene 4 – Summary/conclusion.

Scene 1 storyboard – Peter backing vehicle <u>out of</u> a space in row of cars in a parking lot

Video (Set up scene with shot of Peter emerging from pizza place, carrying pizza box)	***Audio***
1. Peter settles into driver's seat, places pizza box on passenger seat, and fastens belt. Nods at camera while introducing himself.	1. *(Natural sounds only – belt click.)* "Hi, I'm Peter."
2. Peter starts car – could be key or push button (not shown) – then nods towards pizza.	2. "Umm…(*inhaling*). Let me back out of here and try to get home while this pizza is still hot! Ah -- *(inhales)* -- smell those anchovies!"
3. Peter shifts into Reverse.	3. "The first thing I want to do is see what my rearview camera is showing. My display is at the top of my center console – a few cars have them built into their rearview mirrors, but most are like mine, that you see here. The display comes on automatically when you shift into Reverse. (*pause*) And you'll probably see a message on your display telling you not to rely *only* on the camera view when you back up – this is critical!"
4. Peter looks to his outside mirrors and over each shoulder. Then, slowly begins to back his car.	4. "Even if there's nothing right behind you, your rear camera doesn't capture a very wide angle. To make sure there's not another car, a pedestrian, or a biker about to cross your path from the side, check your outside mirrors and glance over each shoulder *before* you start to back up."
5. Bicyclist (obscured by other parked cars) emerges and crosses behind Peter.	5. "There you go!"
6. Peter continues slowly backing.	6. "While I'm backing out of this space and starting to turn in the direction I want to go, the rear camera view is changing. That's why I'm going to keep glancing back and forth between my mirrors and the rear display – display, mirror view, display, mirror view – until I'm stopped and ready to drive away."
7. Peter stops backing, shifts into Drive and begins to move forward.	7. "Your rear camera and display will shut off when you shift into Drive and begin to move forward."
(End scene)	

Review these main points at end of scene:

- Your rear camera display, usually near the top of the center console, comes on automatically when you shift into Reverse.
- The rear camera captures a narrow field of view – great for detecting objects right behind you that you can't see directly or with your mirrors but doesn't let you see anything coming from the side that will cross your path as you back up.

- Check your outside mirrors and glance over each shoulder *before* you start to back up.
- Keep glancing back and forth between your mirrors and the rear display while backing.

Scene 2 storyboard – Peter backing vehicle into a space in a row of cars in a parking lot.

Video	***Audio***
1. Peter slowly cruises along row of cars until he comes to an empty parking space, then stops. Looks approvingly at space; nods; reaches to turn down radio volume.	1. "Sometimes I prefer to back into a parking space. It'll be a lot easier when I'm ready to leave."
2. Peter shifts into Reverse.	2. "My rear-view camera is a *big* help, in this situation."
3. Peter looks to his rearview mirrors and over each shoulder. Then, slowly begins to back his car.	3. "Some systems beep to warn you if you get too close to something while backing. But I'm not using those alerts now – and I don't need them, if I take full advantage of my rear display. Just let me do a quick mirror check, and I'll show you."
4. Peter turns the wheel to begin angling the back of his car so that it aligns with the edges/boundaries of the parking space and proceeds until the rear is directly lined up/centered with the space.	4. "Most rear vision systems have a really handy feature – once you become familiar with it. I'm talking about the guidelines superimposed on the display. See these two lines going straight back? These represent the width of your vehicle. They let you position your car, so it's centered in relation to the space you want to back into."
5. Peter slowly backs into parking space, then hesitates when most of the way in.	5. "If you see horizontal lines on the display - usually in different colors than the ones going straight back -they indicate specific distances behind you. The nearest one shows what's on the ground 18 to 24 inches behind you. Check your owner's manual for the exact distance."
6. Peter eases all the way into the space, coming to a stop.	6. "There. I'm in the middle of my parking space … more or less … and the red bar shows I'm less than two feet from the back edge. Perfect! And I do the same thing, by the way, when I back into my garage. But I never could have done this on my first try. When I got this car, I found an empty lot, and spent half an hour practicing with the backup camera. Do the same … you'll be happy with the result!"
(End scene)	

Review these main points at end of scene:

- Your rear vision system has features that can be a tremendous aid when backing into a single parking space at the mall, the grocery store … or your garage at home.
- If you see parallel lines extending straight back, these show the width of your car – steer to keep these aligned within the space you are parking in.
- If you see horizontal bars, they mark specific distances on the ground behind you – use them to position the rear of your car just where you want it.

Scene 3 storyboard – Peter backing vehicle a long distance, including a curved segment, staying close to but not crossing the edge of the path (i.e., hitting the curb). [Locations 1 and 2 at Borough Hall]

Video	***Audio***
1. [At location 1: parked at stop sign] Peter sits in car, idling, looking to his right down a sidewalk on the side of a building, waiting for someone. Taps his phone to check the time. Has a puzzled/ annoyed expression on his face.	1. *Sound of engine idling.*
2. Peter's phone rings. He glances at the Caller ID and answers.	2. "Where are you? I've been waiting here almost 15 minutes! *(pause)* But you said the end of the sidewalk. What? You're back by the steps, at the entrance?"
3. Peter glances in rearview mirror, then twists to look over his shoulder.	3. *(Sighs)*. "Alright, fine, I'll have to back up … Hold on, this will take a minute or so."
4. Peter shifts into Reverse.	4. "My rear-view camera is really going to come in handy now."
5. Peter looks to his right outside mirror and over his shoulder. Then, he slowly begins to back the car.	5. "I still need to look behind me, and in the mirror … but what I can see with the rear camera really helps. I can use the lines on the display to stay on track … let's see if I can back all the way through the curve without hitting the curb."
6. Peter continues slowly backing. When he reaches the stop point [location 2: in front of steps at building entrance], he shifts into Park.	6. "There! *(waves to person waiting)* Once you get familiar with your rear vision system, you'll really appreciate how much it helps you in a situation like this – or *any*time you need to back up."
(End scene)	

Review these main points at end of scene:

- If you need to back up over a long distance, use the rear camera view to supplement what you can see in your mirror and with direct looks over your shoulder.
- The lines extending behind your car can help you stay lined up with a curb or the edge of the pavement.

Scene 4 storyboard – Summary/conclusion

Varying neck/torso shots of Peter (video) speaking to camera. Background stills shift from one emphasis point to another, as most appropriate to content.

Video Show appropriate stills in background; overlay emphasis points above or below Peter.	***Audio*** Peter reading from prompter
Point 1: *Before you release the brake and start backing, check the rear camera view.*	1. "Let me wrap this up with a few points to remember. The other day, I crunched my granddaughter's scooter in the driveway, backing out of my garage. Never saw it! The rear camera display must have shown it, but I didn't look until it was too late. ... *Before you release the brake and start backing, check out the rear camera!* This will also save you from running over stuff that damages your suspension, or your exhaust system, or puts you in the market for a new tire."
Point 2. *Don't assume it's 'all clear' based on the camera view alone.*	2. "Or, let's say you're in a commercial parking lot. Once you start backing out of your parking space – *after* your camera shows you the coast is clear directly behind you – you've also got to *look at your mirrors* and *over your shoulder*. Your rear camera can't look *everywhere*. It's not going to help you pick up that guy on the bicycle, or a pedestrian – not to mention another car about to cross your path. So, split your attention between glances at your rear camera and what's happening around you. *Anywhere there may be cross traffic* you need to look back and forth, from your camera view to your mirrors, and over your shoulder, as you begin to back up."
Point 3. *Getting good at using the graphic overlay will take practice!*	3. "It may take some time to fully trust what you see in your camera view, and to rely on the graphic overlay to guide you into a tight space, or keep you lined up as you back along a curb or barrier. Give yourself half an hour somewhere safe, to practice, and you will really build your competence *and* your confidence in your rear vision system."
Point 4. *If you need more help getting comfortable with this technology, it isn't hard to find.*	4. "Getting all the benefits of using your rear vision system might take more than practice. You can find a wealth of instructional videos online. Search for *'How to use a rear – or backup – camera.'* And don't hesitate to visit a dealer. Of course, if you're buying a car, it's the dealer's responsibility to help you get comfortable with using the rear camera, along with all the rest of the car's bells and whistles. But even if you're not making a purchase, you can always contact a local dealer that sells your type of car and ask for help – the good ones will see an opportunity to make you a future customer!"
All points *(show as bullet list)*	5. "Hopefully, this message from the National Highway Traffic Safety Administration will help you back your vehicle more safely. The agency's contact information follows."
(Close scene with NHTSA logo, website and/or contact info – full frame)	

DOT HS 813 565
April 2024

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

16213-041224-v2