ABSTRACT

Research was conducted to assess driver acceptance and performance associated with a spotter mirror feature intended to reduce the incidence of lane-change conflicts by enhancing drivers' ability to detect vehicles in their side blind zone. The spotter mirror consisted of an integrated spherical convex blind zone mirror inset within a larger planar mirror. The spotter mirror's field-of-view was designed to target the vehicle's side blind zone area and to help drivers quickly detect the presence or absence of a vehicle in the blind zone. The study captured normative lane-change behavior during an extended drive on public roadways, with and without access to the spotter mirror system, for a sample of familiar and unfamiliar supplemental mirror users. In order to capture more naturalistic lane-change behavior, drivers were informed that the purpose of the study was to evaluate the adequacy of existing road signs for navigating to a destination. The study also allowed performance under critical conflict situations to be evaluated by adopting the unique approach of using a confederate vehicle to stage conflict situations at designated points along the drive. Results found that access to the spotter mirror increases mirror sampling under critical situations where a vehicle is in the blind spot area. No evidence was found to suggest that use of the spotter mirror increases any inherent risk associated with performing lane changes.

INTRODUCTION

This study assessed driver performance and acceptance associated with a spotter mirror feature designed to aid driver decision making when changing lanes and merging by allowing vehicles in the side blind zones to be detected via simple glances to the outside mirror units. Thirty-six drivers experienced both conventional and spotter mirror systems during an extended 120-mile drive using an instrumented vehicle on public roadways. Drivers were not initially informed of the purpose of the study in order to allow more naturalistic lane-change and mirror search behaviors to be captured and to gauge driver understanding of the spotter feature. The methodology also provided for driver interactions with the mirror systems to be examined during critical conflict situations (staged using a confederate vehicle) whereby a vehicle was positioned within the driver's blind zone area during imminent lane-change events. A number of research factors, in addition to mirror type, were also examined, including driver familiarity with supplemental mirror systems, use of labels to communicate the purpose of the spotter mirror, and driver age and gender.

METHOD

Five independent variables (factors) were experimentally controlled in a mixed factorial design (2×2×2×2 split-plot design) with one within-subject and four between-subjects variables. Mirror type (conventional and spotter mirror) was the single within-subject factor. Each driver received both levels of this treatment in counterbalanced order across drivers. Between-subjects factors included: Familiarity with supplemental “blind spot”-type mirror systems (familiar or unfamiliar; familiar users owned a vehicle with an aftermarket or factory-installed supplemental mirror unit). Although different in design from the spotter mirror feature...
tested as part of this study, it was important to include aftermarket or factory-installed systems users since their experience with these systems could differentially influence understanding, acceptance of, and performance with the spotter mirror. Both Age and Gender were also included in the design with three age groups represented: younger (18-25 years old), middle-aged (40-50 years old), and older (60 years and older) drivers. The last between-subjects factor dealt with the use of a Label (“Blind Spot Area”) affixed to the mirror unit to indicate the purpose of the spotter mirror; this factor was nested within driver familiarity (label versus no label) so that half of the drivers within each familiarity level received the label.

PARTICIPANTS
A total of 36 licensed drivers, ages 18 to 77, participated in this study. Participants were recruited from the Blacksburg and Roanoke, Virginia, areas. Half of the participants owned vehicles equipped with an aftermarket or factory-installed supplemental “blind spot” mirror system. Participants were balanced by age and gender using the following age groups: Young, 18-25 years old; Middle, 40-50 years old; and Older, 60+ years old. Each age group consisted of 6 males and 6 females. Participants were paid $20 per hour, with the typical session running approximately 4 hours, including the necessary pre-drive paperwork, on-road test session, and post-drive questionnaires.

STUDY VEHICLE AND VEHICLE INSTRUMENTATION
This study was performed using a 2003 GMC Envoy equipped with a proprietary Data Acquisition System (DAS) and customized spotter mirror units for both driver- and passenger-side outside mirrors (these were interchanged with the production conventional mirror units, as appropriate). The DAS continuously collected and recorded key vehicle dynamics variables (e.g., vehicle speed, lateral and longitudinal acceleration, turn signal state, radar traces for rear and adjacent vehicles, etc.), including video, at a rate of 10 Hz; all sensor and video data were time stamped and digitally written to a removable hard drive. The entire DAS package was installed in the rear cargo compartment of the truck and out of view of the driver. The MPEG video was collected by five cameras mounted inconspicuously within the vehicle and was synchronized with the data collection system. As shown in Figure 1, cameras were mounted to capture the following views: participant’s face, forward roadway, rear view of the roadway, and split views of the right-side lane markings and left-side lane markings. Together these views enabled driver gaze direction and mirror search to be captured and analyzed during lane-change episodes, as well as tracking of the location of vehicles in the adjacent lanes.

SPOTTER MIRROR
Customized blind zone spotter mirrors were developed by General Motors (GM) and used in the study; these consisted of an integrated spherical convex blind zone mirror inset within a larger planar mirror (refer to Figure 2). The spotter mirror's field-of-view was designed to specifically and exclusively target the vehicle's blind zone area, allowing drivers to quickly detect the presence or absence of a vehicle in the blind zone by simply glancing at the inset portion of the outside mirror. The spotter units were also designed so as not to interfere with the view of the main planar mirror (the spotter occupied approximately 15% of the total area of the compound mirror system) and minimize distortion. Refer to [1] for a detailed description and specification of the spotter mirror units.

PROCEDURE
Drivers completed a 120-mile trip on public roadways in which lane-change and mirror search performance with and
without the spotter mirror were evaluated. A ruse was used in order to capture more naturalistic lane-change and mirror use behavior. Drivers were informed that the purpose of the study was to evaluate the adequacy of existing road signs (both overhead and roadside signage) for navigating to a destination (i.e., Wytheville, Virginia). The true purpose of the study was not revealed until after the driving portion of the study was completed. Half of the drive took place with the spotter mirror and the other half with the conventional mirror (the order was counterbalanced across drivers). An in-vehicle experimenter (seated in the rear passenger compartment) accompanied the participant throughout the drive. The experimental session took approximately 4 hours to complete and included approximately 2.5 hours of driving and 1.5 hours of post-drive questionnaire and debriefing.

Since the task of navigating once on the freeway was not particularly challenging, drivers were asked to indicate the presence of highway on-ramps by changing lanes in advance of certain highway interchanges, the confederate executing these instructions during the first few highway points. Drivers were instructed to move back into the right lane after passing interchange points. Drivers were also asked to engage the cruise control, once on the freeway, in order to maintain a steady speed and ensure they did not exceed the posted legal speed limit of 65 mph. Drivers practiced executing these instructions during the first few highway interchange points to ensure the directions were clearly understood. Drivers were also asked to verbally indicate to the experimenter if they could not execute a lane change due to the presence of traffic in the adjacent lane.

A confederate vehicle driven by a Virginia Tech Transportation Institute (VTTI) experimenter staged conflict situations at designated points along the drive. The confederate, unknown to the participant, joined with the study vehicle once en-route and mixed with the traffic stream. In advance of certain highway interchanges, the confederate vehicle pulled up alongside the study vehicle and hovered in its blind spot area creating a potential conflict situation during imminent lane-change events. This technique enabled conflict situations to be readily staged in order to examine how the availability of the spotter mirror influenced the driver's propensity to make unadvisable lane changes. Drivers passed a total of 15 highway interchange on-ramps during their 60-mile drive to Wytheville; the confederate vehicle positioned itself in the vehicle's blind spot area at four of these locations (two when the participant was expected to make a left-hand lane change and two when the participant was expected to make a right-hand lane change).

Once the participants arrived at their destination, they were invited to take a restroom break and enjoy a free drink. During this time, the second experimenter (the driver of the confederate vehicle) switched the outside mirror configurations on the study vehicle and reset the mirror settings using the stored memory function (participants locked in their mirror settings during the vehicle familiarization). This allowed the mirror units to be swapped without necessarily alerting drivers to the fact. A convincing cover story was used in the event the driver noticed and commented about the mirrors having changed (i.e., mirrors were replaced because they were damaged or, in the case of the spotter mirror, because they were inadvertently left on the vehicle from a previous study). Drivers returned to the vehicle and completed the second part of their drive, returning to Blacksburg under the same instructions to navigate using available road signs. An additional four conflict situations with the confederate vehicle were staged on the return leg of the trip. Once back at VTTI, drivers completed a series of post-drive questionnaires and participated in a static demonstration of the functional characteristics of the spotter mirror feature.

**DEPENDENT MEASURES**

Objective indices of performance with the mirror systems were captured during the on-road driving portion of the study relying on the sensed data and video collected through the vehicle DAS. Of particular interest was driver search behavior associated with lane changes and merges and how mirror systems influenced driver decision making regarding lane-change behavior. The key dependent measures collected and analyzed included the following: incidence of unadvisable lane changes (where a conflict existed with a vehicle in the adjacent lane) and frequency and duration of glances to key spatial locations (outside mirror, review mirror, direct over-the-shoulder looks, etc).

**RESULTS**

More than two-thirds of drivers (67%) reported relying, to some degree, on the spotter mirror feature during their trip. Driver perceptions and impressions of the spotter mirror feature were generally positive, showing that the vast majority of drivers believe the spotter mirror improves safety (94%), is effective (80%) and useful (70%), feel it increases confidence (74%) and helps them make good decisions when making lane changes (65%). Very few drivers (6%) felt that the spotter mirror was distracting. Approximately one-third of drivers (12 out of 36) indicated that they did not rely on the spotter mirror at all during their trip. Familiarity with aftermarket or factory-installed supplemental mirrors appeared to influence use of the current spotter inset; of the drivers who reported relying on the feature, two-thirds owned an aftermarket or factory-installed unit. This suggests that drivers with previous exposure to supplemental mirrors (i.e.,
those familiar with aftermarket systems) may be more inclined to rely on and use the spotter mirrors, at least initially.

Results also found that access to the spotter mirror improves mirror sampling (i.e., the frequency of glances to the outside mirror) during critical situations where a vehicle is in the blind spot area but does not impact sampling at other times. This suggests that drivers were using the spotter mirror during the appropriate conditions to detect and monitor the presence of traffic in the side blind zone. Use of the spotter mirror was not found to appreciably change drivers’ scan patterns as expressed by the percentage of lane changes in which drivers sampled the outside and rearview mirrors or made direct over-the-shoulder looks. No evidence was found to suggest that use of the spotter mirror increases any inherent risk associated with performing lane changes; the spotter unit was not found to lengthen search times, unduly draw attention away from the driving task, or result in riskier lane changes.

**INFLUENCES ON DRIVER LANE-CHANGE DECISION**

This section focuses on driver lane-change behavior under situations where a vehicle is present in the blind spot area; cases include both staged situations where the confederate driver hovered in the blind spot area as well as naturally occurring instances. Together, they constitute critical situations during which use of the spotter mirror is expected to allow drivers the opportunity to detect a vehicle in their blind spot area in advance of executing the lane change.

No statistically significant differences in the lane-change rates under this scenario were found between mirror conditions (Chi-square = 0.2707; \( p = .6029 \)); only one driver failed to detect the vehicle in the blind spot and erroneously executed a lane change under these conditions (that driver was using the conventional mirror at the time). Findings also indicate that the vast majority of drivers (81% overall) under both types of mirror conditions were able to detect the adjacent vehicle and chose not to execute a lane change at the interchange; this behavior was observed for 84% of drivers in the conventional mirror condition and 79% of drivers with the spotter mirror. Thus, driver lane-change decisions under these circumstances (vehicle in blind spot area, both staged and naturally occurring) were not influenced by mirror type. Drivers were as likely to change lanes with the spotter mirror as they were with the conventional mirror.

**NUMBER OF GLANCES (TARGET CASES WITH VEHICLE IN BLIND SPOT AREA)**

Analysis of the average number of glances drivers made to the outside mirror under both the spotter and conventional mirror conditions for situations with and without a vehicle in the blind spot area reveals that drivers increase their scans to the outside mirror when a vehicle is located in the blind spot area; this is the case regardless of the type of mirror. On average, drivers glanced to the mirror 2.84 times before making the lane change if a vehicle was present and 1.78 times when no vehicle was present. This is a statistically significant difference \([F(1,995), p<.0001]\), and as illustrated in Figure 3 the trend is evident for both mirror types. More importantly, significant differences in glance rates were also found between the conventional and spotter mirrors when a vehicle was present in the blind spot area indicating that drivers increase their scans to the outside mirror with the spotter in this situation \([F(1,96), p=.0087]\). As illustrated, when a vehicle is in the blind spot area, drivers made an average of 2.5 glanced to the outside mirror with the conventional mirror and averaged 3.3 glanced with the spotter mirror. Thus, access to the spotter mirror increased the frequency of glances to the outside mirror when a vehicle was in the blind spot area.

![Figure 3. Average number of glances to the outside mirror by mirror type and presence of a vehicle in the blind spot area (executed lane changes).](image)

Results also found that the average duration for each single glance was not significantly influenced by either mirror type or vehicle presence suggesting that use of the spotter mirror did not increase the duration of individual glances to the mirror. The duration of a single glance averaged 0.78 seconds with the conventional mirror and 0.85 seconds with the spotter mirror. Moreover, access to the spotter mirror did not lead to an increase in the percentage of overly long glances to the mirror (single glances more than 2.0 seconds in duration). Thus, while the frequency of glances to the outside mirror was found to increase when drivers had access to the spotter...
mirror, the duration of each glance was not found to increase beyond glances with the conventional mirror. This suggests that access to the spotter mirror did not extend or overly lengthen the amount of time necessary to acquire information with a single glance (drivers were not found to fixate on the spotter feature) but rather enabled drivers to monitor the presence of traffic in the adjacent lane.

**SUMMARY/CONCLUSIONS**

This study assessed driver performance and acceptance associated with a spotter mirror feature designed to aid driver decision making when changing lanes and merging by allowing vehicles in the side blind zones to be detected via simple glances to the outside mirror units. Thirty-six drivers experienced both conventional and spotter mirror systems during an extended 120-mile drive using an instrumented vehicle on public roadways. Drivers were not initially informed of the purpose of the study in order to allow more naturalistic lane-change and mirror search behaviors to be captured and to gauge driver understanding of the spotter mirror feature. The methodology also provided for driver interactions with the mirror systems to be examined during critical conflict situations (staged using a confederate vehicle) whereby a vehicle was positioned within the driver's blind zone area during predicted lane-change events. A number of research factors, in addition to mirror type, were also examined, including driver familiarity with supplemental mirror systems, use of labels to communicate the purpose of the spotter mirror, and driver age and gender.

In summary, results indicate that the spotter mirror affords drivers the opportunity to search, detect, and monitor vehicles in the side blind spot area during lane-change events. Approximately 46% of drivers reported using the spotter mirror during the drive to detect a vehicle they otherwise may have failed to detect had they not had access to the mirror feature. Performance data associated with lane-change events also found that access to the spotter mirror increases mirror sampling under critical situations (vehicle present in the blind spot area), suggesting that drivers were using the feature to detect and monitor the presence of traffic in their side blind spot areas. No evidence was found to suggest that the feature distracts drivers or induces cognitive capture leading to longer processing or glance times to acquire information; comparable search patterns and glance durations were observed under both mirror configurations (conventional and spotter mirror). Labels describing the purpose of the mirror feature (“Blind Spot Area”) were perceived to be useful and found to aid system understanding, particularly for unfamiliar users (drivers with no previous exposure to supplemental mirror systems); nevertheless, the purpose of the mirror feature was clear to the vast majority of drivers without any instruction. Driver perceptions and impressions of the spotter mirror feature were generally positive. These and other study results are outlined below.

- Despite the use of staged conflict situations, few drivers in this study were observed to perform unavoidable lane changes in the presence of a hazard (e.g., vehicle in the side blind zone). Drivers under both mirror configurations were generally vigilant and able to monitor surrounding traffic, including overtaking vehicles and vehicles in the adjacent lanes. Only a single lane-change conflict was observed during the course of the study; this conflict occurred under the conventional mirror condition when the driver made a left-hand lane change into the lane occupied by the confederate vehicle. Thus, insufficient data were available upon which to reliably establish safety benefits of the spotter mirror on the basis of gross level conflict avoidance measures (i.e., number of unavoidable lane changes performed). However, as detailed below, use of the spotter mirror did result in improved mirror sampling.

- When conditions preclude drivers from executing a lane change (e.g., traffic in adjacent lane or present in the blind spot area), mirror sampling rates were found to increase when drivers are afforded access to the spotter mirror. The spotter mirror was found to increase the frequency of glances to the outside mirror during critical situations (vehicle present in the blind spot area) but did not impact sampling at other times. With the conventional mirror, glances to the outside mirrors averaged 2.81 and increased significantly to 3.30 glances with the spotter mirror. This suggests that drivers were using the spotter mirror under the appropriate conditions to detect and monitor the presence of traffic in the side blind zone.

- Access to the spotter mirror was not found to appreciably change drivers' scan patterns as expressed by the percentage of lane changes in which drivers sampled the outside and rearview mirrors or made direct over-the-shoulder looks. In particular, access to the spotter mirror was not generally observed to negate or reduce the number of direct looks over-the-shoulder surrounding lane-change events.

- No evidence was found to suggest that use of the spotter mirror increases the risk associated with performing lane changes, that use of the mirror supplement results in riskier lane changes, or that access to the spotter mirror feature results in cognitive capture or distraction as indexed by glance frequencies and glance durations to the outside mirror units.

**REFERENCES**


**CONTACT INFORMATION**

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