TECH**BRIEF**

To Alert or Assist: Comparing Effects of Different Lateral Support Systems on Lane-Keeping

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OBJECTIVE

This TechBrief describes an experiment examining the effect of lateral support systems on driving behavior and user acceptance of lateral support systems. The research team used a driving simulator to compare lane-keeping behavior when drivers were controlling the vehicle without lateral assistance (i.e., manual control) or were assisted by lane-departure warning (LDW) or lane-keeping assist (LKA) systems. The goal of the study was to assess the effect of each type of lateral support system on drivers' lane-keeping ability in different situations and examine driver acceptance of lateral support technology.

INTRODUCTION

Road-departure crashes, in which a vehicle inadvertently drifts off the road, are among the most severe types of crashes, making up 37 percent of highway fatalities.[1] Lateral support systems have the potential to reduce road-departure crashes by decreasing the probability that a vehicle will leave its intended travel lane. Two lateral support systems on the market are LDW and LKA. LDW systems issue a visual, audible, or haptic warning to alert the driver that the vehicle has crossed a lane boundary. LKA systems actively move the vehicle back into its lane by either applying steering torque or light differential braking.

Both types of lateral support systems have potential safety benefits. LDWs have been found to improve lane-keeping.[2,3] In the event of a lane departure, drivers can directly respond to LDW alerts to guide their vehicle back into their lane. Additionally, the presence of an LDW system has been found to increase drivers' lane-keeping vigilance and turn-signal use.[1,3] However, warning systems require a driver to recognize and respond correctly to an alert, which creates the possibility of drivers sometimes failing to notice an alert, particularly if the driver is distracted.[4]

LKA systems eliminate the possibility that a driver may fail to correctly respond to a lane departure by taking corrective action when a lane departure occurs. This action also reduces the risk that a driver will overcorrect in response to an LDW. Nevertheless, some researchers have expressed concern over potential human factors issues related to LKA. Pohl and Ekmark found that drivers who were naïve about an LKA system had difficulty understanding it.[5] Beruscha et al. point out that

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if a driver misinterprets a change in torque felt on the steering wheel as a wind gust or vehicle malfunction, then the driver may steer in the opposite direction of the automatic corrective action, overriding the potentially positive impact of the system.[4] Other authors have expressed concern that the automation provided by LKA could lead to a degradation in lane-keeping ability that would negatively affect driver safety in the event of a system failure.[2,6,7]

Both LDW and LKA systems are designed to help keep the vehicle in its intended travel lane and prevent road-departure crashes. Meeting these goals requires a positive interaction between the lateral support system and the driver to promote safer driving behavior in different situations. First, a lateral support system should increase the amount of time that a driver spends in their lane relative to manual driving. If a driver does leave their lane, an effective lateral support system should minimize the time the vehicle spends outside of the lane either by alerting the driver about the lane departure or automatically correcting the lane departure. While less common, it is likely that drivers will also occasionally encounter situations in which a lateral support device issues an unneeded alert or lane correction. For example, when entering a work zone or maneuvering around obstacles in the roadway, drivers may need to cross lane boundaries, which will activate a lateral support system. Drivers need to ignore an LDW alert or override an LKA correction with sufficient ease during these false-positive situations to prevent a potentially dangerous driver–system interaction. Finally, drivers may encounter situations in which a lateral support system does not issue a needed alert or correction. Lateral support systems use sensors to detect lane lines and may not function correctly on roadways on which lane lines are faded, absent, or obscured. Additionally, lateral support systems may fail in situations where sensors are obscured by debris or weather. Drivers need to be able to maintain adequate lane-keeping in the event of an unexpected system failure.

The current study compared lane-keeping behavior when drivers drove without lateral assistance, with LDW, or with LKA. The goals of the study were to assess the effect of each type of lateral support system on lane-keeping ability during conditions in which a driver unintentionally leaves their travel lane, assess how drivers respond to lateral support systems triggered in response to an intended lane departure, and determine whether drivers respond appropriately to lane departures following an unexpected lateral support system failure. User acceptance of each system was also examined.

RESEARCH

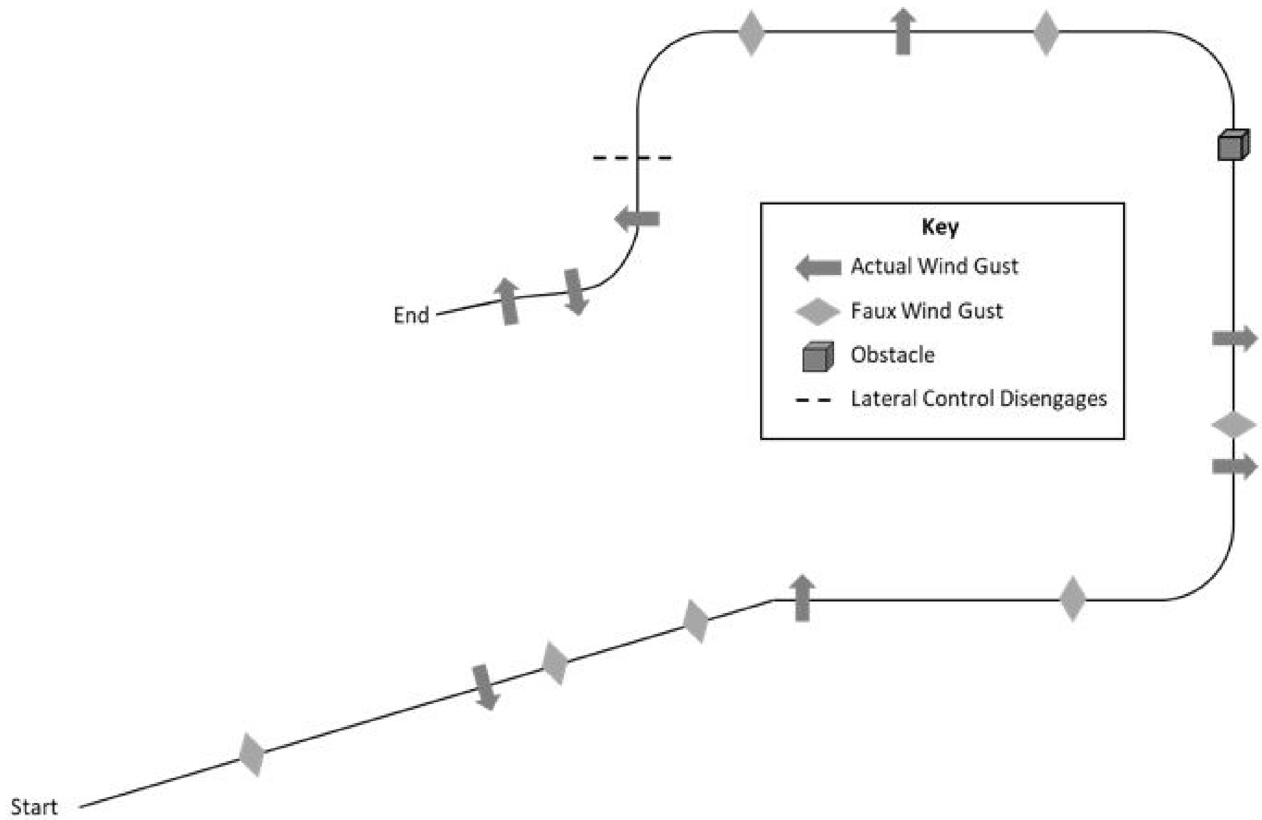
Seventy-two licensed drivers from the Washington,DC, metropolitan area participated in the study. The study was conducted in a fixed-base driving simulator equipped with LDW and LKA systems. When either lateral support system was engaged, a green icon depicting a car crossing a lane line appeared in the central console (figure 1). The icon turned yellow when the vehicle crossed a lane line without a turn signal. The icon was not visible when the lateral support system was not engaged. Haptic LDW alerts took the form of lateralized vibrations in the driver's seat. LKA corrections took the form of torque applied to the steering wheel that moved the vehicle back toward the center of the lane. The torque could be felt and overridden by the participant. One-third of participants drove with LDW, one-third drove with LKA, and one-third drove without either lateral support system.

All participants drove on a 22-mile-long undivided two-lane road in a semirural setting. Figure 2 shows the simulated route participants drove. Light traffic in the opposing lane encouraged participants to remain in their lane, but traffic was not present during any event intended to induce a lane departure. Simulated wind gusts occurred at eight points during the drive to induce lane departures. Wind gusts were designed to push the participant's vehicle in a predetermined direction across a lane boundary. An audio recording of wind played as part of each wind gust. In the LDW condition, crossing a lane boundary triggered a haptic alert. In the LKA condition, crossing the lane boundary triggered a steering correction. No alert or steering correction occurred in the manual-driving condition when crossing the lane boundary. In addition to the eight simulated wind gusts, faux wind gusts occurred seven times during the drive to prevent participants from anticipating wind gusts. During a faux wind gust, the

Figure 1. Illustration. Lateral support icon.

Source: FHWA.

Figure 2. Illustration. Lateral support icon.



Source: FHWA.

wind sound played but lateral force was not applied to the vehicle. Between the fourth and fifth wind gusts, participants encountered an obstacle in their travel lane. The obstacle, a metal desk, was large enough that participants had to depart the lane to avoid it. After the fifth wind gust, the lateral support system unexpectedly disengaged; the lateral support icon went dark, and lane departures no longer triggered LDW alerts or LKA corrections. Participants experienced three additional wind gusts before reaching the end of the scenario. Following the drive, all participants completed the Van der Laan questionnaire.[8] This nine-item questionnaire provides separate measures of the usefulness and user satisfaction with new in-vehicle technologies.

RESULTS

Comparison of lane-keeping across lateral support conditions found that drivers in the LDW condition tended to have better lane-keeping than those in the LKA or manual conditions (table 1). Drivers in the LDW condition spent less of the drive outside of their lane, returned to their lane more quickly when a lane departure occurred, and held a more constant position while in their lane. Drivers' lane-keeping in the LKA

Table 1. Driving performance as a function of condition.

Condition	Mean of Drive Spent Outside Lane (%)	Mean Lane Departure Duration (s)	Mean Lane Position Variability (ft)	Mean Speed (mi/h)
LDW	1.51	1.21	0.99	44.9
LKA	3.27	1.78	1.12	45.19
Manual driving	3.02	2.86	1.17	43.14

condition did not match those in the LDW condition, but the group did show reduced lane-departure durations relative to those in the manual driving condition. Participants in the manual driving condition also showed reduced travel speeds relative to those in the LDW or LKA conditions, suggesting that the difference in lane-keeping ability was not due to a lane-keeping/speed tradeoff. In fact, participants in the LKA condition maintained similar levels of lane-keeping to participants in the manual condition while driving more quickly, suggesting that LKA improved drivers' lane-keeping.

During the drive, participants were required to maneuver around an obstacle in their travel lane (figure 3). Drivers needed to use the turn signal prior to exiting the travel lane to avoid receiving an alert from the LDW system or steering correction from the LKA system. Most participants (i.e., 62.5 percent) used the turn signal prior to exiting the travel lane. Turn-signal use did not vary by lateral support condition, and every participant successfully avoided the obstacle.

When maneuvering around the obstacle, participants were free to choose their path. They could venture far into the opposing lane or remain close to the obstacle. This choice was reflected in the distance traveled during their lane departure. Participants in the LDW and LKA conditions did not travel as far (*mean* = 446.5 ft and *mean* = 527.9 ft, respectively) when maneuvering around the obstacle compared to those in the manual driving condition (*mean* = 599.3 ft).

Lane-keeping and speed were also measured when the lateral support system unexpectedly failed. Participants who used LDW or LKA during the first section of the drive had similar lane-keeping performance when those systems were disabled compared to participants who drove manually.

Following the drive, all participants completed the Van der Laan questionnaire, which provides separate measures of the usefulness and user satisfaction with new in-vehicle technologies. Scores for each measure range from +2 to −2, with positive scores indicating a positive view of the system and negative scores indicating a negative view. Results indicated that participants had a positive impression of both lateral support systems. Participants gave the LDW and LKA systems positive ratings for both user satisfaction and usefulness (*mean* = 1.11 and *mean* = 1.3, respectively). The systems were rated positively not only by participants who experienced the lateral support system during the experiment but also by participants who selected ratings based on their expectations about the systems after reading information about each one prior to completing the questionnaire.

Figure 3. Screenshot. Obstacle encountered during the drive.

Source: FHWA.

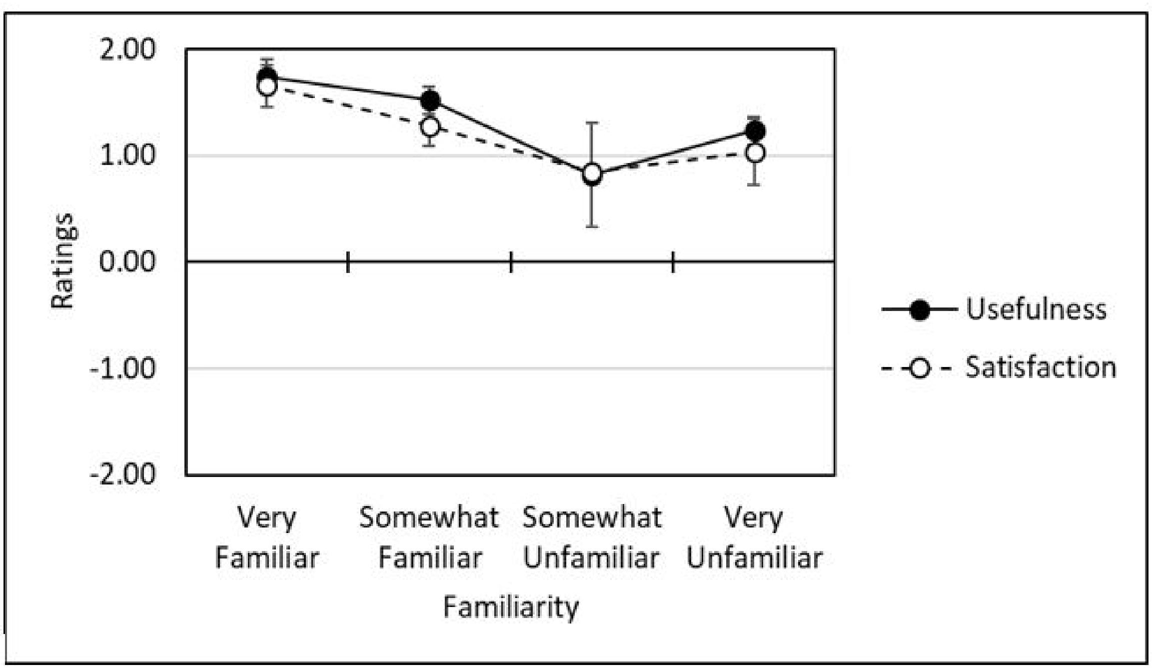
Most participants (i.e., 54 percent) indicated that they were very unfamiliar with lateral support technologies prior to the experiment. However, the more familiar a participant indicated they were with LDW or LKA systems, the higher they rated its usefulness and their satisfaction with it (figure 4).

CONCLUSIONS

This study assessed the influences of lateral support systems on lane-keeping. Participants were divided into three conditions: LDW, LKA, and manual driving. Simulated wind gusts were used to induce lane departures throughout the drive. Participants in the LDW condition spent less of the drive outside of their lane, returned to their lane more quickly when a lane departure occurred, and held a more constant position while in their lane. Participants in the LKA condition did not match those in the LDW condition, but the group showed reduced lane-departure durations relative to those in the manual driving condition. Participants in the manual driving condition also showed reduced travel speeds relative to those in the LDW or LKA conditions, suggesting that the difference in lane-keeping was not due to a lane-keeping/speed tradeoff. In fact, participants in the LKA condition maintained similar levels of lane-keeping compared to participants in the manual condition while driving more quickly, suggesting that LKA improved drivers' lane-keeping ability. The findings speak to the potential usefulness of lateral support systems for reducing lane departures.

One concern associated with lateral support systems is whether drivers react appropriately during situations in which the lateral support system activates when a driver intends to leave their lane. Will drivers be able to ignore the LDW alert or override the LKA correction with sufficient ease to prevent a potentially dangerous system–driver interaction if a lateral support system issues an unwarranted or unneeded alert or lane correction? To assess this research question, the current study included an unexpected obstacle in the participants' travel lane. The size of the obstacle required participants to cross their lane boundary to avoid it. All participants successfully avoided the obstacle without issue. The results indicate that the LDW and LKA systems did not create a dangerous situation when drivers had to change lanes suddenly during an avoidance maneuver. Participants who did not use their turn signal prior to exiting their lane experienced an LDW alert or an LKA correction when making this avoidance maneuver. These participants chose a path that returned them to their lane more quickly than those who used their turn signal and thus did not trigger the lateral support system. The warnings and corrections issued by the lateral support systems may have reminded participants of the potential dangers of driving in the opposing lane of traffic, such that they remained in the opposing lane for less time than those in the manual-driving condition; however, additional research is needed to verify this hypothesis.

Figure 4. Graph. Usefulness and satisfaction ratings as a function of familiarity with the lateral support system being rated.



Source: FHWA.

Another potential concern associated with lateral support systems is drivers becoming so reliant on the systems that their lane-keeping ability may be compromised if the lateral support system unexpectedly fails.[2,6,7] Lateral support systems currently on the market depend on sensors that detect lane lines and are unable to function correctly on roadways on which lane lines are faded or absent or in situations where lane lines or sensors are obscured by debris or inclement weather. One issue of interest is whether drivers who use lateral support systems can maintain adequate lane-keeping in the event of an unexpected system failure. To assess this issue, lateral support systems stopped functioning during the last section of the drive. Participants did not show any reduction in lane-keeping ability because of unexpected lateral support system failure. These results are consistent with the findings of Petermeijer et al., who found that drivers who are not distracted quickly recover lane-keeping after lateral support failure.[9]

Finally, for lateral support system to be successful, drivers need to understand and trust the systems. The current study used a questionnaire to assess the perceived usefulness of and user satisfaction with the LDW and LKA systems. Participants in all conditions indicated that they found the systems both useful and satisfying to use. Moreover, the more familiar participants were with the lateral support system in question, the higher their trust in the system. The results are consistent with past research indicating that user acceptance of vehicle automation increases with increased system use.[10] The current findings expand on previous work by demonstrating that even drivers who indicated they were very unfamiliar with the lateral support system being tested rated the system positively. The results indicate high user acceptance of lateral support automation. Overall, the results of the current study suggest that lateral support technology is poised to improve driver and roadway safety.

REFERENCES

1. LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, J., Mefford, M., et al. (2006). *Road Departure Crash Warning System Field Operational Test: Methodology and Results*, The University of Michigan Transportation Research Institute, Ann Arbor, MI.
2. Brown, C.M. (2001). "*New in-vehicle technologies: are lane departure warnings a good thing.*" Proceeding of the SELF-ACE 2001 Conference–Ergonomics For Changing Work, Montreal, Canada.
3. Rimini-Doering, M., Altmueller, T., Ladstaetter, U., and Rossmeier, M. (2005). "*Effects of lane departure warning on drowsy drivers' performance and state in a simulator.*" Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design. Rockport, ME.
4. Beruscha, F., Augsburg, K., and Manstetten, D. (2011). "Haptic warning signals at the steering wheel: a literature survey regarding lane departure warning systems (short paper)." *Haptics-e, The Electronic Journal Of Haptic Research, 4*(5), pp. 1–6, New York, NY.
5. Pohl, J. and Ekmark, J. (2003). *"A lane keeping assist system for passenger cars-design aspects of the user interface."* Proceedings: 18th International Technical Conference on the Enhanced Safety Of Vehicles, Nagoya, Japan.
6. Kovordányi, R., Ohlsson, K., and Alm, T. (2005). *"Dynamically deployed support as a potential solution to negative behavioral adaptation."* 2005 Intelligent Vehicles Symposium Proceedings, 1, pp. 613–618, Las Vegas, NV.
7. de Winter, J.C.F. and Dodou, D. (2011). *"Preparing drivers for dangerous situations: A critical reflection on continuous shared control."* 2011 IEEE International Conference on Systems, Man, and Cybernetics, pp. 1050–1056, Anchorage, AK.
8. Van Der Laan, J.D., Heino, A., and De Waard, D. (1997). "A simple procedure for the assessment of acceptance of advanced transport telematics." *Transportation Research Part C: Emerging Technologies, 5*(1), pp. 1–10. Amsterdam, The Netherlands.
9. Petermeijer, S.M., Abbink, D.A., and de Winter, J.C.F. (2015). "Should drivers be operating within an automation-free bandwidth? Evaluating haptic steering support systems with different levels of authority." *Human Factors, 57*(1), pp. 5–20, Washington, DC.
10. Sullivan, J.M., Flannagan, M.J., Pradhan, A.K., and Bao, S. (2016). *Literature Review of Behavioral Adaptations to Advanced Driver Assistance Systems*, AAA Foundation, Washington, DC.

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