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Cooperative Intersection Collision Avoidance System – Stop Sign Assist: Experiments to Validate Use of an In-Vehicle Interface Design

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16. Abstract (Limit: 250 words)

The three studies included in the current report examine the transition from an infrastructure-based rural intersection crossing assist system to one located inside a vehicle. The primary goals of the first study, conducted in a simulator, were to examine the effect of potentially confounding factors, such as the drivers' familiarity with the assist system and the impact of cognitive load on the drivers' performance. Next, we examined the efficacy of several different designs of such system to determine the optimal interface design to be used for the in-vehicle system. Finally, the optimal design of the system was examined in the third study, as a field test. The results showed that the use of the system under cognitively demanding conditions did not result in any adverse consequences, which suggested that the processing of the system required minimal cognitive resources. Additionally, the results showed that the benefits of the assist system, such as reduced probability of accepting a critical gap were exhibited under the limited visibility conditions when the perceptual task of determining an appropriate crossing gap became overly demanding. The results from the field study showed that the use of the assist system resulted in improved intersection crossing performance exhibited in increased likelihood of making a complete stop at the stop sign and showed a strong trend toward a decreased probability of accepting critical gaps. Additionally, the impact of the in-vehicle CICAS-SSA was equivalent for older and younger drivers; that is, both age groups benefited from the use of the system.

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Cooperative Intersection Collision Avoidance System – Stop Sign Assist: Experiments to Validate Use of an In-Vehicle Interface Design

Final Report

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EXECUTIVE SUMMARY

Intersection crashes, especially those that occur in rural areas represent a significant proportion of roadway fatalities. The Cooperative Intersection Collision Avoidance System – Stop Sign Assist (i.e., CICAS-SSA) was developed with the aim of reducing the number of fatalities at rural intersections. The CICAS-SSA was developed as a roadside-based system, which assists drivers on a minor road to select the appropriate gap when crossing a rural highway. In this report we present the research which transitions the Roadside-based CICAS-SSA to a system in which the displays presenting traffic-related information are located inside a vehicle.

To thoroughly examine the feasibility of the in-vehicle CICAS-SSA, we conducted three studies, each of which explored specific issues. The initial two studies in this project were completed in a simulator while the final Study was conducted as a field experiment. The primary goals of the first simulator Study were to examine the effect of potentially confounding factors, such as the drivers' familiarity with the assist system and the impact of cognitive load on the drivers' performance. These issues were examined because reliance on the driver assist system may be affected by the level of a driver's understanding of that system. Also, drivers' use of the assist system and the subsequent intersection crossing performance may be affected by a concurrent secondary task in which drivers frequently engage (e.g., conversing on a cell-phone). The principal goal of the second simulator Study was to evaluate the efficacy of several different designs of the system on the drivers' intersection crossing performance and to determine the optimal design of the in-vehicle CICAS-SSA. The findings from the first two studies conducted in the simulator were used to determine the conditions and design of an in-vehicle CICAS-SSA, which was examined in the final Study. The final Study evaluated the efficacy of the in-vehicle CICAS-SSA on the drivers' rural intersection crossing performance, as a Field Study.

Before the final evaluation of an in-vehicle CICAS-SSA was conducted as a field test, and before the optimal interface of the system was determined, we addressed several important issues. These included the examination of the impact of a driver's understanding of the assist system as well as the impact of cognitive load (e.g., conversation) on a driver's crossing performance. The results from the first simulator study showed that the use of an in-vehicle CICAS-SSA resulted in the improvement of certain safety aspects of intersection crossing, such as an increased likelihood of stopping at the median and waiting longer before crossing. Furthermore, the use of the system under cognitively demanding conditions did not result in any adverse consequences, which suggested that the processing of the system required minimal cognitive resources. Finally, participants who were fully informed about the purpose and the functioning of the in-vehicle CICAS-SSA reported a greater level of familiarity with the system and were less likely to be confused about its intended use.

The design of the Roadside CICAS-SSA sign may not be the optimal interface to use inside a vehicle. The principal goal of the second simulator study was to evaluate the effectiveness of several in-vehicle CICAS-SSA designs and determine the optimal interface to be examined in a Field Study. The three designs that were compared differed in their complexity, as determined by the amount of information about the traffic that was presented to the driver. The second simulator study also examined the impact of Visibility on the drivers' use of the system and their driving performance. Furthermore, the second simulator study investigated the effect of the

location of the intersection crossing assist system by comparing driving performance when using the Roadside-based and in-vehicle based CICAS-SSA. The results from the second simulator study revealed that the use of an in-vehicle based CICAS-SSA resulted in improved rural intersection crossing performance, such as reduced probability of accepting critical gaps. The version of the in-vehicle CICAS-SSA that resulted in best overall intersection crossing performance was also the most informative about traffic. The optimal in-vehicle version of the sign was identical to the Roadside-based CICAS-SSA. The results also showed that the benefits of an in-vehicle based CICAS-SSA were exhibited under the Limited Visibility condition when the perceptual task of determining an appropriate crossing gap became overly demanding. Lastly, the in-vehicle based CICAS-SSA was at least as effective as a Roadside-based system, and in some cases, was more effective, such as when the likelihood of stopping at the stop sign was examined.

The results from the simulator studies determined the design of the final stage of this research project, which was to assess the feasibility of an in-vehicle CICAS-SSA in a Field Study. The primary goal of the Field Study was to evaluate the effectiveness of the in-vehicle CICAS-SSA. Secondarily, we examined the age-related differences on the drivers' use of the system and their driving performance. The results from the Field Study showed a consistent trend regarding the impact of the in-vehicle CICAS-SSA on rural intersection driving performance. The use of an in-vehicle CICAS-SSA resulted in improved rural intersection crossing performance, such as increased likelihood of making a complete stop at the stop sign and showed a strong trend toward a decreased probability of accepting critical gaps. Additionally, the impact of the in-vehicle CICAS-SSA was equivalent for Older and Younger drivers; that is, both age groups benefited from the use of the system. In conclusion, no negative effects were observed in the Field assessment of the in-vehicle CICAS-SSA, which coupled with the findings of improved intersection crossing performance, suggests that the real-world implementation of the system offers significant potential benefits without unintended consequences.

1 INTRODUCTION

This report presents the continuation of the Cooperative Intersection Collision Avoidance System-Stop Sign Assist (CICAS-SSA) project research. In the studies described and discussed in this report, the CICAS-SSA display was transitioned from its previous location on the roadside into a vehicle. The first two studies were completed in a driving simulator while the final one was conducted as a Field Study. The first of the simulator studies examined the impact of the level of instruction and concurrent cognitive load on adherence to the CICAS-SSA sign and driving performance. These variables are important because of the potentially varying impact of these two factors on the drivers' use of the system and as such, the impact on rural intersection crossing safety. The findings from the first study fed into the methodology employed in the second study. The second simulator study explored the efficacy of an in-vehicle CICAS-SSA Sign On driving performance in a simulated setting. The second simulator study determined the most optimal design of the in-vehicle CICAS-SSA, a design which was then tested in the Field Study. The efficacy of an in-vehicle CICAS-SSA as the primary research focus of this project was also examined in the final study, conducted in the field. As part of this report, we present the background and literature related to this work, discuss the importance of conducting the studies, and then provide the justification for the inclusion of each study.

2 BACKGROUND AND LITERATURE

One of the results of technological advancement in general and in the automotive industry in particular, includes an increased focus into transportation safety research. The incorporation of proximity warning and lane departure systems in manufacturers' vehicles (e.g. Ford, Lexus among others) in recent years highlights the push toward safer driving. However, certain locations and traffic conditions still represent situations of higher risk. Intersections represent one such potentially dangerous location as evidenced by the statistic that 20% of all fatalities in the United States occur at intersections (FHWA, 2006). The high percentage of fatalities that occur at intersections is especially worrying considering that intersections represent only a small proportion of total roadways. A distinction should also be made between rural and urban intersections. Although 60% of all intersection fatalities occur in an urban setting (FHWA, 2006), crashes at rural intersections are considered more dangerous. Crashes that occur at rural intersections result in fatalities more frequently than do crashes at urban intersections (Knapp, Campbell & Kienert, 2005), most likely due to higher velocity of vehicles on rural highways.

In this report we investigate the effectiveness of an in-vehicle driver support system designed to help drivers reject unsafe gaps when crossing rural intersections. Moreover, the present studies focus on stop-sign controlled rural intersections, in which traffic from a low-volume minor road crosses a high-volume highway on which vehicles travel at high speeds. Major factors contributing to crashes at these intersections include failure to accurately estimate the gap between cross traffic vehicles and time to contact (Laberge, Creaser, Rakauskas & Ward, 2006). The driver's ability to estimate time to contact lessens with higher approach velocity (Hancock & Manser, 1997a; Hancock & Manser, 1997b; Kiefer, Flannagan & Jerome, 2006), thereby increasing the risk at rural intersections. Research has shown that most crashes at these intersections occur when drivers attempt to cross the intersection as a single stage maneuver (Preston, Storm, Donath & Shankwitz, 2004). In a single stage maneuver a driver crosses the intersection without stopping or slowing down in the median before crossing the far lanes of traffic. Preston et al. (2004) proposed a Cooperative Intersection Collision Avoidance System-Stop Sign Assist (CICAS-SSA) system that would be located at rural intersections and aid drivers in determining the appropriate crossing gap. The design of the CICAS-SSA (see Figure 1b) sign was based on an already existing "divided highway" sign (see Figure 1a) and is designed such that a driver viewing the CICAS-SSA sign for the first time would easily interpret and utilize the sign (Creaser, Manser & Rakauskas, 2008).

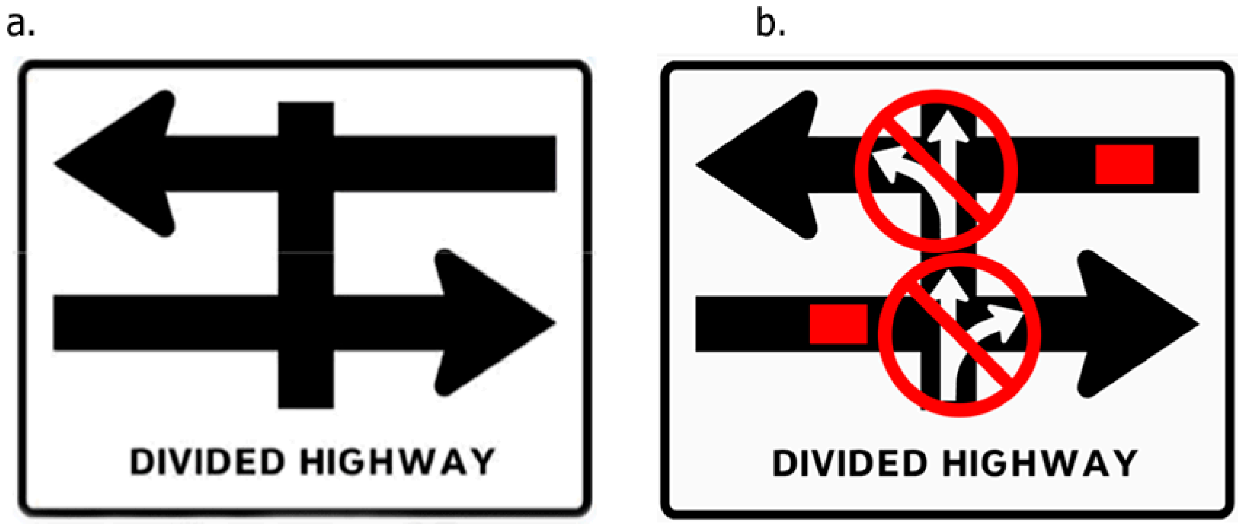


Figure 1. Figure 1a depicts a common sign for a divided highway, located on a minor road. Figure 1b depicts the CICAS-SSA sign as tested in the field operational test.

In the initial stages of this project, we identified a single sign (see Figure 1b) that was the most effective in aiding driver's rural intersection crossing performance, as well as its ideal location and rotation relative to the driver (Creaser et al., 2008). In the next stage of this project, we conducted a simulator and an on-road study in which we evaluated drivers' intersection crossing performance with the CICAS-SSA sign turned on and compared it to the Control (i.e., Sign Off) condition. The simulated environment consisted of an exact replica of a real-world intersection (HW 52 and CR 9 in Minnesota, see Figure 2) that was the location of our earlier field study (Rakauskas, Creaser, Manser, Graving & Donath, 2009). In these studies, participants were asked to cross the intersection safely and utilize the CICAS-SSA sign according to their preference. Since the CICAS-SSA sign was designed to be user-friendly and easily interpretable, participants in these studies were not given a detailed description of the system. The findings of these studies showed similar intersection crossing performance between the Sign and Control conditions, suggesting that the use of the CICAS-SSA does not result in any adverse consequences. However, we also found that drivers rejected a greater percentage of unsafe gaps when the CICAS-SSA was turned on compared to the Control condition. We are currently conducting a year-long on-road study that will allow us to examine the long-term effect of the use of the CICAS-SSA on intersection crossing performance, thus determining the potential of a wider application of the CICAS-SSA sign (e.g., greater number as well as more various types of intersections).

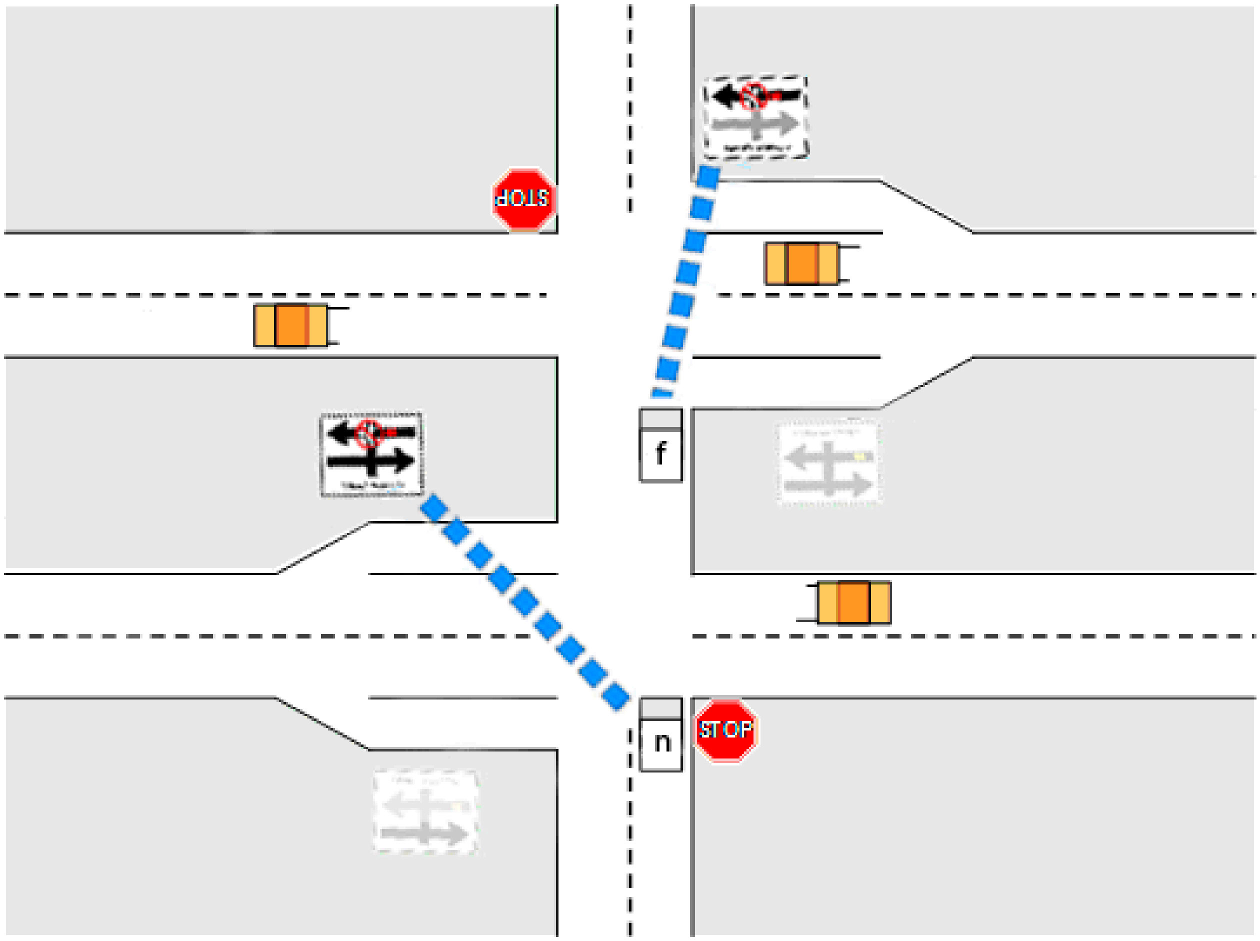


Figure 2. Diagram of a stop-controlled intersection with relative location of CICAS-SSA signs. Lightly drawn signs represent the positions of the signs as seen by a vehicle approaching for the other side. Viewing locations while entering the highway from the minor road are indicated by a vehicle labeled "n" (from stop sign, "near") and "f" (from median, "far").

The CICAS-SSA was viewed as a low cost alternative to other options aimed at reducing the number of crashes (e.g. options such as a highway overpass), but its benefits are limited to the few intersections where the system will be installed. Since the desired installation of the CICAS-SSA signs on a larger scale (i.e. the majority of rural intersections in the state) would be cost-prohibitive, an in-vehicle interface of the CICAS-SSA would provide a possible alternative. A substantially lower cost of an in-vehicle CICAS-SSA display would be a strong incentive, but it is not the only one. An in-vehicle display on which the sign would be presented could also serve as a display for various other information (e.g., work zones). With the intersection assist system integrated in a vehicle, drivers would have an opportunity to utilize such a system at any instrumented intersection. The current studies examine the effectiveness of an in-vehicle CICAS-SSA interface.

In-vehicle systems designed to assist the driver while navigating the ever increasing complexity of our environment have become ubiquitous. A variety of early warning systems alert the driver to a potential collision (Kramer, Cassavaugh, Horrey, Becic & Mayhugh, 2007; Kiefer, LeBlanc

& Flannagan, 2005) and lane departure warnings aid drivers in lane keeping (Blaschke, Breyer, Färber, Freyer & Limbacher, 2009; Kozak et al., 2006). These are in-vehicle interfaces designed to assist a driver through a dynamic update of their vehicle's interaction with the surrounding environment. Such devices provide continuously updated information which drivers' can use to make instantaneous driving decisions, based on the current road/traffic conditions. On the other hand, most roadside signs and symbols present a driver with a static update of the traffic environment. In general, static roadside signs state the rules of the road, while the in-vehicle warning systems provide the information about the driver's vehicle interaction with objects in the environment. Additionally, some roadside signs (e.g., railroad light) also present dynamically updated information.

It is clear that some information can only be presented through an in-vehicle interface (e.g., drifting outside one's lane), but can such an interface be used for information that is traditionally presented on roadside signs? A traffic situation for which both in-vehicle and roadside warning systems are possible would serve as a platform to answer such a question. Does a driver respond differently when presented with an in-vehicle warning compared to a similar roadside warning only? This question is of a particular interest because of the recent regional attempts (e.g., IntelliDrive efforts by MnDOT) regarding the use of an in-vehicle display to present traffic information, including that which can be found on a roadside (e.g., work zone, speed limit). Examining the effectiveness of the incorporation of the CICAS-SSA system inside a vehicle as well as the comparison of the efficacy of the Roadside and In-Vehicle CICAS-SSA, are the main goals of the current studies.

2.1 IN-VEHICLE CICAS-SSA: AN OVERVIEW OF RESEARCH GOALS

The primary goal of the current project is to examine the effectiveness of an In-Vehicle CICAS-SSA in aiding the drivers' rural intersection crossing performance. The initial two studies in this project were completed in a simulator while the final study was conducted as a Field Study. The primary goals of each of the studies are:

- Simulator studies
    - The primary goal of the first simulator study included examining potentially confounding factors, such as the drivers' familiarity with the assist system and the impact of cognitive load on drivers' performance. The reliance on the driver assist system may be affected by the level of the driver's understanding of that system. Also, the drivers' use of the assist system and their subsequent intersection crossing performance may be impacted by a concurrent secondary task in which drivers engage (e.g., conversing on a cell-phone).
    - The principal goal of the second simulator study is to evaluate the efficacy of several different designs of the Sign On the driver's intersection crossing performance and determining the optimal design of the sign.
- Field Study
    - The findings from the first two studies conducted in the simulator are used to determine the conditions and design of an In-Vehicle CICAS-SSA examined in the final, Field Study. This study evaluates the efficacy of the In-Vehicle CICAS-SSA on the driver's rural intersection crossing performance, in a real-world setting.

3 STUDY ONE

Before the final evaluation of an In-Vehicle CICAS-SSA can be conducted as a field test, several other important issues need to be addressed, including determining the optimal design of the system to be used inside a vehicle. The greater level of experimental control, as well as the lower cost are the primary reasons for conducting this research in a simulated environment. Additional issues need to examine the impact of driver's understanding of an assist system activated in a vehicle as well as the impact of cognitive load (e.g., conversation) on the driver's performance. These are issues which may potentially endanger the driver in a field test, which is why experimental studies addressing these issues are best suited to be carried out in a simulator.

3.1 INTRODUCTION

Although the CICAS-SSA has been shown to be highly intuitive and easy to interpret (Creaser et al., 2008), it does not necessarily follow that the understanding and usage of the sign would be instantaneous. Building confidence and trust in a system may require more than a handful of interactions with a system. A highly confident driver is more likely to use a support system than a moderately confident driver. Furthermore, Older adults require longer exposure to new technology before they reach a certain level of confidence (Shinar, Dewar, Summala, & Zakowska, 2003). One way to manipulate the participants' exposure time and their confidence in the system is through different levels of instruction they receive about that system. Practically, this manipulation addresses the potential need for public educational campaigns when a new CICAS-SSA is installed (Roadside or vehicle-based). Study One was designed to assess the impact of the level of instruction drivers receive about the In-Vehicle CICAS-SSA on their adherence to the sign and their driving performance. The findings about the effects of instruction were then incorporated into the methodology of Study Two investigating the primary goal, the efficacy of an In-Vehicle CICAS-SSA.

Drivers are frequently engaged in dual-task situations, such as talking on a cell-phone while driving, during which their attention is distributed across different tasks and cognitive resources are limited. This potentially dangerous habit of today's drivers only highlights the need for exploring the impact of any new technology in situations when driver's attention is divided and their cognitive resources are stretched. For this reason, Study One also explored the effect that a concurrent secondary task may have on the drivers' use of the In-Vehicle CICAS-SSA and their intersection crossing behavior.

To accomplish these objectives, Study One was conducted in the HumanFIRST driving simulator at the University of Minnesota. Participants drove through an exact replica of the US 52 and CSAH 9 intersection, near Cannon Falls, Minnesota, which is the same environment that was used in our previous studies (Rakauskas et al., 2009). Driving performance in the Control condition (i.e., no Sign condition) was compared to the Treatment condition in which drivers were exposed to an In-Vehicle CICAS-SSA system. This comparison determined the effectiveness of an in-vehicle intersection assist interface. Driving performance for drivers in the Full level of Instruction condition was compared to the performance of drivers in the Minimal level of Instruction. This comparison determined the impact of the level of instruction on the driver's adherence to the sign and their intersection crossing performance. Finally, the driver's performance under cognitive load was compared to their performance in the Baseline condition (i.e., without cognitive load). This comparison examined the impact of cognitive load on the driver's understanding and use of the driver assist sign and their driving performance.

3.2 METHODS

3.2.1 Participants

Forty eight adults participated in Study One. Participants were divided into two age groups: Older participants between the ages of 60 and 69 (13 women, 11 men; with a mean age of 62.2 and sd = 2.83 years) and Younger participants between the ages of 19 and 28 (13 women, 11 men; with a mean age of 22.1 and sd = 2.52 years). The Younger drivers had an average of 13.9 years of education while Older drivers had an average of 15.2 years of education. All of the participants had a valid driver's license, normal or corrected-to-normal vision (visual acuity of at least 20/40, normal color vision) and no previous history of disorders predisposing them for motion sickness (e.g., epilepsy). Older participants were recruited for participation because they exhibit significant perceptual declines (Salthouse, 1996), something that can be of a great concern given that our task, estimating a safe gap when crossing an intersection, is a highly perceptual task. Younger participants were recruited through flyers posted at the University of Minnesota campus while the Older participants were recruited through flyers and online and newspaper ads. Participants were compensated $40 for their two-hour long participation.

3.2.2 Materials and Apparatus

3.2.2.1 Driving Simulator

Study One was conducted in a partial motion-base driving environment simulator manufactured by Oktal. The driving environment simulator consists of a 2002 Saturn SC2 full vehicle cab featuring realistic control operation and instrumentation including force feedback on the steering and realistic power assist feel for the brakes. The simulator provides high fidelity simulation for all sensory channels to generate a realistic presence within the simulated environment. The visual scene is projected to a high-resolution (2.5 arc-minutes per pixel) five-channel, 210-degree forward field of view with rear and side mirror views provided by a rear screen and vehicle-mounted LCD panels.

The driving environment simulator system software generated an exact replica of US 52 and CSAH 9 intersection, near Cannon Falls, Minnesota. Auditory and haptic feedback was provided by a 3D surround sound system, car body vibration, and a three-axis electric motion system producing roll, pitch, and yaw motion within a limited range of movement (partial-motion). These systems generate natural sound and motion cues to increase the perceived realism and ecological validity of the simulation.

In our previous simulator study (Rakauskas et al., 2009), the traffic flow accurately represented the flow at the specified intersection, which increased the validity of the study. This traffic flow included a high percentage of very small gaps. For most drivers these are very risky gaps and moreover, easily identified as such. In order to make the perceptual task more difficult, we adjusted the distribution of the traffic flow in Study One. We decreased the number of very small gaps (< 3 seconds) and increased the number of gaps for which safe crossing is more difficult to determine (4-7 seconds).

3.2.2.2 The Modified CICAS-SSA Sign

The primary goals of Study One included exploring the impact of the level of Instruction and secondary task Load on the driver's understanding of the CICAS-SSA sign, and adherence to the same. To accomplish these goals we created a more compact and Modified CICAS-SSA sign (mCICAS-SSA, from here on) than the version used in our previous study (Rakauskas et al. 2009). Presenting an earlier version of a CICAS-SSA on a small display may potentially increase the clutter as well as the processing time. A simplified version of the sign is likely to counter the distraction potential that the increased clutter may have. For this reason in Study One we used a Modified version of the CICAS-SSA sign (see Figure 3), rather than the previously established design. This Modified version resembled the original CICAS-SSA, so the potential effects of the Instruction and cognitive load would be expected to apply to the original version of the CICAS-SSA as well. The mCICAS-SSA was divided into two parts. The near lane representing traffic traveling to the right was overlaid onto the left side mirror (see Figure 3a). The far lanes representing traffic traveling to the left was overlaid onto the right side mirror (see Figure 3b). The splitting of the sign into south-bound and north-bound lanes resulted in less clutter being overlaid onto the side mirrors. This is important because less cluttered image would still allow the driver to use the side mirrors to view the traffic behind them.

Like the original CICAS-SSA sign, the Modified version uses icons to indicate the presence of vehicles on the major road. The rectangular shaped icons can be either yellow or red. The yellow icon signifies a presence of a vehicle on the major road and that a driver should exercise

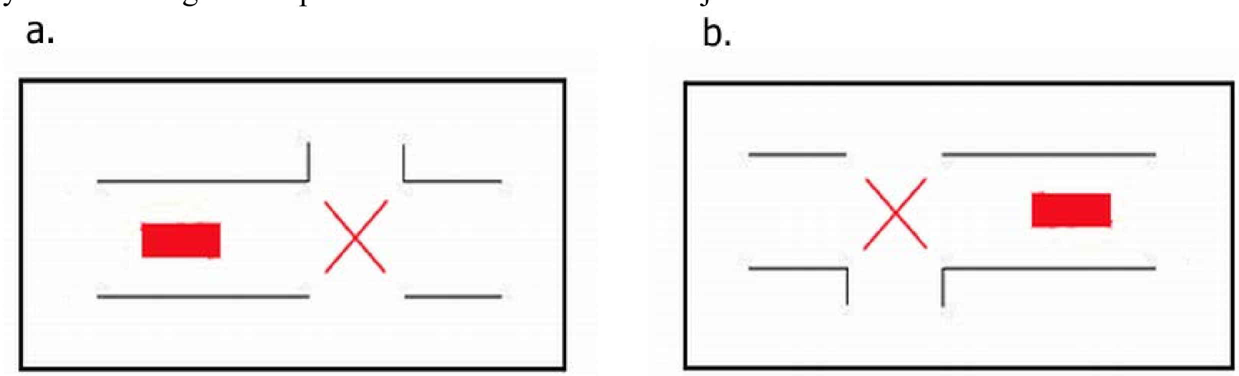


Figure 3. Representation of the Modified CICAS-SSA sign showing an unsafe crossing gap as depicted in the left (Figure 3a) and right (Figure 3b) side mirror.

caution when making a decision to cross. The red icon signifies that a vehicle on the major road is too close to the intersection and crossing would not be safe. The blinking yellow icon indicates that the icon is about to become red at which point the intersection crossing would be unsafe. While the yellow icon is blinking a driver should cautiously start the crossing maneuver as soon as possible. The blinking yellow icon represents another change that was included with the mCICAS-SSA, compared to the original CICAS-SSA sign. It is possible that in the previous studies, because of the variable presentation duration of the yellow icon, participants viewed the yellow icon as potentially dangerous as the red icon. For this reason, a transient state was added to the Modified version of the sign. Table 1 presents the different states of the mCICAS-SSA and an explanation of each.

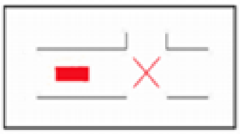
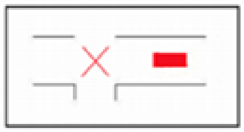
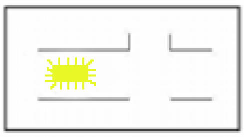
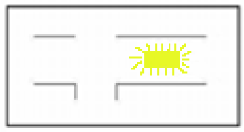
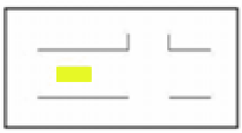
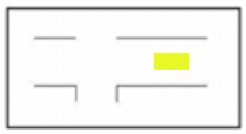
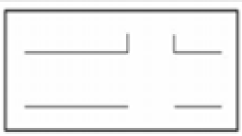
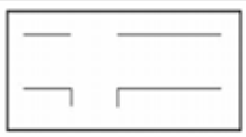
3.2.2.3 Questionnaires

At the beginning of the study participants were administered the driving history questionnaire (Appendix A). At the end of the study, participants completed the System Trust (Appendix B) and the usability (Appendix C) questionnaires that were designed to assess the degree to which the mCICAS-SSA helped them navigate the intersection. The questionnaires that participants completed at the end of the study inquired about participants' preferences and ease of use, satisfaction and understanding of the Modified version of the CICAS-SSA as well as any potential confusion relating to the design and the use of the Sign.

3.2.3 Procedure

After completing the consent form and driving history questionnaire, participants completed a practice block, consisting of three trials in which they acclimated to the dynamics of the simulator vehicle, as well as learned how to approach the intersection in such a manner as to allow the best view of cross traffic. Following the practice drive, participants began the driving portion of the study. Driving performance was examined through a trial-based driving task in which participants were asked to approach the intersection, stop at the stop sign, and then cross the intersection in a safe and timely manner. Each trial ended after the participant crossed the intersection.

Table 1. All display states of the Modified CICAS-SSA sign as overlaid on the left and right side mirror.

States of Modified CICAS-SSA		Message Meaning
Left mirror	Right Mirror	
		Do not enter the intersection; a vehicle is detected too close to the intersection (time-to-contact is less than 6.5 seconds).
		A vehicle is detected approaching the intersection (time-to-contact is between 7.5 and 6.5 seconds) and the appropriate crossing gap is closing. If already started, crossing should be completed rapidly.
		A vehicle is detected approaching the intersection (time-to-contact is between 11 and 7.5 seconds). Drivers may be able to cross, but should proceed with caution.
		No vehicles are detected approaching the intersection. If a vehicle is present on the major road it is more than 11 seconds away. You may be able to proceed with caution.

Half of the participants from each Age group (12 Older and 12 Younger) were randomly assigned to a Full Instruction condition while the rest of the participants were assigned to a Minimum Instruction condition. All participants received general instructions in which they were told that in some of the trials a new technology designed to aid driving performance would be activated in the vehicle. Both groups of the participants were told about the specific location where they may expect to see the system (i.e., in side mirrors) and that they should use it, or not, according to their preference.

Participants in the *Full Instruction* condition were given detailed description regarding the purpose of the Modified CICAS-SSA. They were shown and provided with an explanation about different states of the sign before the start of the study. Participants in the *Minimal Instruction* condition received only the general instructions and were not explained the proper way of interpreting the system. They were told that in some trials a new technology would be activated in the vehicle which was designed to assist a driver in driving performance. The instructions that the participants in the Minimal Instruction condition received mimicked the instructions that the participants received in our earlier studies (Rakauskas et al., 2009; Creaser et al., 2008). All participants were instructed that they should use the information the system provides as they see fit.

In half of the trials, all participants completed an additional in-vehicle secondary task while crossing the intersection. The Counting 1-Back task was designed to load the driver's cognitive resources, resembling real-world dual-task conditions in which drivers are frequently engaged (e.g., driving while conversing on a cell-phone). In essence, Counting 1-Back task placed participants under Cognitive Load conditions. In this task, participants heard two, two-digit numbers, presented to them through headphones. They were instructed to provide two answers. First, the participants were required to add the last digits from the two numbers they heard. For example, if the participants heard "27, 32", they were required to say "9" to answer correctly. Second, the participants needed to determine if their current answer was greater than or smaller than their previous answer. They were instructed to say their answers out loud which were recorded for later transcription.

Each participant was administered a total of 16 trials, divided evenly between different conditions. Table 2 presents experimental conditions that participants completed.

Table 2. Experimental conditions the participants completed in Study One.

	Instructions	
	Full	**Minimal**
Older	No Sign, No Load	No Sign, No Load
	No Sign, With Load	No Sign, With Load
	With Sign, No Load	With Sign, No Load
	With Sign, With Load	With Sign, With Load
Younger	No Sign, No Load	No Sign, No Load
	No Sign, With Load	No Sign, With Load
	With Sign, No Load	With Sign, No Load
	With Sign, With Load	With Sign, With Load

3.3 EXPERIMENTAL DESIGN

3.3.1 Independent Variables

The independent variable that examined the impact of the mCICAS-SSA on the driver's intersection crossing performance was *Sign State*, consisting of Control (Sign Off) and Treatment (Sign On) conditions.

The independent variable of *Instruction* is a potential factor that may have influenced the driver's use of the mCICAS-SSA and their subsequent driving performance. The participants who received Full Instructions represented someone who is very knowledgeable about the purpose and the functioning of the system and confident about its use (e.g., owner of a car). Those participants who received Minimal Instructions represented someone exposed to the system for the first time, without prior knowledge about its exact purpose which may affect their confidence about using the system.

Performing a concurrent secondary task while driving may impact a driver's understanding and use of the mCICAS-SSA. It is possible that with the cognitive resources strained, drivers may rely on an external factor (e.g., an assist system) to complete a challenging driving maneuver (e.g., determining the safe crossing gap). However, if the assist system (i.e., In-Vehicle mCICAS-SSA, in this case) is not instantaneously understandable and usable, its presence may serve as an additional task further depleting driver's cognitive resources. These two potential impacts of a secondary task were examined through a *Cognitive Load* variable. Drivers are frequently engaged in dual-task situations (e.g., conversing on a cell-phone while driving), which makes the inclusion of a secondary task a relevant factor when examining the efficacy of a driver support system.

Deficits that older adults exhibit in cognitive and perceptual tasks have been well established (Salthouse, 1996), however they also have much greater driving experience which may offset some of these deficits (Kramer et al., 2007). The effectiveness of the mCICAS-SSA was examined across different Age groups, exploring whether age-related differences exist with the use of the sign.

Therefore, the independent variables that were manipulated in Study One were:

- Sign state (Sign On, Sign Off)
- Instruction (Minimal, Full)
- Cognitive load (Present, Absent)
- Age (Older, Younger)

3.3.2 Dependent Variables

To achieve a robust understanding of the impact of the independent variables on a drivers' performance we collected data within two measurement constructs. The objective effectiveness of driver support systems, as measured by the response time to critical events, is important, but so is the subjective efficacy. A system that is viewed as both useful and effective by a driver is more likely to be utilized and not ignored. The two measurement constructs that were collected are:

- *Driving Performance* measures when crossing the intersection
- *Usability* measures intended to assess drivers' understanding, trust and impression of the Modified In-Vehicle CICAS-SSA.

3.3.2.1 Driving Performance

- *Time-to-contact (TTC)*, as measured in seconds represented potential time to contact between the nearest approaching cross-traffic vehicle and the participant's vehicle at the time of entering of the intersection. In situations when the closest approaching cross-traffic vehicle was beyond the sensor range, *time-to-contact* was not available.
- *Adjusted time-to-contact* represented a Modified TTC measure in which the upper value was limited to a value of the critical gap (i.e., 6.5 seconds). If a participant exhibited a crossing gap of 9 seconds for example, in the analyses this value was reduced to 6.5 seconds. The purpose of this measure was to determine the frequency of instances in which a participant crossed the intersection when TTC was less than the critical value (i.e., 6.5 seconds). An average adjusted TTC of 6.5 seconds indicated that all the intersection crossings were completed when the crossing gap was greater than 6.5 seconds. The smaller the adjusted TTC value, the riskier was the crossing. If we consider that the average crossing gap when crossing the intersection may be well over 8 seconds, any explanation of potential differences between the Sign On and Sign Off conditions would be inadequate because neither of those average values would be

considered risky. An average TTC of 8 seconds may consist of three higher values (e.g., 9 seconds or larger) and a single smaller value (e.g., 4 seconds or smaller). An average TTC of 8 seconds may suggest an overall adequate crossing, but would fail to account for the single risky crossing. Adjusted time-to-contact measure placed greater importance on the inappropriate gaps.

- *Wait time* represented the time between a complete stop at the stop sign or in the median and the start of intersection crossing. Trials on which a participant failed to make a complete stop before entering the intersection (i.e., rolled through the stop sign) or in the median, were not included as part of the wait time measure.
- *Likelihood of stopping* represented the proportion of trials in which a participant made a complete stop. Failure to stop at the median indicated a single-stage crossing maneuver.
- *Movement time* represented the time required for a participant to cross the intersection from the point of entrance to exit.
- *Accepted critical gap* represented the weighted proportion of trials in which a participant crossed an intersection when TTC was less than the critical value (i.e., 6.5 seconds). Crossing the intersection when TTC was very small (e.g., 2 seconds) was considered more dangerous compared to the same crossing when TTC was 4 seconds. While both of these crossings were considered risky, the *accepted critical gap* measure weighted them differently, placing a greater value (i.e., higher risk) on the crossing when TTC was only 2 seconds. Although similar in characteristics with the adjusted TTC measure, the proportion of accepted gaps measure was a more sensitive measure of a driver's propensity to accept a critical gap when crossing the intersection.
- The *rejected non-critical gap* represented the proportion of times that a participant failed to cross the intersection when TTC was greater than the critical gap (i.e., 6.5 seconds).
- The *80th Percentile rejected gap* represented the largest gap which was rejected 80% of the time across all intersection crossings within conditions.

While the approach to the analysis of driving performance in this report was similar to our previous studies (Creaser et al., 2008; Rakauskas et al., 2009), the current report included certain updates in regards to the measures examined. Measures such as *lead gap* and *safety margin* which were included in the previous reports were forgone in the present studies. The lead gap measure is difficult to interpret unambiguously. It could be argued that a lead gap value of 0.5 seconds is potentially risky, as it suggests that a participant started the crossing maneuver almost at the same time as the cross-traffic vehicle passed the intersection. However, the same small lead gap could also be viewed as efficient. Likewise, a lead gap of 2 seconds may be considered appropriate, but also inefficient. Safety margin measure is highly correlated with average time-to-contact and dependent only on the time it takes a driver to cross the intersection. Since movement time measure was included in the current report, the safety margin measure became redundant. The current report included several new measures (e.g., adjusted TTC, accepted critical gap) which more accurately interpreted participants' intersection crossing driving performance.

3.3.2.2 Usability

- System trust questionnaire, which assessed the driver's understanding and potential confusion in the use of the mCICAS-SSA.

- Usability questionnaire, which examined the drivers' impression of the usefulness, ease of use and satisfaction of the mCICAS-SSA.

3.4 RESULTS

The results section of Study One consisted of two parts. First, the performance in the intersection crossing task was analyzed by examining driving related measures. Driving performance measures were examined separately for the crossing of the southbound (i.e., stop sign as the starting position) and northbound (i.e., the median as the starting position) lanes. Second, the participants' responses regarding the trust and the use of the mCICAS-SSA system were examined.

Study One featured a 2 x 2 x 2 x 2 mixed design with Sign State (Sign Off, Sign On) and Cognitive Load (Present, Absent) as within-subject factors and Age (Older, Younger) and Instruction level (Minimal, Full) as between-subjects factors.

3.4.1 Driving Performance

Each participant completed four intersection crossing trials in each condition (see Table 2). Depending on the measure examined, participants' driving performance within a condition was either averaged across trials (i.e., Adjusted TTC, Wait time, Movement time) or combined across the conditions when probabilities and percentiles were calculated (Likelihood of stopping, Accepting critical gap, Rejected non-critical gap). Although participants completed practice trials, it is possible that they still required additional time for acclimatization to the vehicle's dynamics and the driving scenario. In that case, the first trial would act as an additional learning trial, rather than the experimental trial.

To examine the possibility of learning, the performance between the first and the last trial was compared. However, the t-test did not reveal any differences, suggesting that a potential learning effect within a condition did not occur.

Due to a technical issue with the data collection software, intersection traffic data was missing for two participants for a single trial (1 young in Full condition, 1 young in Minimal condition). As a result, the data for these two participants were examined across three trials.

In the results section of Study One, dual-task condition refers to driving while performing the concurrent secondary task, while the single-task condition refers to only performing the driving task.

3.4.1.1 Time-to-Contact

Southbound. The time-to-contact (TTC) measure was submitted to a 4-way ANOVA, however the results did not reveal significant effects involving the Sign State, Instruction or Cognitive Load factors. The 4-way ANOVA revealed a marginal effect of Age ($F(1,44) = 3.97$, $p = .053$) showing that Younger drivers accepted smaller gaps when crossing intersections, as time-to-contact of a cross traffic vehicle was smaller for Younger drivers (6.28 seconds) than their Older counterparts (6.67 seconds).

Northbound. The mixed model ANOVA conducted on TTC for the northbound lanes showed a significant effect of Age ($F(1,44) = 6.97$, $p = .011$) with Younger participants accepting smaller gaps (M = 7.18 seconds) when crossing intersection compared to Older participants (7.81 seconds).

As the analysis of the average TTC for the northbound lanes showed, correctly interpreting age-related differences may not be a straightforward process. Although Younger drivers exhibited smaller TTC when crossing the northbound lanes, the average TTC of 7.18 seconds was considered as an appropriate crossing gap in Study One. Due to potentially ambiguous interpretation of average TTC findings, we included *adjusted TTC* as an alternative measure in Study One. Only adjusted TTC measure was included in the other studies in this report (i.e., Study Two, Field Study).

3.4.1.2 Adjusted Time-to-Contact

Southbound. The analysis of adjusted TTC measure revealed a significant main effect of Age ($F(1,44) = 4.76$, $p = .034$). Younger drivers accepted smaller gaps when crossing the southbound lanes than their Older counterparts (M = 5.79 and 5.54 seconds for Older and Younger drivers, respectively).

Northbound. The 4-way mixed model ANOVA performed on the adjusted TTC measure for the northbound lanes revealed a significant effect of Age ($F(1,44) = 5.86$, $p = .02$). Similar to the findings for the southbound lanes, Younger drivers were more likely to accept a critical gap compared to Older drivers (M = 6.24 and 5.99 for Older and Younger participants, respectively). This analysis also exposed a significant 3-way interaction between Age, Sign State and Cognitive Load ($F(1,44) = 4.71$, $p = .035$). As illustrated in Figure 4, the Sign State and Cognitive Load interaction was significant for Older drivers ($F(1,22) = 4.33$, $p = .049$), but not for Younger drivers ($p > .28$). When performing a concurrent secondary task while driving, Older drivers accepted smaller gaps when the sign was turned off compared to the Treatment, Sign On condition (M = 6.12 and 6.36 for Sign Off and Sign On conditions, respectively). When Older participants performed the driving task only, the state of the mCICAS-SSA sign did not impact their acceptance of gaps.

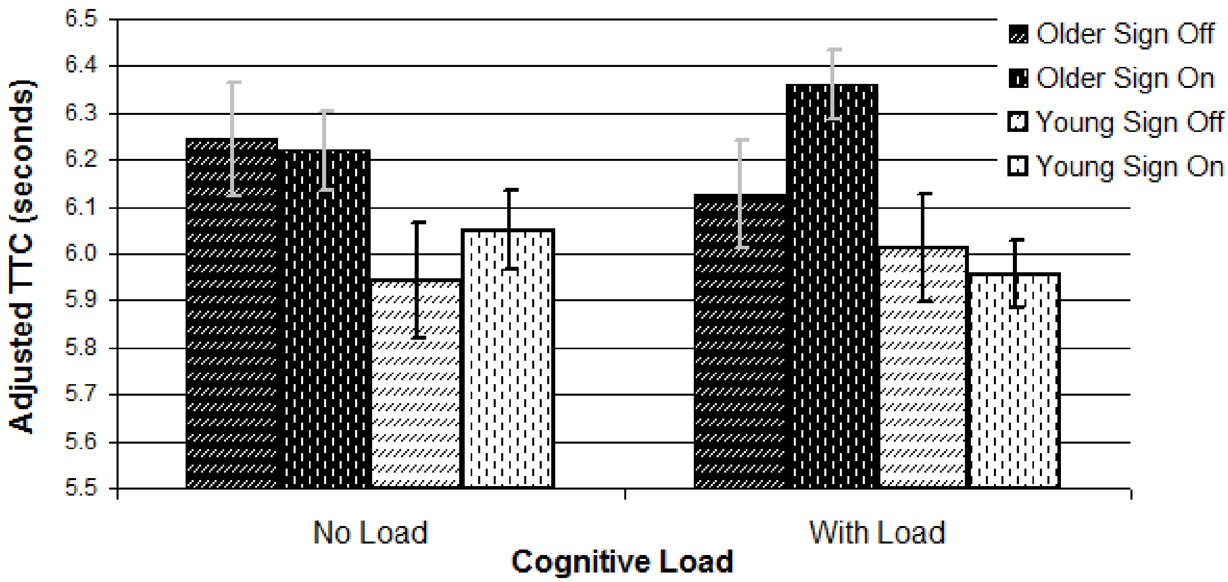


Figure 4. Accepted critical gap as a function of Cognitive Load, Age and Sign State with standard error bars.

3.4.1.3 Wait Time

Southbound. The wait time measure was submitted to a 4-way ANOVA, revealing a significant main effect of Sign State ($F(1,42) = 10.67$, $p = .002$). Drivers waited longer to cross the southbound lanes when the CICAS sign was turned on (10.3 seconds) compared to when the mCICAS-SSA sign was turned off (7.27 seconds). This analysis also showed a significant interaction between Cognitive Load and Sign State ($F(1,42) = 16.73$, $p < .001$). As depicted in Figure 5, when driving only participants waited longer to cross the intersection when the sign was turned on compared to the Control, Sign Off condition ($F(1,42) = 25.71$, $p < .001$; $M = 5.5$ and 10.3 seconds for Sign Off and Sign On conditions, respectively). However, when completing a concurrent secondary task, the duration of the wait time did not depend on the state of the mCICAS-SSA sign ($p > .8$).

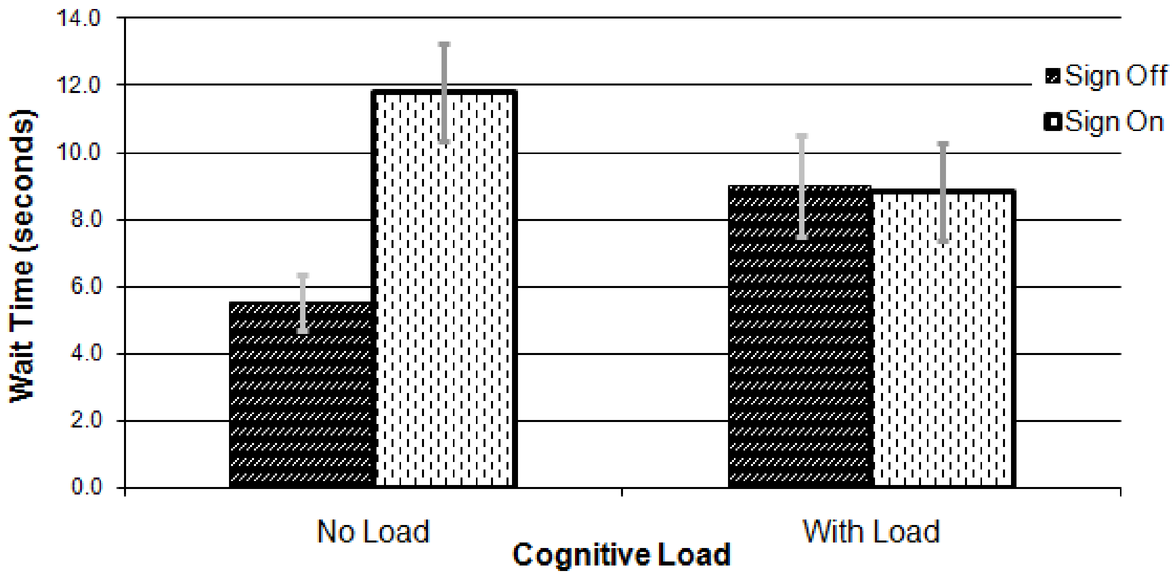


Figure 5. Wait time before crossing of the southbound lanes, as a function of Cognitive Load and Sign State with standard error bars.

Northbound. The wait time measure for the northbound lanes was submitted to a 4-way ANOVA, revealing a significant main effect of Sign State ($F(1,38) = 7.13$, $p = .011$). Drivers waited longer to cross the northbound traffic when the mCICAS-SSA sign was turned on in the Treatment condition (10.94 seconds) compared to when the sign was turned off in the Control condition (8.73 seconds). This is an identical pattern as the wait time for crossing of the southbound lanes.

3.4.1.4 Likelihood of Stopping

Southbound. The likelihood of stopping measure was submitted to a 4-way ANOVA, revealing a marginal main effect of Sign State ($F(1,44) = 3.67$, $p = .062$). Drivers exhibited a trend toward greater likelihood of making a complete stop at the stop sign when the mCICAS-SSA sign was turned on (.862 of trials) compared to the Control condition in which the sign was not activated (.813 of trials). The 4-way ANOVA also revealed a significant 3-way interaction between Sign State, Age, and Instruction level ($F(1,44) = 5.09$, $p = .029$). As illustrated in Figure 6, Sign x Instruction interaction was significant for Older adults ($F(1,22) = 4.84$, $p = .039$), but not for their Younger counterparts ($p > .32$). Older drivers that received Full Instructions were more likely to make a complete stop at the stop sign when the mCICAS-SSA sign was activated (.875 of trials) compared to the Control condition which did not feature an active Sign (.729 of trials). However, the likelihood of Older drivers who received Minimal Instructions to make a complete stop at the stop sign was not affected by the states of the sign ($M = .833$ and .823 for Sign Off and Sign On conditions, respectively).

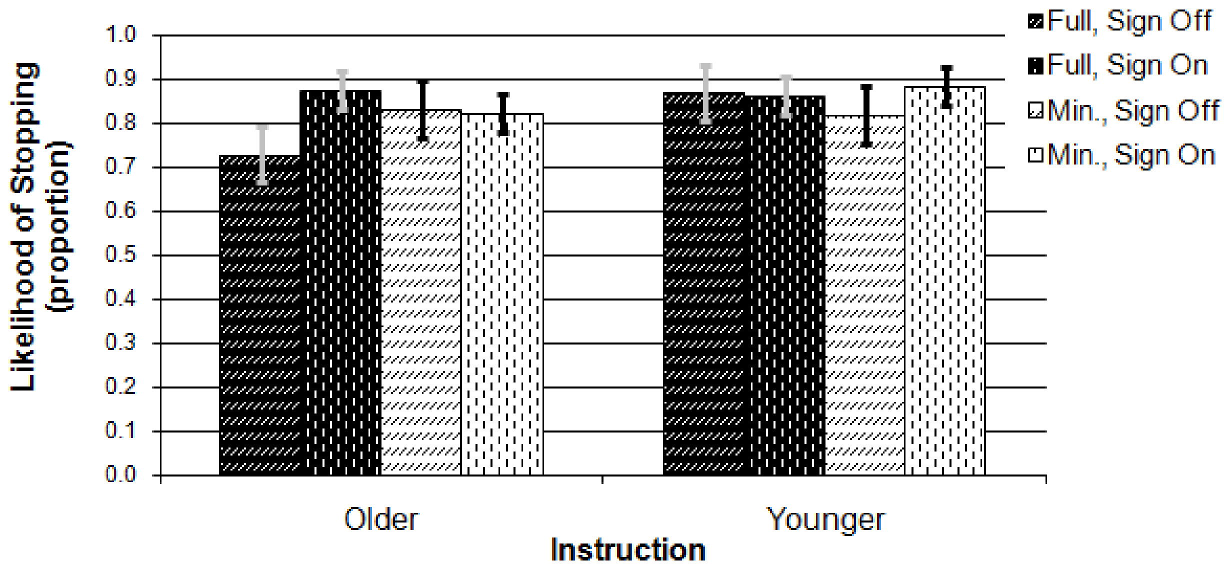


Figure 6. The proportion of intersection crossings in which participants made a complete stop at the stop sign, as a function of Instruction, Age and Sign State with standard error bars.

Northbound. The mixed model ANOVA revealed a significant effect of Cognitive Load ($F(1,44) = 4.67$, $p = .036$). Contrary to expectations, results showed that drivers completing a concurrent secondary task were more likely to make a complete stop at the median (.755 of trials) compared to when they were performing only the driving task (.69 of trials). It is possible that drivers recognized the inherent risk of completing an additional task while driving and as a result decided to make a stop before assessing the possibility of crossing. However, the same pattern was not found when crossing the southbound lanes. This same analysis also revealed a significant main effect of Age ($F(1,44) = 7.36$, $p = .009$). As expected, Younger drivers were less likely to stop at the median than did the Older drivers (M = .805 and .631 of trials for Older and Younger drivers, respectively). Finally, this mixed model ANOVA exposed a significant interaction between Cognitive Load and Sign State factors ($F(1,44) = 5.32$, $p = .026$). As shown in Figure 7, when completing the driving task only, participants were more likely to stop at the median when the mCICAS-SSA sign was turned on compared to when the sign was not activated ($F(1,44) = 7.98$, $p = .007$; M = .62 and .74 of trials for Sign Off and Sign On conditions, respectively). However, when completing the concurrent secondary task while driving, participants' frequency of stopping at the median was not affected by the state of the mCICAS-SSA sign ($p > .9$).

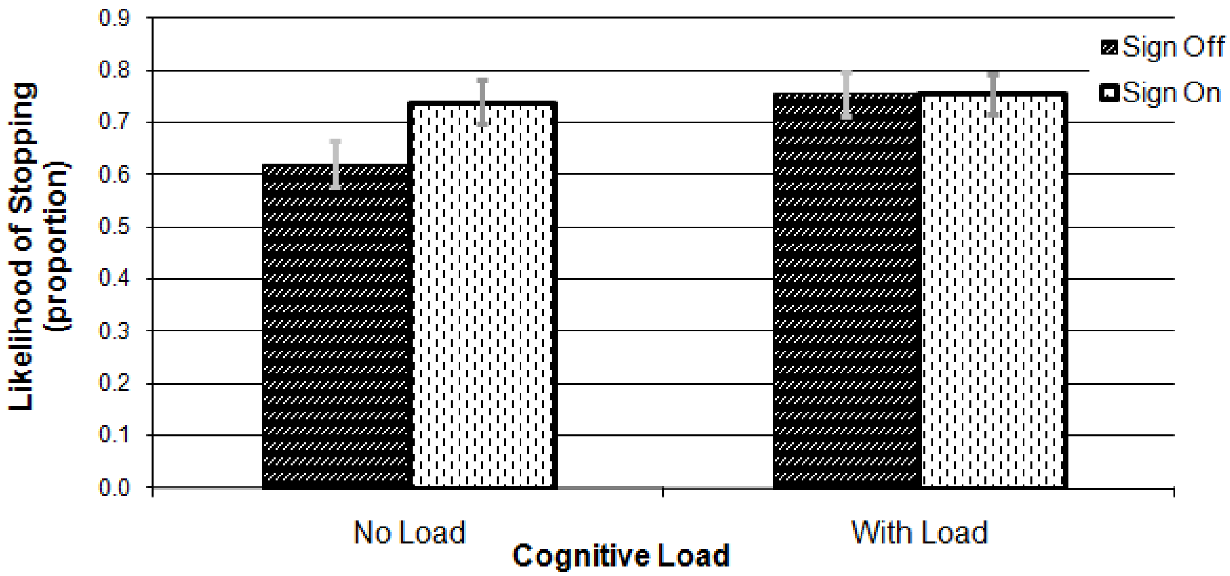


Figure 7. The proportion of intersection crossings in which participants made a complete stop at the median, as a function of Cognitive Load and Sign State with standard error bars.

3.4.1.5 Movement Time

Southbound. The movement time measure submitted to a 4-way ANOVA revealed a main effect of Age ($F(1,44) = 4.64$, $p = .037$). Older drivers required more time to cross the southbound lanes than the Younger drivers (2.07 and 1.7 seconds for Older and Younger drivers, respectively).

Northbound. The 4-way mixed model ANOVA did not show any significant effects, but it did reveal a marginal effect of Sign State ($F(1,44) = 3.87$, $p = .055$). Drivers exhibited a trend toward longer movement time across the northbound lanes of traffic when the mCICAS-SSA sign was turned on ($M = 1.52$ and 1.58 seconds for Sign Off and Sign On conditions, respectively).

3.4.1.6 Accepted Critical Gap

Southbound. A marginal main effect of Age was found ($F(1,44) = 3.87$, $p = .056$), showing that Younger drivers accepted a larger proportion of critical gaps, compared to Older drivers ($M = .12$ and .09 for Younger and Older drivers, respectively), following the same pattern found in the adjusted TTC measure. This analysis also revealed a significant interaction between Cognitive Load and Instruction level factors ($F(1,44) = 4.91$, $p = .032$). As depicted in Figure 8, the impact of Cognitive Load on participants who received Full level of Instructions was non-existent ($p > .34$). However, drivers who received only Minimal Instructions regarding the use and the function of the mCICAS-SSA sign were more influenced by the presence of the secondary task ($F(1,22) = 3.98$, $p = .059$). Participants who received Minimal Instructions about the use of the sign were more likely to accept a critical gap under dual-task compared to when driving only ($M = .13$ and .1 weighted proportion of trials for dual-task and single-task conditions, respectively).

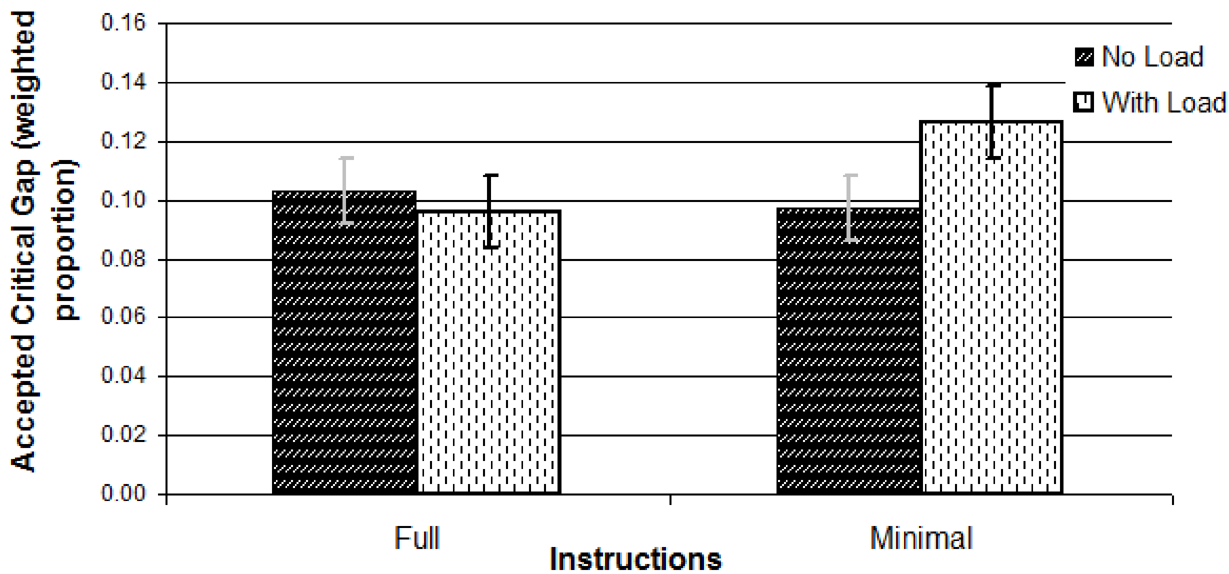


Figure 8. Proportion of critical gap acceptance when crossing the southbound lanes, as a function of Instructions and Cognitive Load with standard bars.

Northbound. The analysis of accepted gap when crossing the northbound lanes revealed a significant effect of Age ($F(1,44) = 5.7$, $p = .021$), again showing that Younger drivers were more likely to accept a critical gap when crossing the intersection ($M = .064$ and .037 for Younger and Older drivers, respectively). The same analysis also showed a significant three-way interaction between Cognitive Load, Age and Sign State factors ($F(1,44) = 4.78$, $p = .034$). As Figure 9 illustrates, the Age and Sign State factors did not interact in single-task condition, when drivers only performed the driving task ($p > .77$). However, in dual-task condition, the interaction of Age and Sign State factors was significant ($F(1,44) = 5.31$, $p = .026$). Younger drivers were more likely to accept a critical gap when completing the concurrent secondary task ($M = .054$ and .073 weighted proportion of trials for single- and dual-task conditions, respectively). Older drivers more readily recognized the potential danger of dividing attention and reduced the probability of accepting a critical gap when engaged in a concurrent secondary task ($M = .048$ and .023 weighted proportion of trials for single- and dual-task conditions, respectively).

3.4.1.7 Rejected Non-Critical Gap

Southbound. The 4-way mixed model ANOVA performed on the rejected non-critical gap measure for the southbound lanes showed a significant effect of Cognitive Load ($F(1,42) = 4.11$, $p = .049$). As shown in Figure 10, out of all gaps that drivers rejected in single-task condition, 87% of them were critical gaps and 13% were non- critical gaps, when completing a concurrent secondary task, 82% of all rejected gaps were critical, while 18% were non-critical.

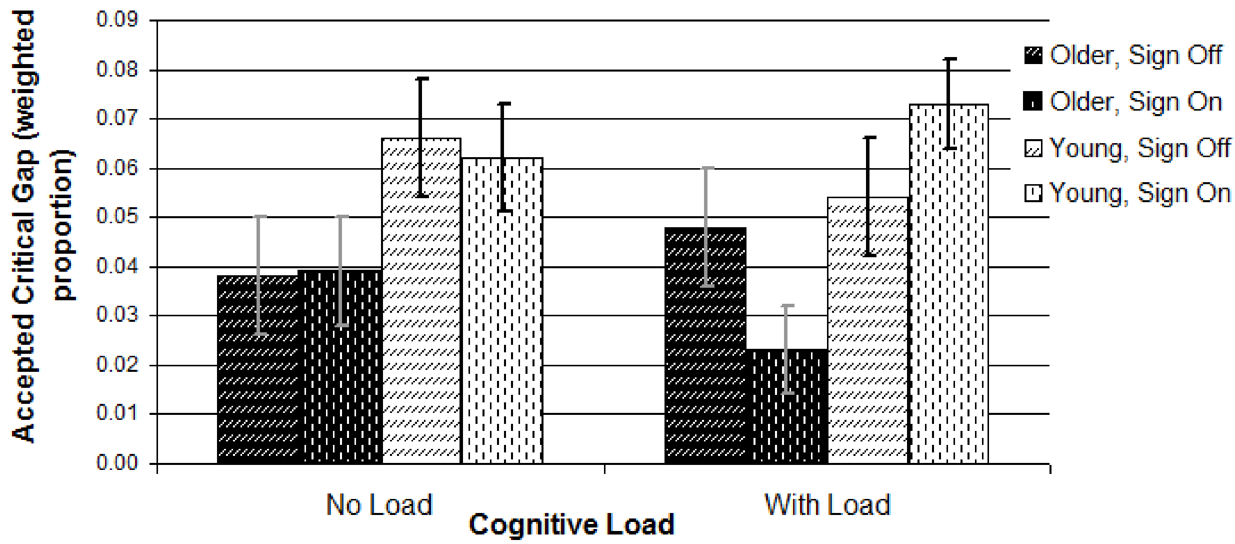


Figure 9. Proportion of critical gap acceptance when crossing the northbound lanes, as a function of Age, Cognitive Load and Sign State with standard bars.

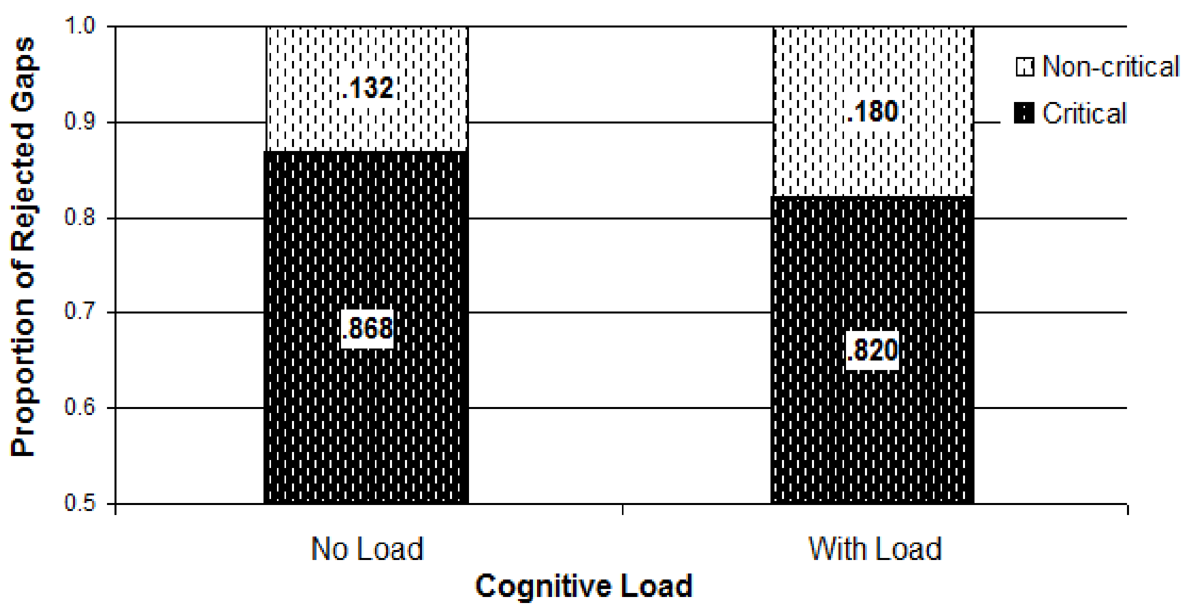


Figure 10. Proportion of rejected critical and non-critical gaps when crossing the southbound lanes, as a function of Cognitive Load.

This analysis also revealed a significant 3-way interaction between Instruction level, Sign State, and Cognitive Load ($F(1,42) = 4.51$, $p = .04$). As depicted in Figure 11, the Sign State and Instruction level interaction was significant in single-task condition when participants only completed the driving task ($F(1,42) = 6.74$, $p = .013$), but not under dual-task condition ($p > .86$).

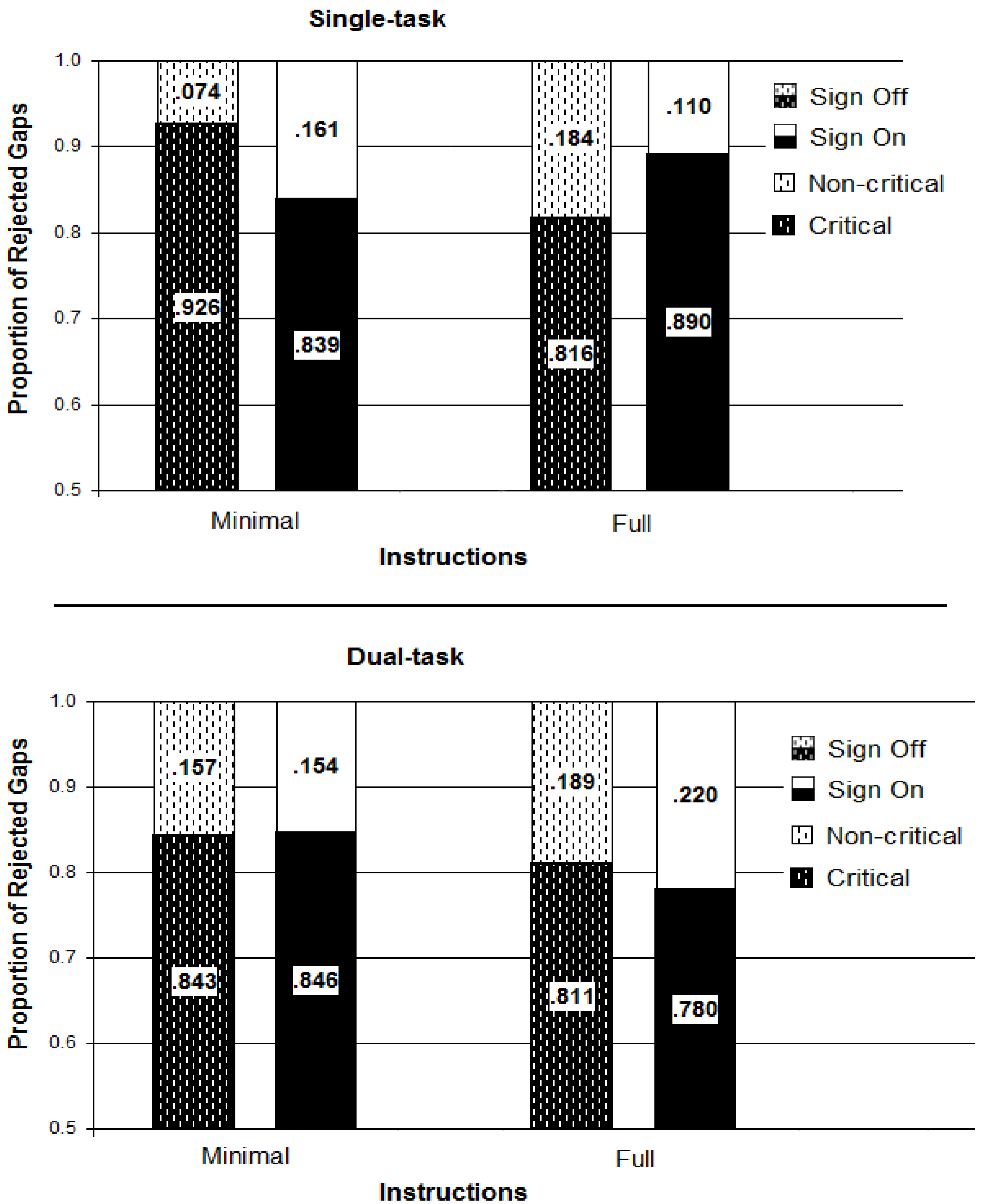


Figure 11. Proportion of rejected critical and non-critical gaps when crossing the southbound lanes, as a function of Instruction level and Sign State in single-task (top panel) and dual-task (bottom panel) conditions.

In the single-task condition, the Sign State factor had a differing impact on rejected gaps for participants who received Full and those who received Minimum level of Instructions. For participants who received Full Instructions, the smaller proportion of all rejected gaps were non-critical gaps when the mCICAS-SSA was activated compared to the Control, Sign Off condition (see top panel of Figure 11). This finding suggests that greater knowledge of the system influenced the type of the gaps that drivers rejected. Participants who received Minimal Instructions exhibited an opposite pattern; they rejected greater proportion of non-critical gaps when the mCICAS-SSA was activated (see top panel of Figure 11), suggesting potential challenges as a result of inadequate explanation of the driving assist system.

Northbound. The 4-way mixed model ANOVA performed on the rejected non-critical gap measure for the northbound lanes showed a significant effect of Age (F(1,42) = 5.02, p = .03). Older drivers again exhibited a more conservative driving habits, as they rejected greater proportion of non-critical gaps, compared to their Younger counterparts (M = 14% and 9% of non-critical gaps were rejected, for Older and Younger drivers, respectively). Additionally, this analysis also revealed a significant main effect of Sign State (F(1,42) = 6.81, p = .013). Interestingly, drivers were more likely to reject a non-critical gap when the mCICAS-SSA was activated, compared to Control, Sign Off condition (M = 9% and 14% of rejected gaps were non-critical, for Sign Off and Sign On conditions, respectively).

3.4.1.8 80th Percentile Rejected Gap

Southbound. The 80th percentile rejected gap measure was submitted to a 4-way ANOVA, revealing a significant main effect of Instruction (F(1,42) = 5.85, p = .071). The gap that was rejected 80 percent of time was larger for the participants who received Full Instructions (80^{th} percentile gap of 6.19 seconds) compared to those participants who received Minimal Instructions (80^{th} percentile gap of 5.7 seconds). The 80th percentile rejected gap measure could be viewed as a measure of safety or cautious driving. An 80th percentile rejected gap that is substantially smaller than the critical gap of 6.5 seconds may be an indication of an unsafe driving behavior. The smaller this measure is, the greater the probability of accepting an unsafe gap. Additionally, this analysis also showed a marginal Age x Sign State interaction (F(1,42) = 4.04, p = .051). As portrayed in Figure 12, the 80th percentile rejected gap for Older adults was greater when the mCICAS-SSA was turned on, compared to the Control condition (F(1,21) = 5.83, p = .025).

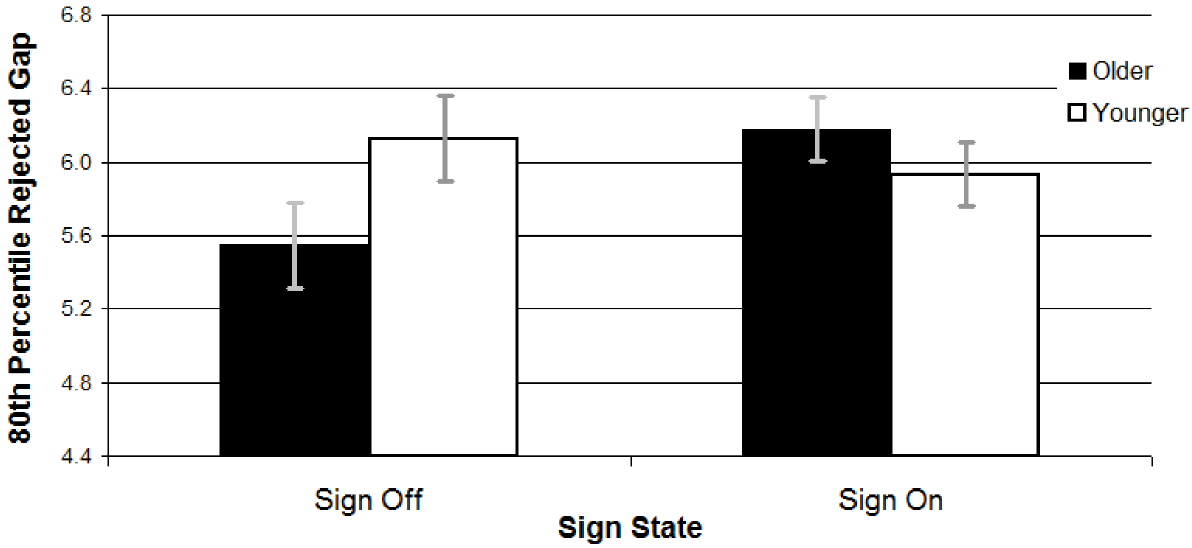


Figure 12. The 80th percentile gap as a function of Age and Sign State with standard error bars.

3.4.2 Usability Measures Results

3.4.2.1 System Trust Questionnaire

The system trust questionnaire scores were averaged across the Age and Instruction level groups. The responses were assigned values between 0 and 100. The low value indicates that the participant strongly disagreed with a specific statement while the high value indicates that a participant strongly agreed with a statement. See Appendix B for the exact statements/questions that were included in the System Trust questionnaire. The responses to each question were submitted to a 2 x 2 between-subjects ANOVA with Age and Instruction level as the factors. Table 3 displays the overall mean response for each question and any significant effects that were revealed by the analysis.

Overall, participants did not exhibit strong reactions in regards to the reliability and safety of the system (Questions 1,4,5 and 6). The responses to Question 2 showed a significant effect of Instruction level ($F(1,44) = 6.37$, $p = .015$). When responding to Question 2 (i.e., I am familiar with the operations of the system), participants who received the Full level Instructions (78.1) agreed to a greater extent with that statement than did the participants who received the Minimal level of Instructions (56.1). While the effect of Instruction on driving performance was not extensive, receiving Full Instructions afforded participants greater level of familiarity with the system. None of the other questions in the System Trust questionnaire revealed main effects or interactions.

Table 3. The average scores and significant effects for responses to questions in the system trust questionnaire (on scale 0-100).

Question	Overall Mean	Significant Effects *
1. The system enhanced my safety.	47.0	
2. I am familiar with the operations of the system.	67.1	Instruction (F > M)
3. I trust the system.	51.4	
4. System is reliable.	61.2	
5. System is dependable.	59.6	
6.System has integrity.	58.2	
7. I am comfortable with the system's intent.	68.9	
8. I am confident in my driving without the system.	89.8	

*All denoted effects were significant at .05 level.

3.4.2.2 Usability Questionnaire

The scores on the Usability questionnaire were averaged across the Age and Instruction level groups. The responses were assigned values between 0 and 100. The low value indicates that the participant strongly disagreed with a specific statement while the high value indicates that a participant strongly agreed with a statement. See Appendix C for the exact statements/questions that were included in the Usability questionnaire. The responses to each question were submitted to a 2 x 2 between-subjects ANOVA with Age and Instruction level as the factors. Table 4 displays the overall mean response for each question and any significant effects that were revealed by the analysis.

Other than exhibiting a great belief in their own driving skills (Question 10), the average responses to questions in the usability questionnaire did not show a strong reaction in either direction (agreement or disagreement). Participants who received Full Instructions acknowledged greater familiarity in the system in the system trust questionnaire. The same group of the participants (i.e. those who received Full Instructions) was less likely to feel confused when using the mCICAS-SSA sign than did participants who received Minimal level of Instructions, as shown in the significant effect of Instruction for Question 2 in the Usability questionnaire ($F(1,44) = 5.55$, $p = .023$; M = 41.7 and 61.46 for participants who received Full and Minimal Instructions, respectively). The similarly worded question (Question 7) however, did not show a significant effect of Instruction level.

Table 4. The average scores and significant effects for responses to questions in the usability questionnaire.

Question	Overall Mean	Significant Effects *
1. I felt confident using the sign.	53.6	
2. I felt it was confusing using the sign.	51.6	Instruction (F < M)
3. The sign made me safer.	46.4	
4. I trusted the information provided by the sign.	56.8	Age (O < Y)
5. I like the sign.	49.0	
6. The sign was reliable.	63.0	Age (O < Y)
7. The sign was easy to understand.	64.1	
8. Sign's information was credible.	65.1	Age (O < Y)
9. Sign was useful.	52.1	
10. I could complete the maneuver the same way without the sign.	81.8	

*All denoted effects were significant at .05 level.

The questions relating to the belief and trust in the system (Questions 4, 6 and 8) all revealed a significant effect of Age. Older adults were less likely to trust the information provided by the Sign (Question 4), were less likely to view the mCICAS-SSA sign as reliable (Question 6) and questioned the credibility of the information provided by the Sign to the greater extent (Question 8) than did Younger drivers. The lack of Age x Instruction interaction suggested that receiving Full Instructions did not do enough to offset the Older driver's distrust in the new technology.

3.5 DISCUSSION

Study One had two principal goals. The first goal of Study One was to assess the impact of level of Instruction drivers receive about the mCICAS-SSA on their adherence to the Sign and their intersection crossing performance. This was accomplished through the manipulation of the Instructions that the participants received at the beginning of the study about the purpose and use of the mCICAS-SSA. The findings are discussed in terms of the impact of this factor and the implications for the following studies. The second goal of Study One was to assess the effect of a secondary, non-driving task on driver's use of the sign and their subsequent driving performance. This was accomplished through the use of a working memory task that participants completed while driving. The results are discussed in terms of the impact of the secondary task and the interaction between the use of the sign and Cognitive Load on drivers' intersection crossing performance.

3.5.1 The Impact of Cognitive Load

An important question to ask when incorporating new technology in a vehicle, in addition to its potential benefits, relates to possible discord or even cost when paired with an additional, frequently performed non-driving task (e.g. cell-phone conversation). Examining the impact that a new technology may have on a driver conversing on a cell-phone can be detrimental to safety. Conversing on a cell-phone while driving is already a potentially dangerous activity (Strayer, Drews & Johnston, 2003), so any new technology should not add any additional cognitive or motor demands on the driver. The inclusion of the Cognitive Load factor addressed just that concern. The results showed numerous interactions involving the Cognitive Load factor, but also a few main effects of Cognitive Load.

The results showed that when crossing the northbound lanes drivers were more likely to make a complete stop at the median when engaged in a concurrent secondary task, compared to when driving without the secondary task. This is a rather unexpected finding, but it is possible that drivers recognize the inherent risk of engaging in an additional task (e.g., cell-phone conversation) while driving and therefore made a determination to stop at the median before assessing the possibility of crossing the northbound lanes. However, the same pattern was not found when crossing the southbound lanes, but the likelihood of stopping at the stop sign was greater compared to the median (.84 and .72 of trials for stopping at the stop sign and at the median, respectively). Completing a concurrent secondary task while driving may prompt some drivers to adopt a more conservative driving behavior. That explanation would be consisted with the finding of the rejected gap measure showing that drivers were rejecting gaps that were greater than the critical threshold of 6.5 seconds more frequently when they performed a concurrent secondary task compared to when they were driving only.

The potential interaction between Sign State and Cognitive Load factors could go in two possible directions. In our previous CICAS-SSA related studies, we found equivalent performance between the Sign On and Sign Off conditions for many of the intersection crossing measures. Let's assume that to be the case for Study One findings as well. What kind of an impact might we expect the Sign State factor to have when drivers engage in a concurrent secondary task while crossing intersections? One potential consequence of engaging in a non-driving task would include an improvement in driving performance (e.g., an increase in the accepted TTC) when the CICAS-SSA sign is turned on compared to the Control, Sign Off condition. This would suggest that drivers relied on the assist system to cross the intersection when their cognitive resources were strained by another non-driving task. For this to occur, the processing of the CICAS-SSA sign would need to be almost entirely effort-free. This best case scenario would suggest a beneficial aspect of the sign under cognitively demanding conditions of intersection crossing. On the other hand, we could also find a decrement in driving performance measures (e.g., a decrease in the accepted TTC) with the CICAS-SSA sign turned on compared to the Control condition in which the Sign was not activated. Significant research (Strayer et al., 2003; Recarte & Nunes, 2003, among others) would suggest that we may expect to find a decrement in driving performance measures under the Cognitive Load conditions. If processing of the CICAS-SSA sign requires substantial resources, we may see an additional cost in the intersection crossing performance with the Sign On when completing a concurrent secondary task. This additional cost would signify a potentially negative consequence of using the CICAS-SSA sign.

The results showed an interesting interaction involving Cognitive Load, Sign State and Age in the accepted critical gap measure. Older drivers appear to have more readily recognized the inherent danger of dividing attention between driving and an additional task and therefore relied on the mCICAS-SSA sign when crossing the intersection when their cognitive resources were strained by the working memory task. Older drivers were less likely to accept a critical gap (gap smaller than 6.5 seconds) under Cognitive Load condition when the mCICAS-SSA sign was activated, suggesting reliance on the assist system under highly demanding cognitive conditions. It is also possible that the Older drivers abandoned the secondary task while focusing their attention on the primary task of driving. This is a likely possibility as similar findings have been reported by other researchers (Kramer et al., 2009). In regards to their Younger counterparts, Younger drivers may appear more confident in their ability to successfully complete the secondary task when crossing the intersection without the help of the assist system.

The results have also shown a Cognitive Load and Sign State interaction for the wait time. When driving only, participants waited longer to cross the intersection when the mCICAS-SSA sign was turned on compared to the Control, Sign Off condition. This finding can be rather easily explained by additional time that is needed for the processing of the sign but also a novelty effect, which may attenuate with the prolonged use of the system. A more interesting part of this interaction is the equivalent wait period between the Sign On and Sign Off conditions when drivers performed a concurrent secondary task. The presence of the mCICAS-SSA sign did not negatively impact driving performance measure under demanding cognitive conditions, suggesting that the processing of the mCICAS-SSA sign does not require substantial cognitive resources. This does not stand in contrast with the earlier explanation of the CICAS-SSA sign processing under normal Cognitive Load. When cognitive resources are abundant, as may be the case in the driving only condition, drivers may feel more comfortable to spend extra time and attention to explore the new technology. However, when the cognitive resources are strained, as in the dual-task condition, additional attention for processing of the CICAS-SSA sign does not appear to be required.

Additional indication of the beneficial interaction of the mCICAS-SSA sign and Cognitive Load was found in the likelihood of stopping measure. When completing the driving task only, participants stopped at the median more frequently when the mCICAS-SSA sign was turned on compared to when the Sign was not activated, providing clear evidence of the beneficial aspect of the mCICAS-SSA sign. When completing a concurrent secondary task while driving, the likelihood of stopping at the median was not influenced by the state of the sign, again providing evidence that the use of the sign does not hinder driving performance under demanding cognitive conditions.

3.5.2 The Impact of Instruction

The effects of Instruction level on the driving performance measures were not very prominent or substantial. Still, a few interactions involving the Instruction factor do require a more detailed analysis. Older drivers who received Full Instructions substantially increased the likelihood of making a complete stop when the mCICAS-SSA sign was turned on compared to the Control condition, suggesting a benefit of making a full disclosure regarding the purpose and the functioning of the mCICAS-SSA sign. Although simplistic in design, the mCICAS-SSA sign represents a new technology and as such *may* be viewed as foreign or unknown and therefore less trusted or less likely to be used. The acceptance of a new technology may be especially problematic for Older adults (Shinar et al., 2003). The results revealed a significant effect of Instruction for the 80th percentile rejected gap. The gap that was rejected 80 percent of time was larger for the participants who received Full Instructions compared to those participants who received Minimal Instructions.

While the impact of Instruction level that participants received was not substantial, a few findings do suggest some benefits of fully explaining to the participants the purpose and the exact functioning of driver's support system. More importantly, providing participants with Full Instructions did not result in any negative unintended consequences. The responses to the questions in the Usability and System Trust questionnaires suggest that providing drivers with complete Instructions about the use and purpose of the mCICAS-SSA sign results in their greater familiarity with the system and reduced potential for the confusion when using the mCICAS-SSA sign.

3.6 CONCLUSION

The results from Study One revealed some interesting and useful findings relating to the impact of demanding cognitive conditions and the level of Instructions that participants receive about the driver support systems on the drivers' intersection crossing behavior and their use of the mCICAS-SSA sign. We can summarize the main findings in the following points:

- The use of the mCICAS-SSA sign resulted in the improvement of certain safety aspects of intersection crossing such as an increased likelihood of stopping at the median and even waiting longer before crossing.
- The use of the mCICAS-SSA sign under cognitively demanding conditions did not result in any adverse consequences, suggesting that the processing of the system required Minimal cognitive resources.
- Participants that were fully informed about the purpose and the functioning of the mCICAS-SSA sign reported a greater level of familiarity with the system and were less likely to be confused in regards to its use.

3.7 LIMITATIONS

Although the simplified design of the mCICAS-SSA sign used in Study One resembled the original CICAS-SSA greatly, it is still a Modified version of the original CICAS-SSA. Furthermore, this design included an additional state, a blinking yellow icon. Since the presentation duration of the yellow icon is variable in the original CICAS-SSA we considered a possibility that participants may view the yellow icon as potentially dangerous as the red icon. And while we do not believe this to be the case, we need to acknowledge the possibility that because of the changes in the design of the mCICAS-SSA sign the results obtained in Study One may not be applicable for the original CICAS-SSA. Study Two, which includes the design of the original version of the CICAS-SSA will answer this potential limitation.

The traffic flow in Study One was manipulated to increase the difficulty of the perceptual task (i.e., determining the gap size), however it does not accurately represent the traffic flow at the intersection of HW 52 and CSAH 9, thus reducing the real-world validity of the study. Study

Two, in which the traffic flow resembles the flow at this intersection, will answer this potential limitation.

4 STUDY TWO

4.1 INTRODUCTION

The use of an existing road sign (i.e., divided highway) as a basic platform on which the CICAS-SSA sign was created, afforded familiarity which, as suggested by our earlier studies (Creaser et al., 2008) would reduce the processing time required to comprehend the sign. However, the interface of the CICAS-SSA sign located on a roadside may not be the optimal interface to use inside a vehicle. The existing literature on the design and the effectiveness of in-vehicle warning systems would be a good starting point for our current goal of moving the CICAS-SSA sign from its location on a roadside to a new location inside a vehicle.

Many studies examined a myriad of warning systems which alert the driver to a variety of potentially dangerous situations (e.g., frontal collision, blind spot detection, lane departure). The methods by which drivers are alerted to a potential danger also differ. Some warning systems utilize auditory cues to alert the driver to a potential danger (Chang, Lin, Hsu, Fung and Hwang, 2009) while other systems may use visual (Scott & Gray, 2008), tactile (Mohebbi, Gray & Tan, 2009) or some combination of stimuli, creating a bi-modal warning (Ho, Reed & Spence, 2007; Kramer et al., 2007). Spatially relevant cues have also shown to be effective (Ferris, Penfold, Hameed & Sarter, 2006), such that a spatially relevant auditory cue (e.g., a tone sounding from the left when departing a lane to the left) is more effective in capturing driver's attention than a spatially irrelevant auditory cue (e.g., a tone sounding from the location in front of the driver). Another consistent finding reported in the literature relates to the benefit of a bi-modal warning cue compared to a uni-modal cue. Researchers commonly reported faster response times to sudden events when drivers were alerted by a bi-modal signal (e.g., auditory/visual, auditory/haptic) compared to a uni-modal cue (Kramer et al., 2007; Ho, Reed & Spence, 2007). Both Older and Younger drivers responded faster (e.g., braking or steering) to a potential frontal collision to which they were alerted by a visual/auditory warning compared to when being alerted by a visual only or auditory only warning. The benefit of a redundant alert is apparent in warning systems which is the main reason why we examined its potential benefits when designing an interface for the In-Vehicle CICAS-SSA.

We created three different versions of the In-Vehicle CICAS-SSA sign to examine in Study Two, each of which addressed a potential concern. The purpose of the CICAS-SSA system is somewhat different to that of a typical warning system. The goal of a typical warning system, such as forward collision, is to immediately direct driver's attention to a potential crash. This situation of high priority also requires the driver's immediate response in order to avoid the crash. Other warning systems may monitor the driver's behavior and alert them in the early stages of a potentially dangerous situation (e.g., deviating within one's lane). These descriptions of a typical warning system differ from the rural intersection crossing scenario for which the sign was created in one important aspect. The proper use of the CICAS-SSA sign assumes that a driver at the rural intersection will make a complete stop at the stop sign. The sign then provides information regarding the gap of vehicles on the major road and as such does not require the driver to make a quick maneuver in order to avoid a potential collision. That is, the CICAS-SSA system is not a warning system; it is an information display system. The sign provides a driver with information about gap sizes of vehicles on the major road, however it is up to the driver to determine when to act (i.e., cross the intersection). The consequence of not acting (i.e., not crossing) is nearly non-existent, the driver remains at the stop sign. However, the consequence of not acting upon a warning system alert (i.e., forward collision alert) could potentially be life threatening.

Although effective in the context of a warning system, auditory and/or haptic cues as part of the In-Vehicle CICAS-SSA system may render the Sign ineffective or even distracting. The tones or vibrations that may be used to signal an inappropriate gap in the In-Vehicle CICAS-SSA would need to last the duration of an inappropriate gap, which during a rush hour may last several minutes. Constant or even frequent beeping/vibrations to a situation of which driver is already cognizant of, due to signal saturation may result in the driver learning to ignore those signals (Lahrmann, Runge, & Boroch, 2001). Also, in this situation the "go signal" for the driver would be the lack of signal, which is harder to detect than presence of a signal. If tones or vibrations are used to signal only an appropriate gap, at least one potentially confusing situation may occur. In that situation the "go signal" is represented by a tone/vibration which would conflict with the meaning of tones/vibrations in a typical warning system, where it usually indicates a potential danger. So, the three versions of the In-Vehicle CICAS-SSA sign all use a visual interface and do not rely on any auditory or haptic cues to inform the driver about gap sizes on the major road.

All three In-Vehicle CICAS-SSA designs in Study Two used two displays to present information about the state of traffic on the major road. The use of a single display to present the In-Vehicle CICAS-SSA interface was considered and then rejected. One weakness of a single-display interface relates to diminishing visual field. When the driver turns to the side (e.g., left) to examine the gap size of traffic coming from that direction, the display located centrally would appear in the distant part of driver's peripheral vision. The visual acuity and detection of stimuli in the peripheral vision declines substantially compared to stimuli located closer to the focal point. For this reason, the In-Vehicle CICAS-SSA interfaces in Study Two were presented on two displays, located on the left and right A pillars (see Figure 13). This configuration of displays negates the need for eye and/or head movements that would be required when monitoring the In-Vehicle CICAS-SSA interface presented on a centrally located display only. When a driver turns to the left to examine traffic coming from that direction, in that same glace a driver is able to extract the information from the sign presented on the left display. Similarly, when a driver turns to the right to examine traffic coming from that direction, in that same glace a driver is able to extract information from the sign presented on the right display.

Figure 13. The location of the displays for the In-Vehicle CICAS-SSA interfaces.

Our previous studies investigating the effectiveness of the CICAS-SSA sign located on a roadside, revealed similar performance between Control and Treatment conditions (Rakauskas et al., 2009). The primary goal of Study Two is to evaluate the effectiveness of three different versions of the In-Vehicle CICAS-SSA on rural intersection crossing performance. As secondary goals, Study Two explored the impact of Visibility conditions and Age-related effects on the drivers' use of and adherence to an In-Vehicle CICAS-SSA. Self-reports from the participants in the currently conducted on-road study investigating the efficacy of the CICAS-SSA when crossing rural intersections, suggest that drivers may be more likely to utilize and adhere to the sign under Low Visibility conditions. In half of the trials in Study Two, participants were asked to cross the intersection under Good Visibility conditions (i.e., clear, daylight). In the other half of the trials, participants were asked to complete the crossing maneuver under conditions of low Visibility (i.e., fog). The Visibility factor was included to assess the driver's reliance on the assist system under conditions when their own perceptual faculties are limited. The final secondary goal of Study Two compared the effectiveness of an In-Vehicle version of the CICAS-SSA to that of the Roadside CICSA-SSA.

To accomplish these goals, Study Two was conducted in the HumanFIRST driving simulator at University of Minnesota in the same environment as Study One. The traffic flow resembled the flow at the intersection of HW 52 and CSAH 9, near Cannon Falls, Minnesota, increasing the validity of the study. Three different groups of participants were presented with three different versions of the In-Vehicle CICAS-SSA, each addressing a potential concern. Furthermore, the fourth group of participants was presented with a Roadside version of the CICAS-SSA. This condition was identical to our earlier study (Rakauskas et al., 2009).

The following are the main research issues examined in Study Two:

- Evaluation of the effectiveness of each of the In-Vehicle CICAS-SSA designs and determining the optimal design.
    - Driving performance in the Control condition (i.e., no sign) was compared to the Treatment condition in which drivers were exposed to, for each of the In-Vehicle versions of the CICAS-SSA.

    - The difference in driving performance between the Control and the Treatment conditions was compared between each of the In-Vehicle CICAS-SSA designs.
- Examination of the impact of Visibility on the drivers' use of the Sign and their driving performance.
    - Driving performance under conditions of Limited Visibility was compared to their performance in the Good Visibility conditions.
- Investigation of the effects of the location of the intersection crossing assist system on driving performance.
    - Drivers' intersection crossing performance when presented with a Roadside CICAS-SSA was compared to the drivers' performance when presented with the Complete version of the In-Vehicle CICAS-SSA.

4.2 METHODS

The three In-Vehicle CICAS designs were presented on two displays located on the bottom half of the left and right A pillars of the simulator vehicle (see Figure 13). The displays were oriented toward the driver. The information that was presented on the displays depended on the current gap sizes of the vehicles on the major road, while the activation of the displays depended on the location of the driver. When crossing the intersection, only one of the displays was active at any one time. The activation rules were identical for all three In-Vehicle CICAS-SSA interfaces. When the front bumper of the subject's vehicle was within 5 meters of the stop sign, the left display turned on and started presenting information regarding the gap sizes of vehicles on the major road. The left display continued presenting information until the front bumper of the subject's vehicle was within 1 meter of the median. As depicted in Figure 14, the left screen was activated and displayed information when the subject's vehicle was located in Zone 1. At that time, the right display remained off (the screen was black). When the front bumper of the subject's vehicle entered the median, the vehicle entered Zone 2 (see Figure 14), at which point the left display turned off (the screen turned black) and the right display became activated and started presenting information about the gap sizes of vehicles on the major road.

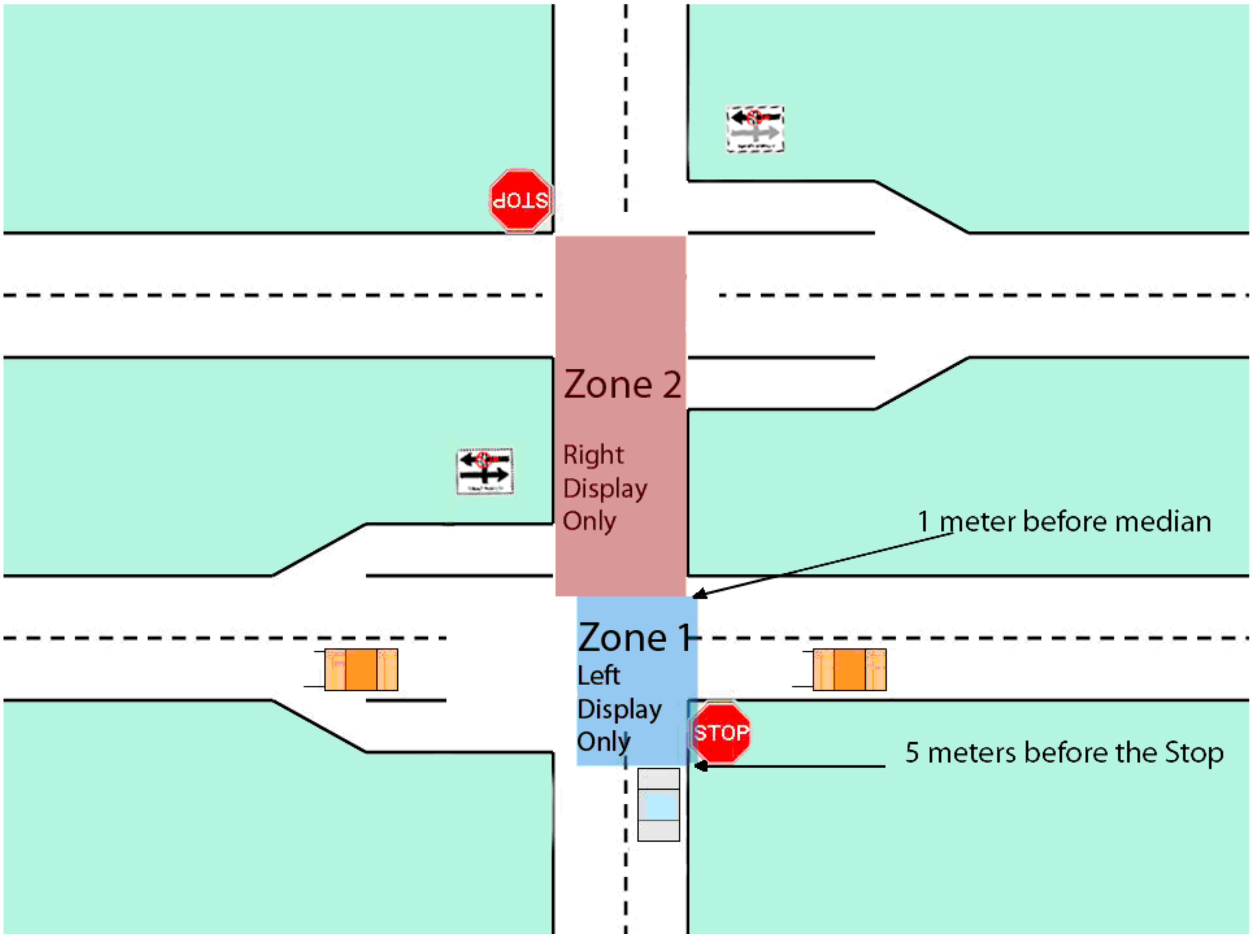


Figure 14. The rules of activation of the left and the right display for In-Vehicle CICAS interfaces.

4.2.1 Participants

Eighty four adults participated in Study Two. Thirty six of those participants were Older between the ages of 60 and 86 (18 women, 18 men; with a mean age of 66 and sd = 6.2 years). Forty eight participants were younger between the ages of 18 and 29 (23 women, 25 men; with a mean age of 22.3 and sd = 2.7 years). The Younger drivers had an average of 13.4 years of education while Older drivers had an average of 15.3 years of education. All of the participants had a valid driver's license, normal or corrected-to-normal vision (visual acuity of at least 20/40, normal color vision) and no previous history of disorders predisposing them for motion sickness (e.g., epilepsy). Older participants were recruited for participation because they exhibit significant perceptual declines (Salthouse, 1996), something that can be of great concern given that our task, estimating a safe gap when crossing an intersection, is a highly perceptual task. Younger participants were recruited through flyers posted at the University of Minnesota campus while the Older participants were recruited through flyers and online and newspaper ads. Participants were compensated $40 for their two-hour long participation.

4.2.2 Materials and Apparatus

4.2.2.1 Driving Simulator

Unlike Study One, the traffic flow in Study Two resembled the traffic flow at the intersection of HW 52 and CSAH 9. This change increased the real-world validity of the study and addressed one potential limitation of Study One.

4.2.2.2 Displays

The displays used to present the In-Vehicle CICAS-SSA interfaces were Samsung i9000 Galaxy S cell-phones using an Android platform (see Figure 15). The phones measured 122 mm in length, 64 mm in width and 10 mm in depth with diagonal screen size of 4 inches. The resolution of the displays was 480 x 800 pixels.

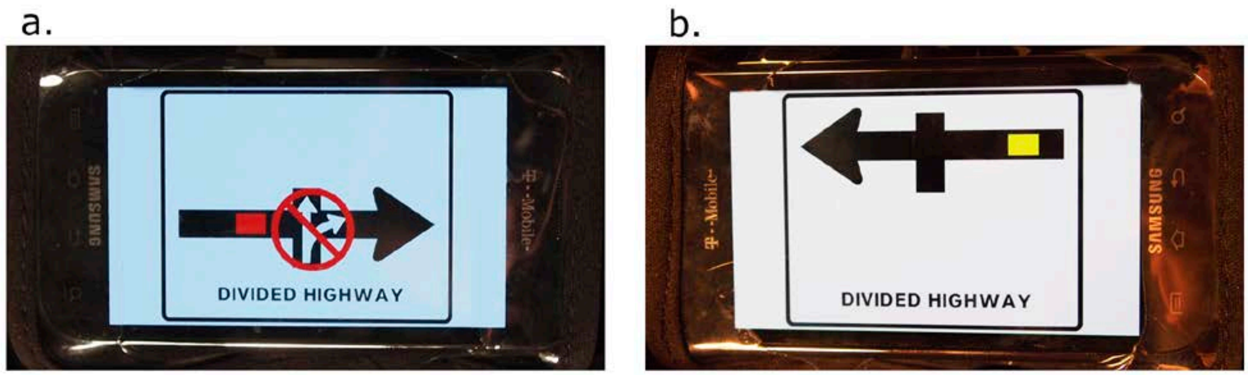


Figure 15. Displays on which the In-Vehicle CICAS-SSA sign was presented. This figure shows the Divided CICAS-SSA sign as presented on the left (Figure a) and the right (Figure b) A pillars.

4.2.2.3 CICAS-SSA Sign Conditions

The three different versions of the In-Vehicle CICAS-SSA sign (Complete, Divided, Prohibitive) were presented on displays mounted on the left and right A pillars of the simulator vehicle. The fourth condition included a Roadside CICAS-SSA, which was presented within the environment, at the intersection.

4.2.2.3.1 Complete CICAS-SSA

This version of the In-Vehicle CICAS-SSA interface represented the direct transition from the Roadside CICAS-SSA. The left and the right displays function like the CICAS-SSA display at the intersection of HW 52 and CSAH 9, that is, the images they display depend on the current gap size of the vehicles on the major road. Including the original CICAS design allowed us to compare driving performance between an identical CICAS-SSA sign located on a roadside and the one located inside a vehicle.

Like the original CICAS-SSA, the Complete CICAS-SSA sign used icons to illustrate the presence of a vehicle on the major road. Figures 16a and 16b show an unsafe crossing gap state of the Complete CICAS-SSA, as presented on the left and right display, respectively.

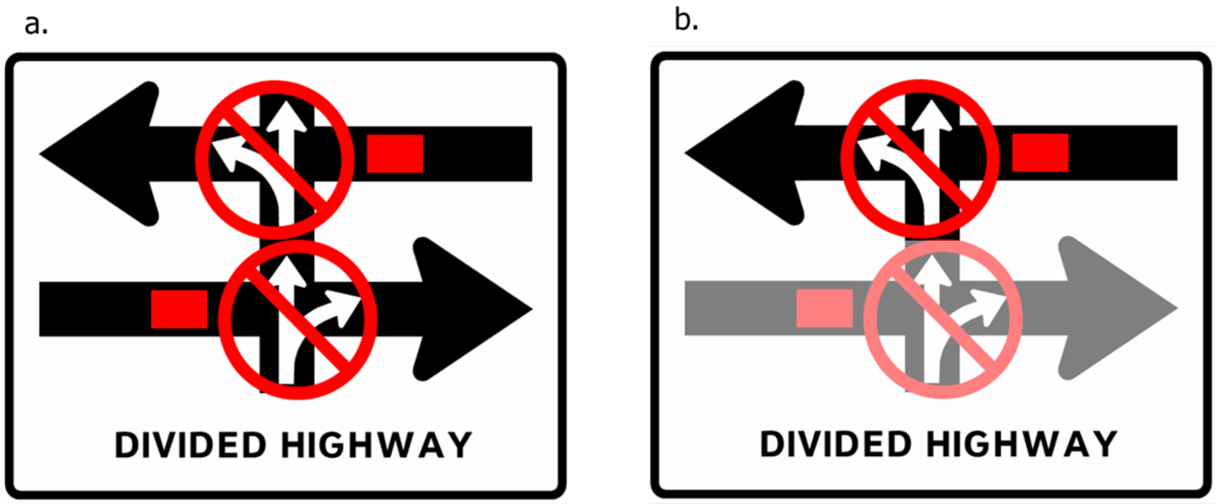


Figure 16. The Complete CICAS-SSA sign showing an unsafe crossing gap as depicted in the left (a) and right (b) display.

The near lanes in the Complete CICAS-SSA represented the cross traffic traveling to the right, while the far lanes represented the cross traffic traveling to the left, relative to the driver. The rectangular shaped icons were either yellow or red. The yellow icon signified a presence of a vehicle on the major road and that the driver should exercise caution when making a decision to cross. The red icon signified that a vehicle on the major road is too close to the intersection and crossing would not be safe. The complete display states of the Complete CICAS-SSA are presented in Tables 5 and 6.

Table 5. All display states of the Complete CICAS-SSA sign as presented on the left display. The red icon in the far lanes could be placed either closer or farther away from the intersection, both of which signified a cross-traffic vehicle located too close to the intersection.

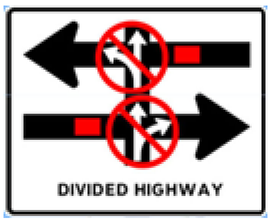
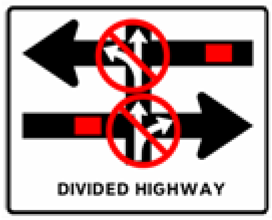
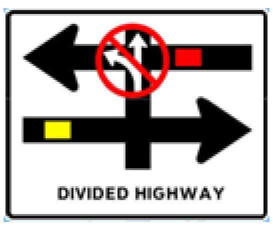
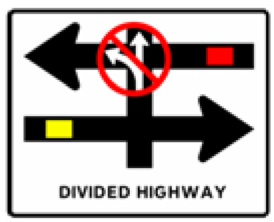
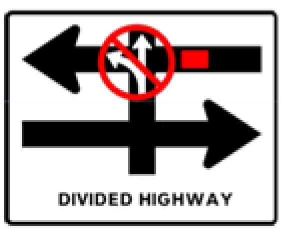
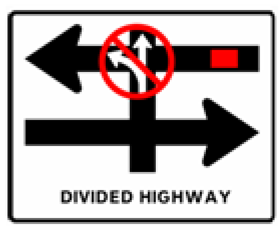
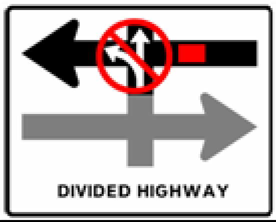
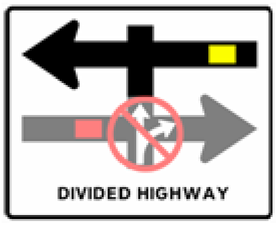
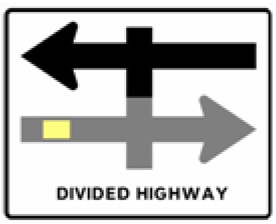
CICAS states Left Display	Message Meaning
 	Do not enter the intersection; a vehicle is detected too close to the intersection travelling to the right (time-to-contact is less than 7.5 seconds).
 	A vehicle is detected approaching the intersection, travelling to the right (time-to-contact is between 11 and 7.5 seconds). Drivers may be able to cross, but should proceed with caution.
 	No vehicles are detected approaching the intersection traveling to the right. If a vehicle, travelling to the right is present on the major road, it is more than 11 seconds away. You may be able to cross, but should proceed with caution.

Table 6. All display states of the Complete CICAS-SSA sign as presented on the right display. The grayed out portion of the sign was dynamically updated, thus presenting the state of traffic of the crossed lanes.

CICAS states Right Display	Message Meaning
	Do not enter the intersection; a vehicle is detected too close to the intersection travelling to the left (time-to-contact is less than 7.5 seconds).
	A vehicle is detected approaching the intersection, travelling to the left (time-to-contact is between 11 and 7.5 seconds). Drivers may be able to cross, but should proceed with caution.
	No vehicles are detected approaching the intersection travelling to the left. If a vehicle, travelling to the left is present on the major road, it is more than 11 seconds away. You may be able to cross, but should proceed with caution.

4.2.2.3.2. Divided CICAS-SSA

One of the goals of Study Two was to reduce the instances of single-stage maneuvers when crossing the intersection of HW 52 and CSAH 9. In a one-stage maneuver, drivers cross the intersection in a single crossing, without making a stop in the median. Consequently, in two-stage maneuvers, drivers make a stop at the median before crossing the second lanes of traffic. It is possible that presenting a driver with the information about both near and far lanes of traffic at the stop sign could do very little to dissuade a single-stage maneuver. This potential weakness of the Complete CICAS-SSA interface was addressed in the Divided version of the In-Vehicle CICAS-SSA.

Since the one-stage maneuvers are the predominant type associated with crashes at HW 52 and CSAH 9 intersection, the Divided CICAS-SSA sign was designed to reduce the rate of one-stage maneuvers. The Divided version of the sign split the upper and lower portions of the Complete CICAS-SSA sign and presented them separately on the left and right display. Figure 17 depicts an unsafe crossing gap state of the Divided CICAS-SSA, as presented on the left and right display.

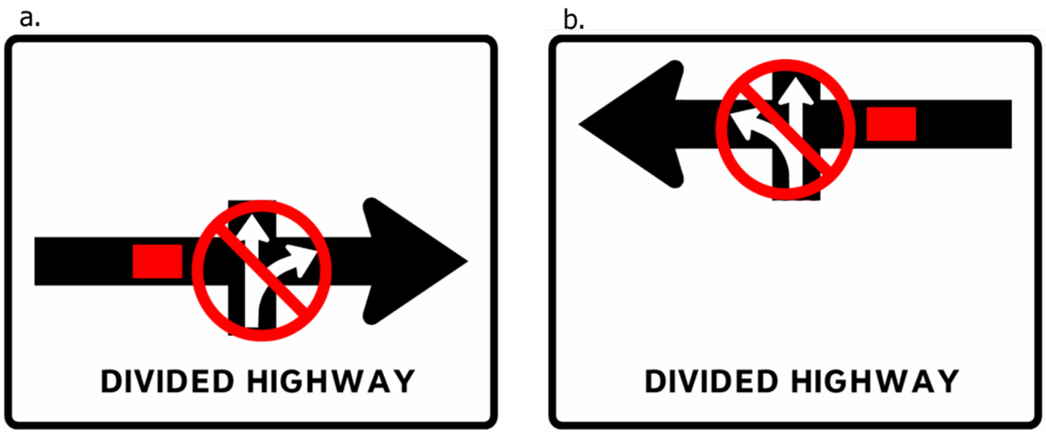


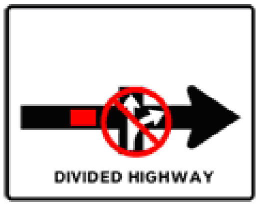
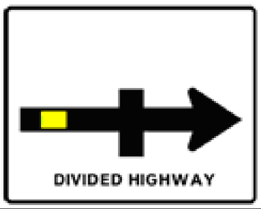
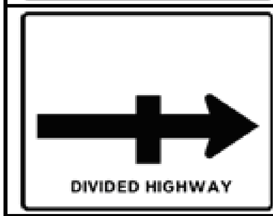
Figure 17. The Divided CICAS-SSA sign showing an unsafe crossing gap as depicted in the left (a) and right (b) display.

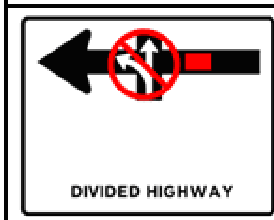
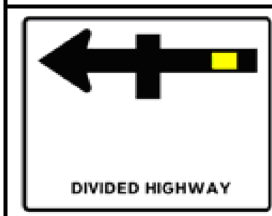
When a driver was located at the stop sign and turned to the left to examine traffic coming from that direction, the left display presented information about gap sizes only for the traffic coming from the left. At that time, the driver did not have access to the information about gap sizes for the vehicles in the far lanes (i.e., traffic coming from the right), thus discouraging the driver to plan a one-stage maneuver. When the driver reached the median and turned to the right to examine traffic coming from that direction, the right display presented information about gap sizes of vehicles coming from the right. In the Divided CICAS-SSA interface, participants were presented with information about gap sizes only for the lanes of traffic they was about to cross, not for the upcoming lanes. The complete set of display states of the Divided In-Vehicle CICAS-SSA are presented in Table 7.

4.2.2.3.2 Prohibitive CICAS-SSA

Although highly intuitive and easy to interpret, it is possible that the interpretation of the original CICAS-SSA sign was not instantaneous. The ease and speed of comprehension are important factors for any assist system and it may be possible to improve the speed of comprehension of the In-Vehicle CICAS-SSA. Speed of processing does not only impact in-vehicle assist systems, it is just as an important factor for a Roadside system (i.e., CICAS-SSA). Complete and Divided versions of the In-Vehicle CICAS-SSA sign inform the driver not only when a vehicle on the major road is too close to the intersection, but also when the system does not detect approaching vehicles. It could be argued that the only information of high priority relates to the presence of vehicles on the major road that are too close to the intersection. Presenting the driver with fewer pieces of information may reduce the information processing time, resulting in faster decision making about intersection crossing. To address the issue of processing time, Study Two examined the efficacy of a Prohibitive CICAS-SSA sign. This version of the sign presents only the "unsafe crossing gap condition" (see Figure 18), separately for the two directions of traffic. The "do not cross/turn" images are elements of the other two In-Vehicle CICAS-SSA interfaces and since they are acknowledged icons in transportation, they provide driver with familiarity.

Table 7. All display states of the Divided CICAS-SSA sign as presented on the left (top panel) and the right (bottom panel) display.

CICAS states Left Display	Message Meaning
	Do not enter the intersection; a vehicle is detected too close to the intersection travelling to the right (time-to-contact is less than 7.5 seconds).
	A vehicle is detected approaching the intersection, travelling to the right (time-to-contact is between 11 and 7.5 seconds). Drivers may be able to cross, but should proceed with caution.
	No vehicles are detected approaching the intersection travelling to the right. If a vehicle, travelling to the right is present on the major road, it is more than 11 seconds away. You may be able to cross, but should proceed with caution.

CICAS states Right Display	Message Meaning
	Do not enter the intersection; a vehicle is detected too close to the intersection travelling to the left (time-to-contact is less than 7.5 seconds).
	A vehicle is detected approaching the intersection, travelling to the left (time-to-contact is between 11 and 7.5 seconds). Drivers may be able to cross, but should proceed with caution.
	No vehicles are detected approaching the intersection travelling to the left. If a vehicle, travelling to the left is present on the major road, it is more than 11 seconds away. You may be able to cross, but should proceed with caution.

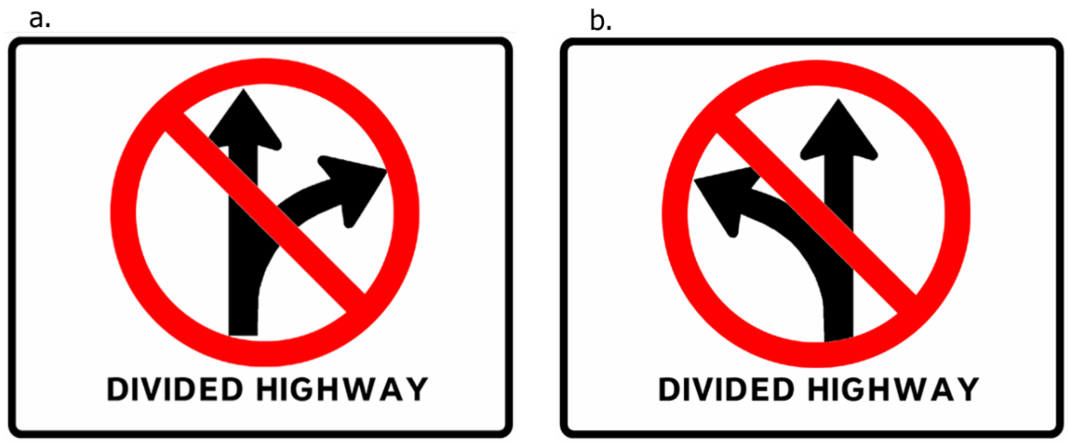


Figure 18. The Prohibitive CICAS-SSA sign showing an unsafe crossing gap as depicted on the left (a) and right (b) display.

The Prohibitive version of the In-Vehicle CICAS-SSA informs the driver about an unsafe crossing gap, but also whether the particular display is active or not. When a driver is located at the stop sign, the left display becomes active. If the CICAS-SSA system does not detect any vehicles travelling from the left that are too close to the intersection, the left display presented a blank, white image. The white image indicated the activation, but also distinguished it from the inactive state of the display, which is denoted by a black display. The complete set of display states of the Divided CICAS-SSA are presented in Tables 8 and 9.

Table 8. All display states of the Prohibitive CICAS-SSA sign as presented on the left display.

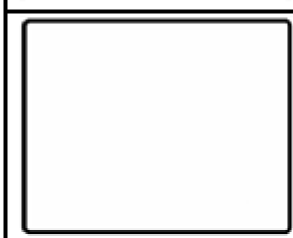
CICAS states Left Display	Message Meaning
	Do not enter the intersection; a vehicle is detected too close to the intersection travelling to the right (time-to-contact is less than 7.5 seconds).
	No vehicles are detected travelling to the right that are too close to the intersection (time-to-contact is greater than 7.5 seconds). You may be able to cross, but should proceed with caution.

Table 9. All display states of the Prohibitive CICAS-SSA sign as presented on the right display.

CICAS states Right Display	Message Meaning
	Do not enter the intersection; a vehicle is detected too close to the intersection travelling to the left (time-to-contact is less than 7.5 seconds).
	No vehicles are detected travelling to the left that are too close to the intersection (time-to-contact is greater than 7.5 seconds). You may be able to cross, but should proceed with caution.

While this simplified version of In-Vehicle CICAS-SSA may result in faster comprehension, it is also possible that drivers may prefer to have access to additional information regarding the gap sizes, as provided by the previously discussed three versions of the In-Vehicle CICAS-SSA.

4.2.2.3.3 Roadside CICAS-SSA

The Roadside version of the CICAS-SSA was identical to the CICAS-SSA sign used in our previous simulator study (Rakauskas et al., 2009), in that it was located within the simulated environment at the intersection of HW 52 and CSAH 9. The location of the CICAS-SSA displays is also shown in Figure 2. As noted earlier, the states of the Roadside CICAS-SSA were identical to the Complete version of the In-Vehicle CICAS-SSA. The location of the CICAS sign (In-Vehicle vs. Roadside) was the only difference between the Complete and the Roadside condition. The inclusion of the Roadside condition allowed us to examine the impact of the location of the intersection crossing assist Sign On driving performance.

4.2.2.4 Questionnaires

The driving history questionnaire (Appendix A) was administered at the beginning of the study. At the end of the study, participants completed system trust questionnaire (Appending B) and usability questionnaire (Appendix C) that were designed to assess the degree to which the CICAS-SSA helped them navigate the intersection. These questionnaires inquired about participant's preferences and ease of use, satisfaction and understanding of all versions of the CICAS-SSA as well as any potential confusion relating to the design and the use of the sign.

4.2.3 Procedure

After they were administered the consent form and driving history questionnaire, participants completed a block of practice trials in which they acclimated to the dynamics of the simulator vehicle, as well as learned how to approach the intersection in such a manner to allow the best view of the cross traffic. Following the practice drive, participants proceeded with the driving portion of the study. Driving performance was examined through a trial-based driving task in which participants were asked to approach the intersection, stop at the stop sign and then cross the intersection in a safe and timely manner. Each trial ended after the participant crossed the intersection.

Table 10 represents experimental conditions that the participants completed in Study Two. Each participant was randomly assigned to one of the four CICAS-SSA conditions. Each of the three In-Vehicle CICAS-SSA conditions (i.e., Complete, Divided, Prohibitive) consisted of 24 participants (12 Younger, 12 Older), while the Roadside condition consisted of only Younger drivers. All the participants were provided with detailed explanation about the purpose of the CICAS-SSA system. Participants were shown each of the possible states of the CICAS condition to which they were assigned and received comprehensive explanation about each state before the start of the study. These instructions mimicked the instructions participants received in the Full Instruction condition in Study One.

Table 10. Experimental conditions the participants completed in Study Two.

		Age	
		Older	**Younger**
CICAS Conditions	**Complete**	No Sign, good vis.	No Sign, good vis.
		No Sign, low vis.	No Sign, low vis.
		With Sign, good vis.	With Sign, good vis.
		With Sign, low vis.	With Sign, low vis.
	Divided	No Sign, good vis.	No Sign, good vis.
		No Sign, low vis.	No Sign, low vis.
		With Sign, good vis.	With Sign, good vis.
		With Sign, low vis.	With Sign, low vis.
	Prohibitive	No Sign, good vis.	No Sign, good vis.
		No Sign, low vis.	No Sign, low vis.
		With Sign, good vis.	With Sign, good vis.
		With Sign, low vis.	With Sign, low vis.
	Roadside	No Sign, good vis.	No Sign, good vis.
		No Sign, low vis.	No Sign, low vis.
		With Sign, good vis.	With Sign, good vis.
		With Sign, low vis.	With Sign, low vis.

Each participant completed 16 trials. Half of the trials were Control trials in which they were not exposed to the CICAS-SSA system while the rest of the trials were Treatment trails in which participants completed the intersection crossing with the assist of one of the versions of the CICAS-SSA system. Furthermore, half of the Control and Treatment trials were completed under Good Visibility condition (i.e., clear daytime) while the other half of the trials were completed under a Limited Visibility condition (i.e., fog).

4.3 EXPERIMENTAL DESIGN

4.3.1 Independent Variables

The independent variable that examined the impact of the CICAS-SSA Sign On intersection crossing performance was *Sign State*, consisting of Control (Sign Off) and Treatment (Sign On) conditions. Drivers' use of the CICAS-SSA may differ under conditions of Good and Limited Visibility. The independent variable of *Visibility* assessed the impact of visibility conditions on driver's use of the sign. The *Visibility* factor consisted of Good and Limited Visibility conditions. The effectiveness of the sign was examined across different *Age* groups, exploring whether Age-related differences exist with the use of the In-Vehicle CICAS-SSA. The independent variable that examined the efficacy of different versions of the Sign On intersection crossing behavior depended on the analyses conducted. When comparing the effectiveness of different designs of an In-Vehicle CICAS-SSA, the independent variable that examined those differences was CICAS-SSA *design* factor, consisting of Complete, Divided, and Prohibitive versions of the In-Vehicle CICAS-SSA sign. When conducting analyses that examined the impact of the location of the CICAS-SSA sign, the analyses included the Location of the sign factor, consisting of Roadside and In-Vehicle conditions. The In-Vehicle condition as part of the analyses exploring the impact of Location was identical to the Complete design of an In-Vehicle CICAS-SSA.

4.3.2 Dependent Variables

Like in Study One, the data in Study Two was collected within two measurement constructs. The Usability measures were identical to the ones collected in Study One. The Driving Performance measures were identical to those in the first study with the only difference being the gap of the critical threshold. The CICAS-SSA sign in Study One contained a transient state, a flashing yellow icon, which reduced the critical gap. Since none of the versions of the CICAS-SSA sign in Study Two contain such transient state, the critical gap was moved back to 7.5 seconds. This critical gap is the same gap used in our previous studies (Rakauskas et al., 2009; Creaser et al., 2008) as well as the current on-road project.

4.4 RESULTS

Like in Study One, the results section of Study Two is separated into two sections. First, we examine and present the analyses of driving performance measures. Driving performance measures were examined separately for the southbound (i.e., stop sign as the starting position) and the northbound (i.e., median as the starting position) lanes. Second, we examine and present the analyses of usability and trust measures.

Study Two featured two separate models of analysis. When examining the impact of different designs of the In-Vehicle CICAS-SSA sign, driving performance measures were submitted to a 2 x 3 x 2 x 2 mixed model ANOVA with Age (Older, Younger) and design of the In-Vehicle CICAS-SSA (Complete, Divided, Prohibitive) as between-subject measures and Sign State (Off, On) and Visibility (Good, Limited) as within-subject measures. Unless noted otherwise, these analyses were conducted on data set of 72 participants, 24 in each level of the design factor, evenly split between Older and Younger participants.

When examining the impact of the location of the CICAS-SSA sign, driving performance measures were analyzed in a 2 x 2 x 2 mixed model ANOVA with Location of the CICAS-SSA sign (Roadside, In-Vehicle) as a between-subject measure and Sign State (Sign On, Sign Off) and Visibility (Good, Limited) as within-subject measures. Unless noted otherwise, these analyses were conducted on data set of 24 participants, all Younger, half in each level of the Location factor. As described in the Methods section, the In-Vehicle level of the Location factor is the same as the Complete level of the design factor. When presenting the Location comparison results, any mention of an In-Vehicle CICAS-SSA design refers only to the Complete design of the In-Vehicle CICAS-SSA sign.

4.4.1 Driving Performance

4.4.1.1 In-Vehicle Comparison

Each participant completed 16 intersection crossing trials, four in each condition (see Table 10). Depending on the measure examined, participants' driving performance within a condition was either averaged across trials or combined when probabilities were calculated. Due to a technical issue with the data collection software, intersection traffic data was missing for three participants for a single trial (2 Older participants, one in the Complete and another in the Divided design group; 1 Younger participant in the Prohibitive design group). As a result, the data across three trials were averaged for these two participants.

4.4.1.1.1 Adjusted Time-to-Contact

Southbound. The Adjusted time-to-contact (TTC) measure was submitted to a 4-way mixed model ANOVA, showing a significant main effect of Visibility ($F(1,66) = 56.06$, $p < .001$). Drivers accepted smaller gaps when crossing the intersection under Limited Visibility conditions (6.36 seconds) compared to when crossing under Good Visibility (6.99 seconds). This analysis also showed a significant interaction between Sign State and Visibility ($F(1,66) = 8.09$, $p = .006$). As portrayed in Figure 19, under Limited Visibility conditions, drivers accepted smaller gaps when the CICAS-SSA sign was turned off compared to Sign On condition ($F(1,66) = 6.98$, $p = .01$; $M = 6.16$ and 6.56 seconds for Sign Off and Sign On conditions, respectively). However, under Good Visibility conditions, adjusted TTC did not depend on the state of the CICAS-SSA sign ($p > .27$).

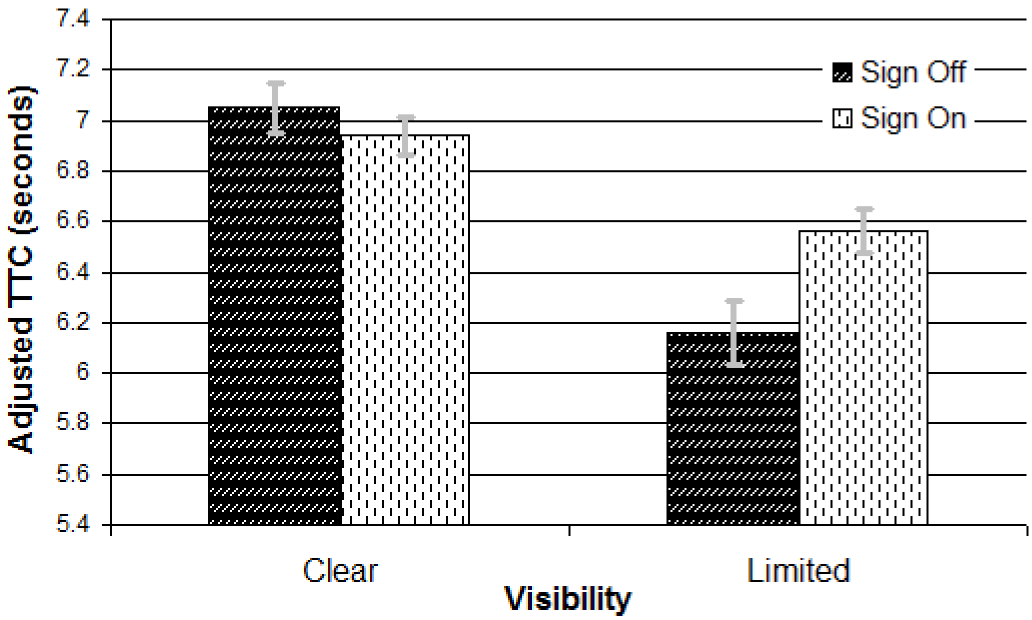


Figure 19. Adjusted time-to-contact when crossing the southbound lanes, as a function of Visibility and Sign State with standard error bars.

Northbound. Adjusted TTC measure was submitted to a 4-way mixed model ANOVA, revealing several significant interactions, as well as significant main effects. As exhibited in the main effect of Visibility ($F(1,66) = 56.03$, $p < .001$), drivers crossing the northbound lanes of traffic accepted smaller gaps under low Visibility conditions (6.47 seconds) compared to crossing the same lanes under Good Visibility (7.04 seconds). Drivers also accepted smaller gaps when an In-Vehicle CICAS-SSA sign was turned off, compared to the Sign On condition, as shown in the significant main effect of Sign State ($F(1,66) = 10.67$, $p = .002$; $M = 6.66$ and 6.86 seconds for Sign Off and Sign On conditions, respectively). This same analysis also showed a significant effect of design ($F(2,66) = 3.41$, $p = .039$). Adjusted TTC was greatest for drivers in the Complete design group (6.86 seconds), followed by drivers in the Divided design group (6.81) and finally those drivers in the Prohibitive design of the sign (6.6 seconds). The pairwise comparisons revealed significant difference between the Complete and Prohibitive conditions ($p = .016$), while the adjusted TTC was comparable between Complete and Divided designs ($p > .62$) and approached significance between Divided and Prohibitive groups ($p = .051$).

The impact of the CICAS-SSA sign when crossing the northbound traffic depended on the variety of factors. One of those factors was the Age of the drivers, as exhibited in the significant Age x Sign State interaction ($F(1,66) = 7.05$, $p = .01$). As depicted in Figure 20, Younger drivers accepted smaller gaps when the sign was turned off compared to the Sign On condition ($F(1,33) = 23.69$, $p < .001$; $M = 6.54$ and 6.89 seconds for Sign Off and Sign On conditions, respectively). The state of the sign did not have an impact on the intersection crossing performance of Older drivers ($p > .7$).

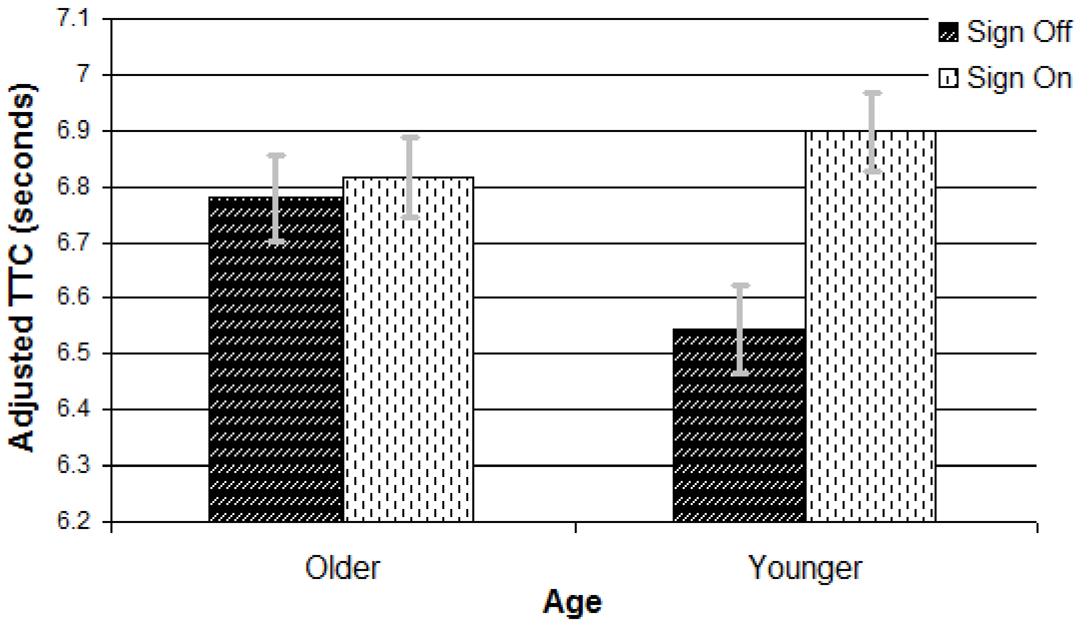


Figure 20. Adjusted time-to-contact when crossing the northbound lanes, as a function of Age and Sign State with standard error bars.

The 4-way ANOVA also revealed a significant interaction between Sign State and design of the sign factor ($F(2,66) = 6.02$, $p = .004$). As shown in Figure 21, participants in the Complete design group accepted greater gaps when the sign was turned on, compared to the Control, Sign Off condition ($F(1,23) = 6.16$, $p = .021$; M = 6.73 and 7 seconds for Sign Off and Sign On conditions, respectively). The state of the sign did not impact intersection crossing performance of the participants in the Divided design group ($p > .33$), however driving performance of the participants in the Prohibitive design group was similar to those in the Complete group. That is, participants in the Prohibitive group also accepted greater gaps when the sign was turned on, compared to the Control, Sign Off condition ($F(1,23) = 10.62$, $p = .003$; M = 6.4 and 6.81 seconds for Sign Off and Sign On conditions, respectively). Complete and Prohibitive designs of the In-Vehicle CICAS-SSA have shown be effective compared to the Control condition, however, the Prohibitive design overall was less effective than the Complete design of the sign.

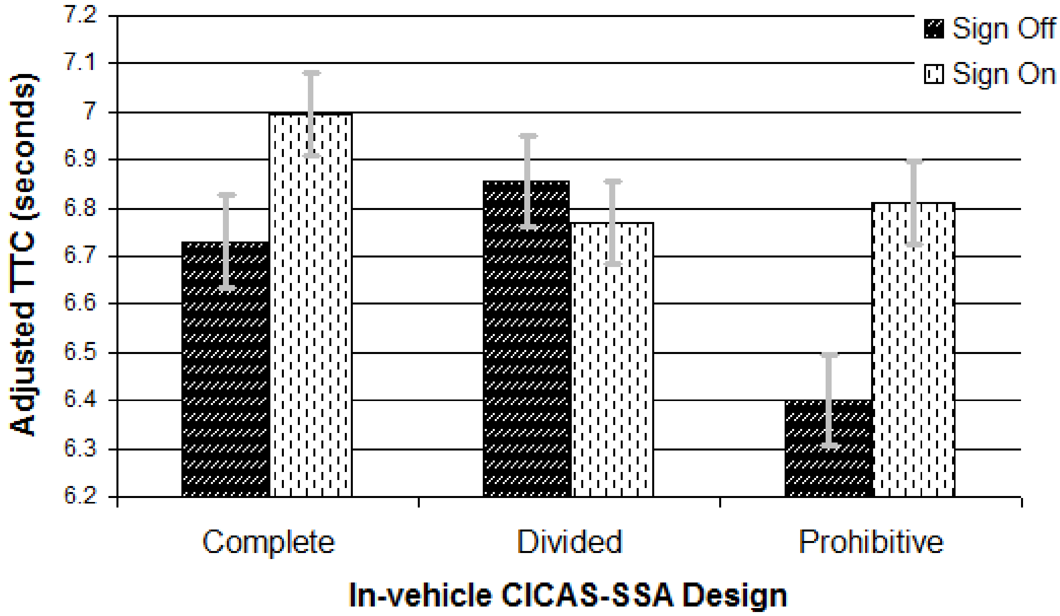


Figure 21. Adjusted time-to-contact when crossing the northbound lanes, as a function of design of and Sign State with standard error bars.

The 4-way mixed model ANOVA performed on the adjusted TTC measure for crossing of the northbound lanes also revealed a significant interaction between Sign State and Visibility conditions ($F(1,66) = 7.99$, $p = .006$). As depicted in Figure 22, the state of the sign did not impact intersection crossing performance under Good Visibility conditions ($p > .47$), however

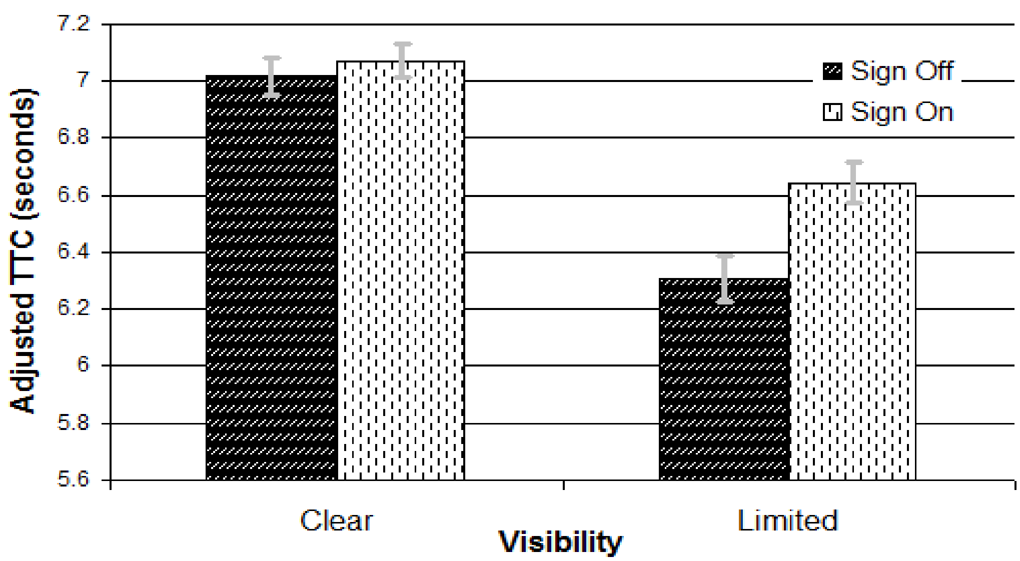


Figure 22. Adjusted time-to-contact when crossing the northbound lanes, as a function of Visibility and Sign State with standard error bars.

when Visibility was Limited drivers accepted greater gaps when the sign was turned on, compared to the Control, Sign Off condition ($F(1,71) = 11.94$, $p = .001$; M = 6.3 and 6.64 seconds for Sign Off and Sign On conditions, respectively).

Our analysis also revealed a significant 3-way interaction between Sign State, design of the sign, and Visibility conditions ($F(2,66) = 7.04$, $p = .002$). As illustrated in Figure 23, the Sign x design interaction was significant when Visibility was Limited ($F(2,69) = 8.89$, $p < .001$), but not under Good Visibility conditions ($p > .17$).

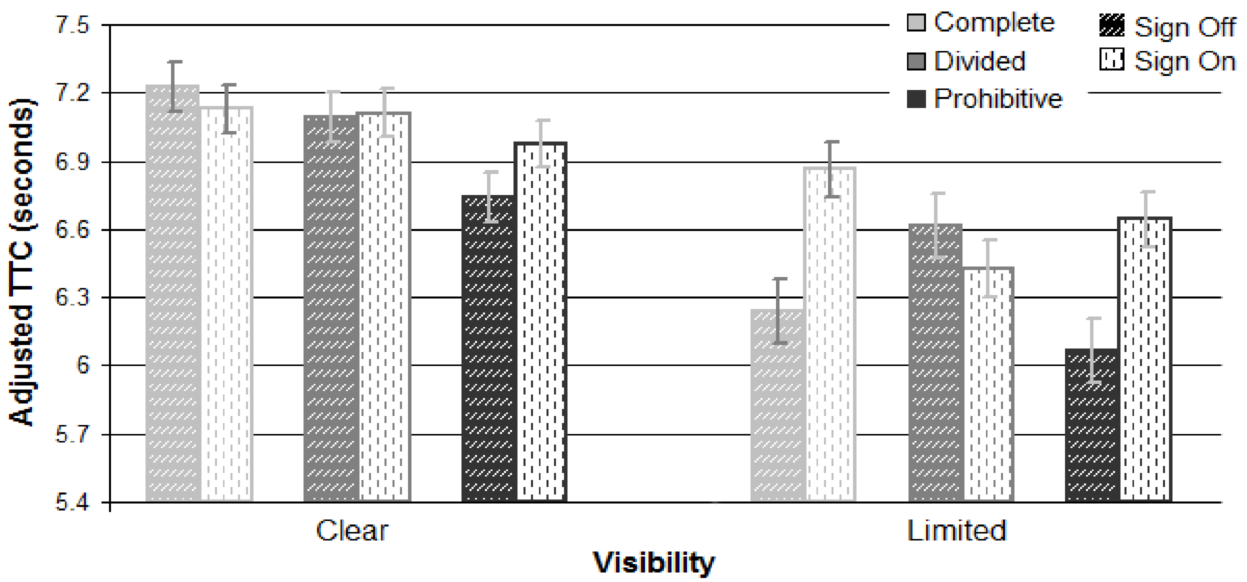


Figure 23. Adjusted time-to-contact when crossing the northbound lanes, as a function of Visibility, design of In-Vehicle CICAS-SSA and Sign State with standard error bars.

When Visibility was Limited, contrary to the drivers in the Divided design group, drivers in the Complete and Prohibitive design groups accepted greater gaps when the sign was turned on compared to the Control, Sign Off condition. The impact of the sign was similar for each of the three design groups in the Good Visibility conditions.

4.4.1.1.2 Wait Time

Southbound. The mixed model ANOVA analysis completed on wait measure revealed significant effect of Visibility ($F(1,65) = 4.58$, $p = .036$). Drivers waited longer to cross the southbound lanes under Good Visibility conditions (17.5 seconds) compared to the Limited Visibility conditions (14.7 seconds). This analysis also showed a significant effect of Sign State ($F(1,65) = 11.28$, $p = .001$). When an In-Vehicle version of the CICAS-SSA sign was turned on, drivers waited longer to cross the intersection, compared to the Control, Sign Off condition (M = 12.6 and 19.6 seconds, respectively). As expected, this analysis showed that Older drivers waited longer when crossing the southbound lanes (21.4 seconds) compared to their Younger counterparts (10.8 seconds), as exhibited in the significant effect of Age ($F(1,65) = 9.27$, $p = .003$). The analysis of wait time measure revealed a couple of significant interactions involving Sign State. One of those interactions involved the Age factor ($F(1,65) = 5.69$, $p = .02$). As depicted in Figure 24, although both Older and Younger drivers waited longer to cross the southbound lanes when the sign was on, the effect of the sign was less substantial for Younger drivers (F(1,35) = 5.94, p = .02; difference of 2 seconds), compared to their Older counterparts (F(1,34) = 7.86, p = .008; difference of 12 seconds).

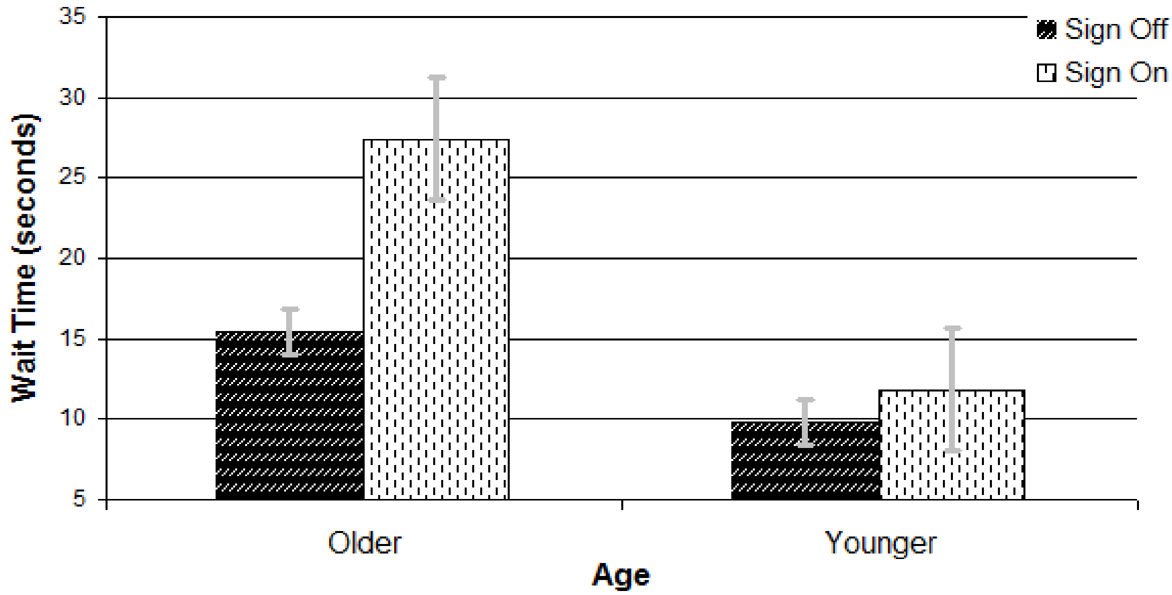


Figure 24. Wait time before crossing the southbound lanes, as a function of Age and Sign State with standard error bars.

Additionally, this analysis showed a significant interaction involving Sign State and Visibility conditions (F(1,65) = 11.39, p = .001). As illustrated in Figure 25, this interaction followed the similar pattern as Visibility x Sign State interaction for other measures, that is, the impact of the sign was greater under Limited Visibility condition. In the Low Visibility conditions, drivers waited longer to cross the southbound lanes when the sign was turned on, compared to the Control, Sign off condition (F(1,65) = 13.91, p < .001; M = 9.3 and 20.1 seconds, for Sign Off and Sign On conditions, respectively). The state of the sign did not have an impact on wait time in Good Visibility conditions (p > .07).

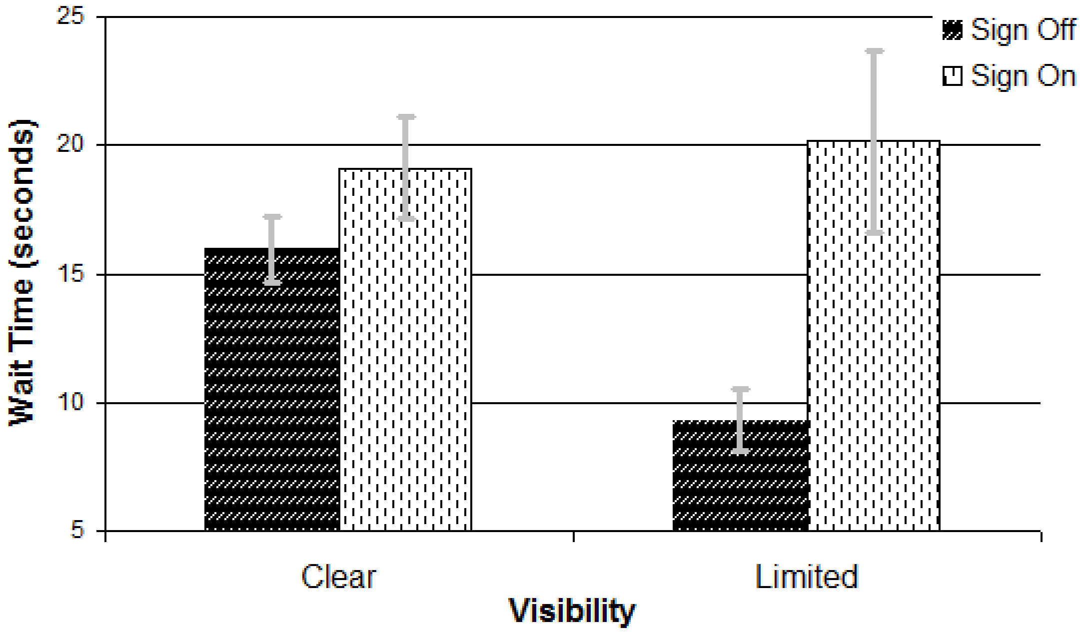


Figure 25. Wait time before crossing the southbound lanes, as a function of Visibility and Sign State with standard error bars.

Northbound. The wait time measure for crossing of the northbound lanes was also submitted to a 4-way mixed model ANOVA. This analysis revealed significant main effects of Sign State ($F(1,62) = 22.97$, $p < .001$), as well as Visibility conditions ($F(1,62) = 6$, $p = .017$). Participants waited longer to cross the northbound lanes when the CICAS-SSA sign was turned on, compared to the Sign Off condition (11.1 and 7.9 seconds for Sign On and Sign Off conditions, respectively). Also, participants waited longer to cross the northbound lanes under Good Visibility conditions (10.5 seconds) compared to times when Visibility was low due to fog (8.5 seconds). The impact of Sign State on wait time differed across Visibility conditions, as shown in the presence of significant Sign State x Visibility interaction ($F(1,62) = 11.7$, $p < .001$). As depicted in Figure 26, the state of the sign played a role in the wait time measure only when the Visibility was Limited. Under Low Visibility conditions, drivers waited longer to cross the northbound lanes when the sign was on, compared to Sign Off condition ($F(1,64) = 37.06$, $p < .001$, M = 11.5 and 5.6 seconds for Sign On and Sign Off conditions, respectively). The impact of the sign under Good Visibility conditions was not significant ($p > .7$).

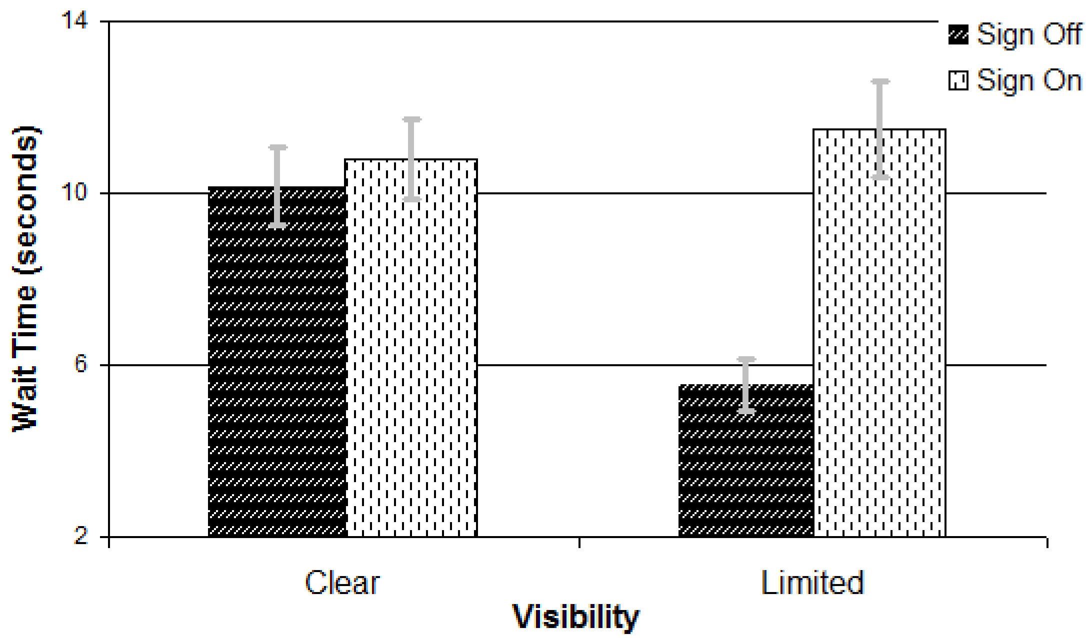


Figure 26. Wait time before crossing the northbound lanes, as a function of Visibility and Sign State with standard error bars.

4.4.1.1.3 Likelihood of Stopping

Southbound. The likelihood of stopping measure was submitted to a 4-way mixed model ANOVA, revealing a significant effect of Sign State ($F(1,66) = 5.53$, $p = .022$). Drivers were more likely to make a complete stop at the stop sign when the sign was turned on (.91 proportion of trials), compared to the Control, Sign Off condition (.87 proportion of trials). This analysis also showed Age-related effects ($F(1,66) = 4.31$, $p = .042$). Older drivers were more likely to make a complete stop at the stop sign than their Younger counterparts (.93 and .86 proportion of trials for Older and Younger drivers, respectively).

4.4.1.1.4 Movement Time

Southbound. The mixed-model ANOVA analysis of movement time across the southbound lanes revealed a significant main effect of Age ($F(1,66) = 12.71$, $p < .001$). Older drivers took longer to cross the southbound lanes (2.2 seconds) compared to their Younger counterparts (1.9 seconds).

4.4.1.1.5 Accepted Critical Gap

Southbound. The accepted critical gap measure submitted to a 4-way mixed model ANOVA revealed a significant main effect of Visibility ($F(1,66) = 41.16$, $p < .001$). When crossing the southbound lanes, drivers were more likely to accept a critical gap under Limited Visibility conditions (.118 weighted proportion of trials) compared to Good Visibility (.055 weighted proportion of trials). Furthermore, this analysis also showed a significant Sign State x Visibility interaction ($F(1,66) = 6.7$, $p = .012$). As illustrated in Figure 27, under Limited Visibility conditions, drivers were less likely to accept a critical gap when an In-Vehicle CICAS-SSA sign was turned on, compared to the Control, Sign Off condition ($F(1,66) = 6.12$, $p = .015$; M = .14

and .09 weighted proportion of trials for Sign Off and Sign On conditions, respectively). The impact of Sign State was not significant in the Good Visibility condition (p > .4).

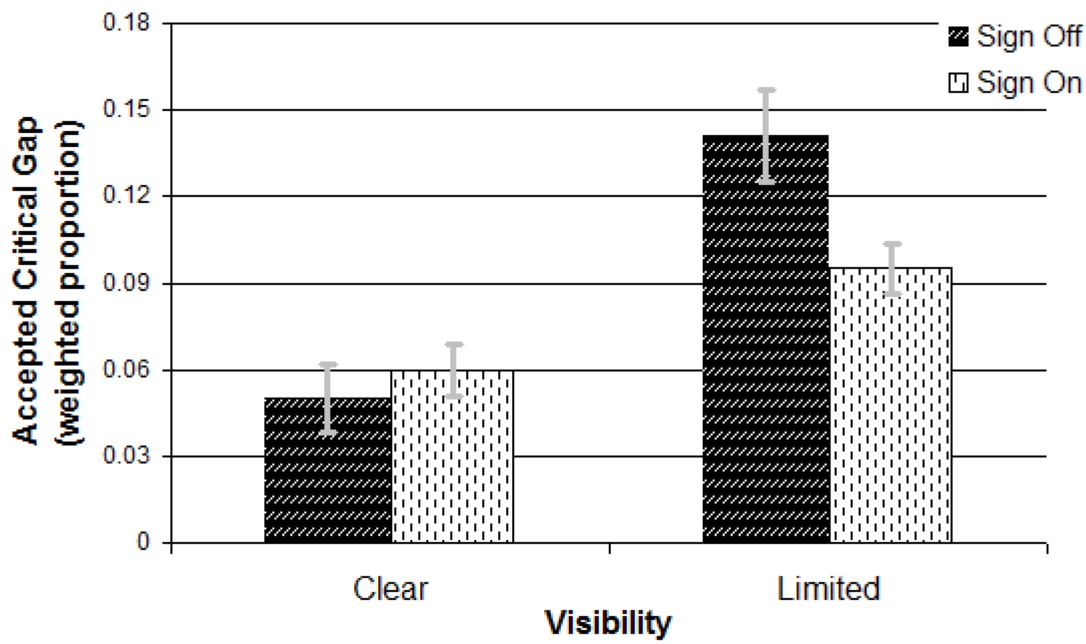


Figure 27. Proportion of critical gap acceptance when crossing the southbound lanes, as a function of Visibility and Sign State with standard error bars.

Northbound. The analysis of the critical gap measure for crossing of the northbound lanes revealed several significant main effects, as well as interactions involving Sign State. The 4-way mixed model ANOVA uncovered significant main effects of Sign State ($F(1,66) = 12.53$, $p = .001$) and Visibility conditions ($F(1,66) = 48.44$, $p < .001$). Drivers were less likely to accept a critical gap when crossing the northbound lanes when an In-Vehicle CICAS-SSA sign was turned on, compared to Sign Off condition (M = .08 and .06 weighted proportion of trials for Sign Off and Sign On conditions, respectively). Following the pattern found when crossing the southbound lanes, drivers were more likely to accept a critical gap under Limited Visibility conditions (.1 weighted proportion of trials), compared to Good Visibility conditions (.05 weighted proportion of trials). This analysis revealed another significant main effect, that of design of the sign ($F(2,66) = 3.65$, $p = .031$). Following the similar pattern as exhibited in the adjusted TTC measure, drivers in the Prohibitive design group were more likely to accept a critical gap (.089 weighted proportion of trials), compared to those drivers in the Divided design (.068 weighted proportion) and in the Complete design (.064 weighted proportion) groups. The pairwise comparison revealed significant difference between the Complete and the Prohibitive design of the sign groups ($p = .014$), as well as between the Divided and Prohibitive designs groups (.039). The accepted critical gap was comparable between the Complete and Divided design groups ($p > .6$).

The analysis of the critical accepted gap measure for crossing of the northbound lanes revealed several interactions involving the Sign State factor. State of the sign interacted with the Age factor, as shown in the significant Sign State x Age interaction ($F(1,66) = 9.09$, $p = .004$). As illustrated in Figure 28, Younger drivers were less likely to accept a critical gap when the sign was turned on, compared to the Control, Sign Off condition (F(1,33) = 25.55, p < .001; M = .057 and .095 weighted proportion for Sign On and Sign Off conditions, respectively). However, for the Older drivers, the accepted critical gap measure was not affected by the state of the sign (p > .7).

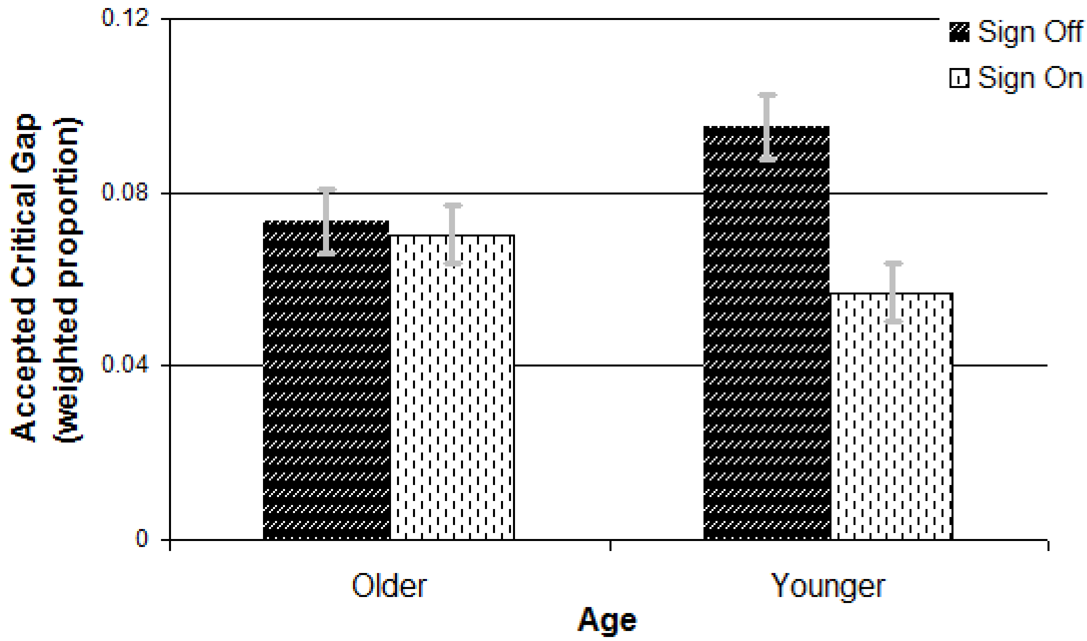


Figure 28. Proportion of critical gap acceptance when crossing the northbound lanes, as a function of Age and Sign State with standard error bars.

The Sign State factor also interacted with the design of the sign (F(2,66) = 6.15, p = .004). Figure 29 shows that drivers in the Complete design group were less likely to accept a critical gap when crossing the northbound lanes when the In-Vehicle CICAS-SSA was turned on compared to the Control, Sign Off condition (F(1,22) = 8.21, p = .009; M = .077 and .05 weighted proportion for Sign Off and Sign On conditions, respectively). The state of the sign did not impact the acceptance of critical gap for the participants in the Divided design group (p > .3) The acceptance of the critical gap, however was affected by the Sign State factor for the participants in the Prohibitive design group (F(1,22) = 10.7, p = .003). When presented with the Prohibitive design of the In-Vehicle CICAS-SSA, participants were less likely to accept a critical gap (.068 weighted proportion of trials), compared to the Control, Sign Off condition (.11 weighted proportion of trials).

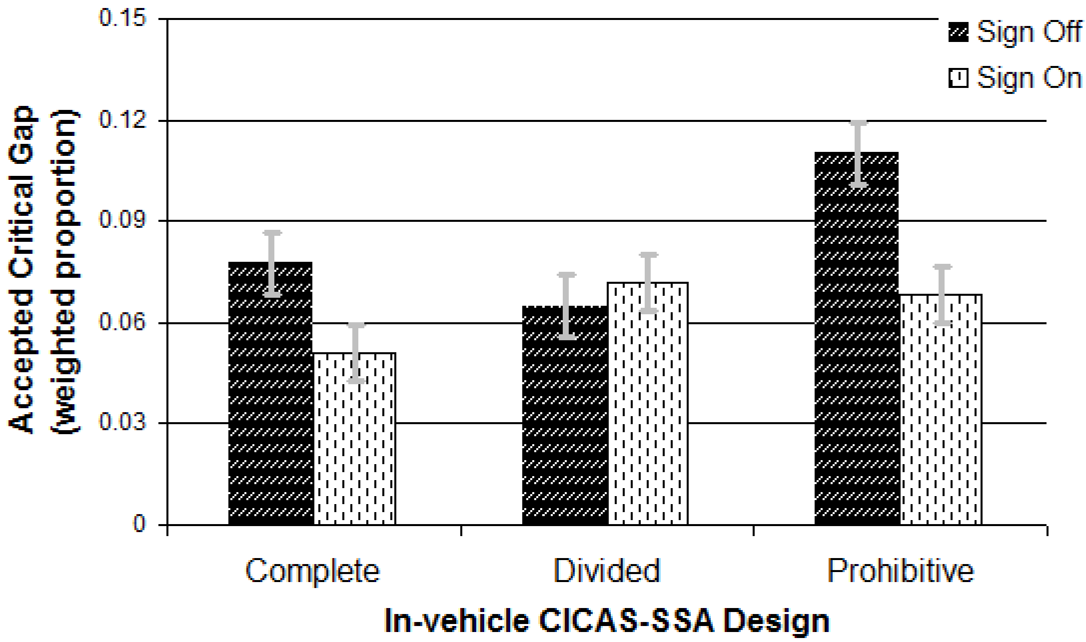


Figure 29. Proportion of critical gap acceptance when crossing the northbound lanes, as a function of design of an In-Vehicle CICAS-SSA and Sign State with standard error bars.

The same interaction that was reported in the analyses of earlier measures, the accepted critical gap measure also revealed a significant Sign State x Visibility interaction ($F(1,66) = 6.96$, $p = .01$). Following the same pattern found in the previously analyzed measures, under the conditions of Limited Visibility, drivers were less likely to accept a critical gap when an In-Vehicle CICAS-SSA sign was turned on (see Figure 30), compared to the Control, Sign Off condition ($F(1,66) = 16.33$, $p < .001$; $M = .083$ and $.118$ weighted proportion of trials for Sign On and Sign Off conditions, respectively). The impact Sign State under Good Visibility conditions was not significant ($p > .3$).

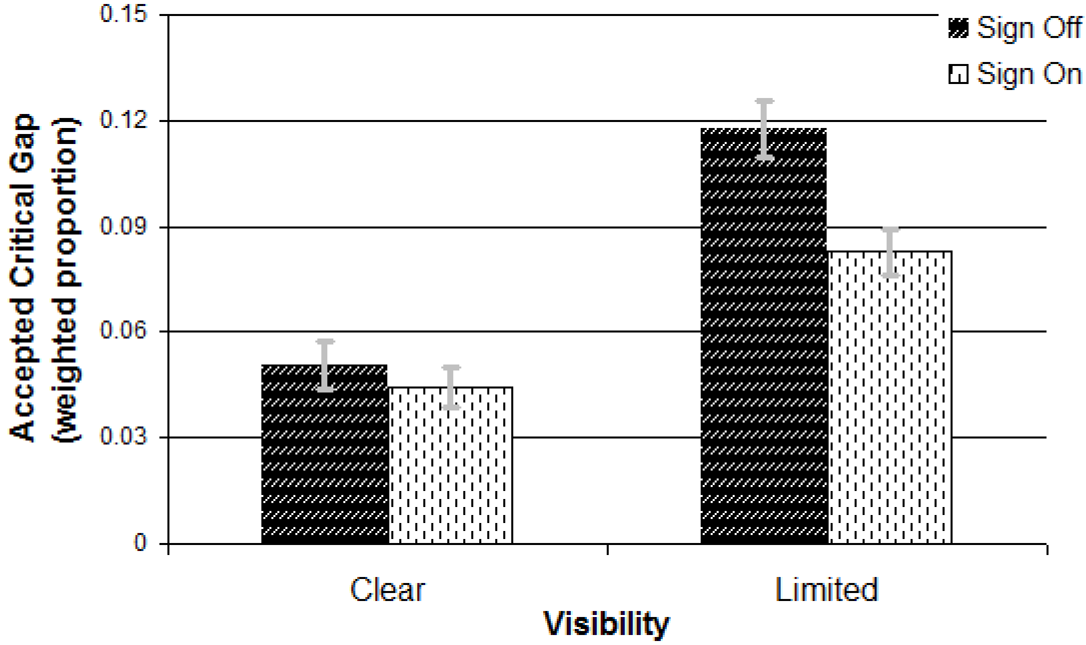


Figure 30. Proportion of critical gap acceptance when crossing the northbound lanes, as a function of Visibility and Sign State with standard error bars.

Finally, the 4-way mixed model ANOVA performed on the accepted critical gap for the northbound lanes revealed a significant three-way interaction between Sign State, Visibility and design of the sign ($F(2,66) = 5.7$, $p = .005$). As the graph in Figure 31 shows, Sign State x design interaction was significant under the conditions of Limited Visibility ($F(2,66) = 8.91$, $p < .001$), but not under Good Visibility conditions ($p > .19$). Drivers in the Complete and Prohibitive design groups were less likely to accept a critical gap when crossing the northbound lanes when the In-Vehicle CICAS-SSA sign was turned on, compared to the Control, Sign Off condition. The acceptance of a critical gap for drivers in the Divided design group did not depend on the state of the sign.

4.4.1.1.6 Rejected Non-Critical Gap

Southbound. The 4-way mixed model ANOVA performed on the rejected non-critical gap measure showed a significant main effect of Age ($F(1,65) = 8.14$, $p = .006$), exemplifying Older drivers' tendency toward a more conservative driving. As shown in Figure 32, out of all gaps that Older drivers rejected, 88% of them were critical gaps (gaps with TTC smaller than 7.5 seconds) and 12% were non-critical (gaps with TTC greater than 7.5 seconds). This distribution was somewhat different for Younger drivers for whom 92% of all rejected gaps were critical, while only 8% of gaps were non-critical. The larger proportion of the rejected non-critical gaps can be an indication of a more conservative driving; Older drivers waited for a gap that was greater than recommended by the system.

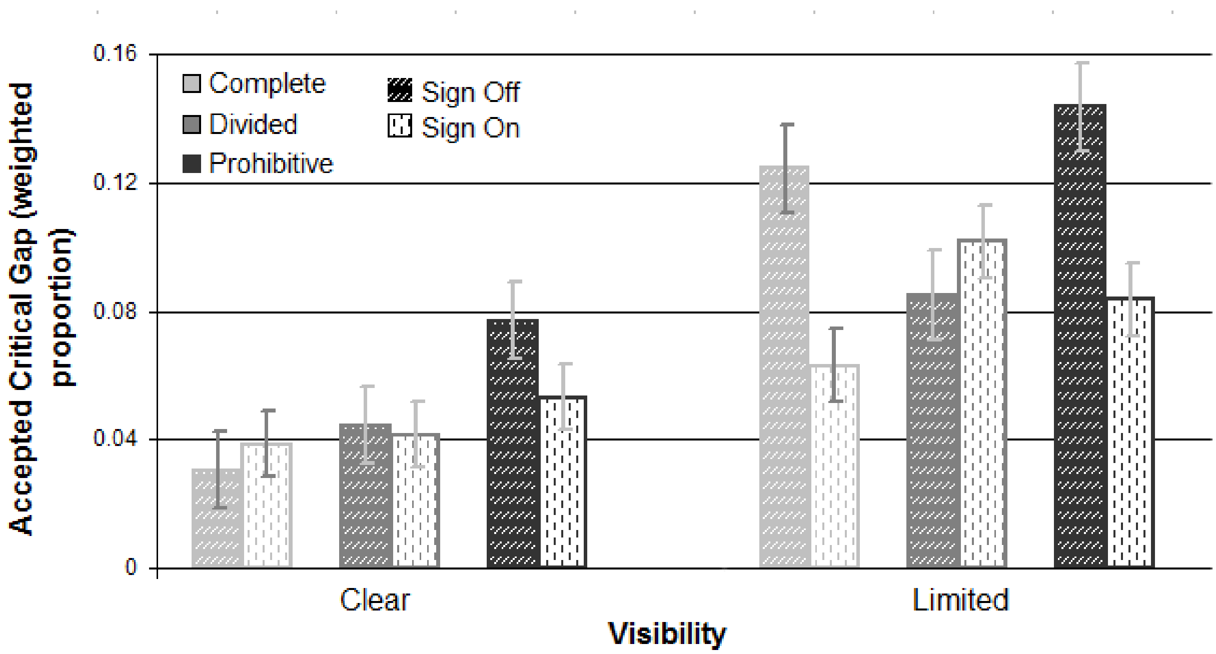


Figure 31. Proportion of critical gap acceptance when crossing the northbound lanes, as a function of Visibility, design of an In-Vehicle CICAS-SSA and Sign State with standard error bars.

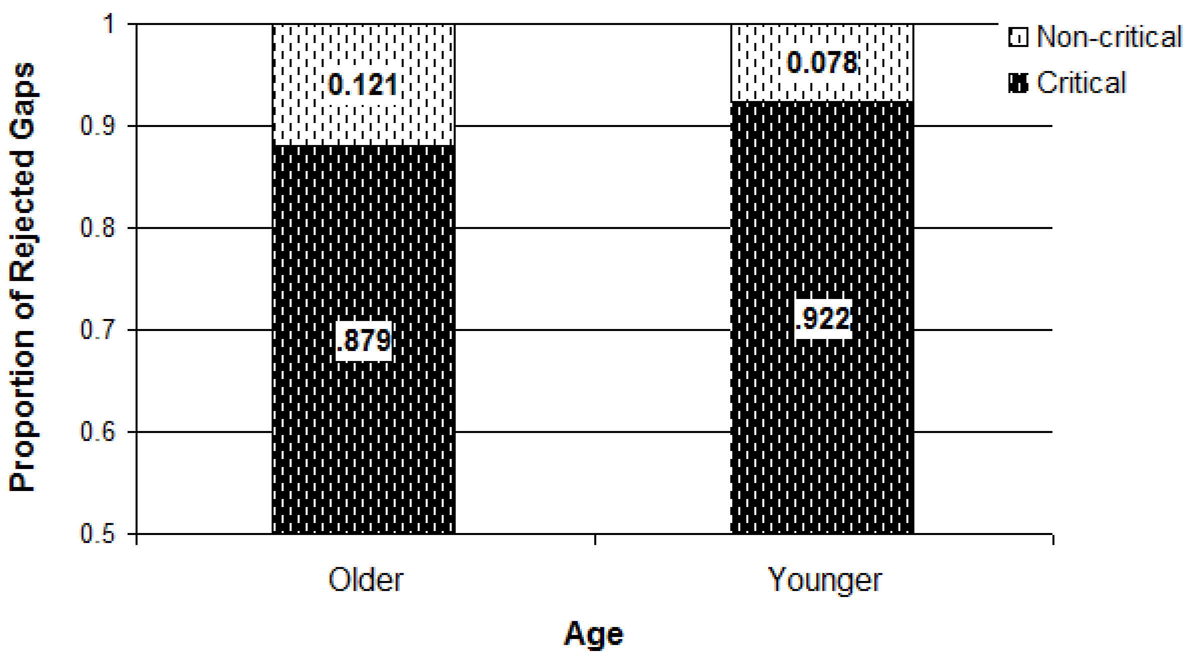


Figure 32. Proportion of rejected critical and non-critical gaps when crossing the southbound lanes, as a function of Age.

Northbound. The analysis of the rejected non-critical gaps when crossing the northbound lanes revealed a significant main effect of Visibility ($F(1,62) = 28.79$, $p < .001$). When driving in the Low Visibility conditions, 96 percent of all gaps that drivers rejected were critical gaps, compared to 91 percent when driving under Good Visibility conditions. As an indication of a more conservative driving, drivers were more likely to reject a non-critical gap (i.e., gap greater than 7.5 seconds) under clear Visibility conditions. The Limited Visibility conditions made it difficult for drivers to detect the cross traffic vehicle located more than 7.5 seconds from the intersection. This failure to detect a vehicle at a distance just beyond the critical gap could be the likely source of Visibility main effect. This analysis also revealed a significant main effect of design of the sign ($F(2,62) = 5.12$, $p = .009$). As illustrated in Figure 33, out of all gaps that participants in the Complete design group rejected, 93 percent of them were critical gaps (i.e., gaps smaller than 7.5 seconds), compared to 91 percent for the participants in the Divided group and 97 percent for the participants in the Prohibitive group. The pairwise analyses showed that the differences between participants in the Prohibitive and Complete groups ($p = .046$), as well a Prohibitive and Divided groups ($p = .002$) were significant. Again, participants in the Complete and Divided design groups exhibited a more conservative driving behavior.

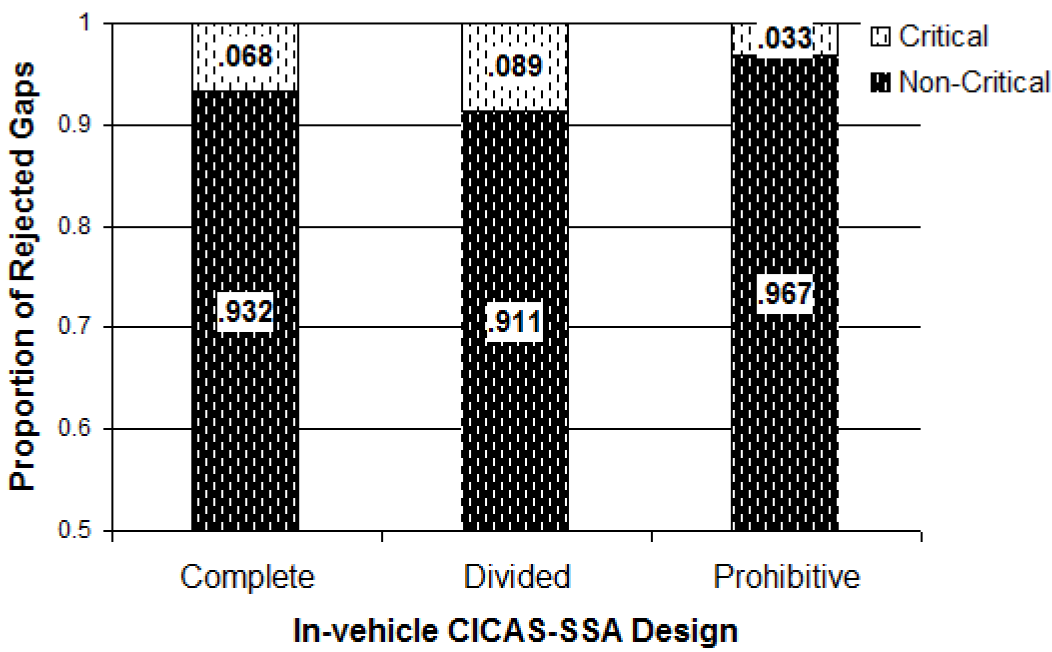


Figure 33. Proportion of rejected critical and non-critical gaps when crossing the northbound lanes, as a function of design of In-Vehicle CICAS-SSA.

4.4.1.1.7 80th Percentile Rejected Gap

Southbound. The 80th percentile rejected gap measure submitted to a 4-way mixed model ANOVA exhibited several significant main effects. As shown in the significant main effect of Visibility ($F(1,63) = 7.08$, $p = .01$), the gap that drivers rejected 80 percent of time was smaller when driving in conditions of Limited Visibility (gap of 5.3 seconds) compared to Good Visibility conditions (gap of 5.8 seconds). The state of the sign also had a marginal impact on the 80th percentile rejected gap measure, as expressed in the marginal main effect of Sign State ($F(1,63) = 3.99$, $p = .05$). The 80th percentile rejected gap was greater when the In-Vehicle CICAS-SSA sign was turned on, compared to the Control, Sign Off condition. The more conservative driving of Older adults was also expressed in this measure ($F(1,63) = 7.52$, $p = .008$), showing greater 80th percentile rejected gap for Older drivers (gap of 5.89 seconds), compared to their Younger counterparts (gap of 5.26 seconds). Significantly different 80th percentile rejected gap was also found between different designs of an In-Vehicle CICAS-SSA, as shown in the main effect of design ($F(2,63) = 6.39$, $p = .003$). The pairwise comparisons revealed a significant difference in the 80th percentile rejected gap between drivers in the Complete and Prohibitive design groups ($p = .001$; M = 6.04 & 5.05 80th percentile rejected gap for Complete and Prohibitive groups, respectively), as well as between drivers in the Divided and Prohibitive design groups ($p = .038$; M = 5.64 80th percentile rejected gap for the Divided group).

This analysis also showed a significant interaction between Sign State and Visibility conditions ($F(1,63) = 10.24$, $p = .002$). As shown in Figure 34, the impact of Sign State on the 80th percentile rejected gap was evident when Visibility was Limited ($F(1,63) = 15.98$, $p < .001$), but not when Visibility conditions were clear ($p > .3$). Under foggy conditions, the 80th percentile rejected gap was greater when the sign was turned on (gap of 5.76 seconds), compared to the Control, Sign Off condition (gap of 4.86 seconds).

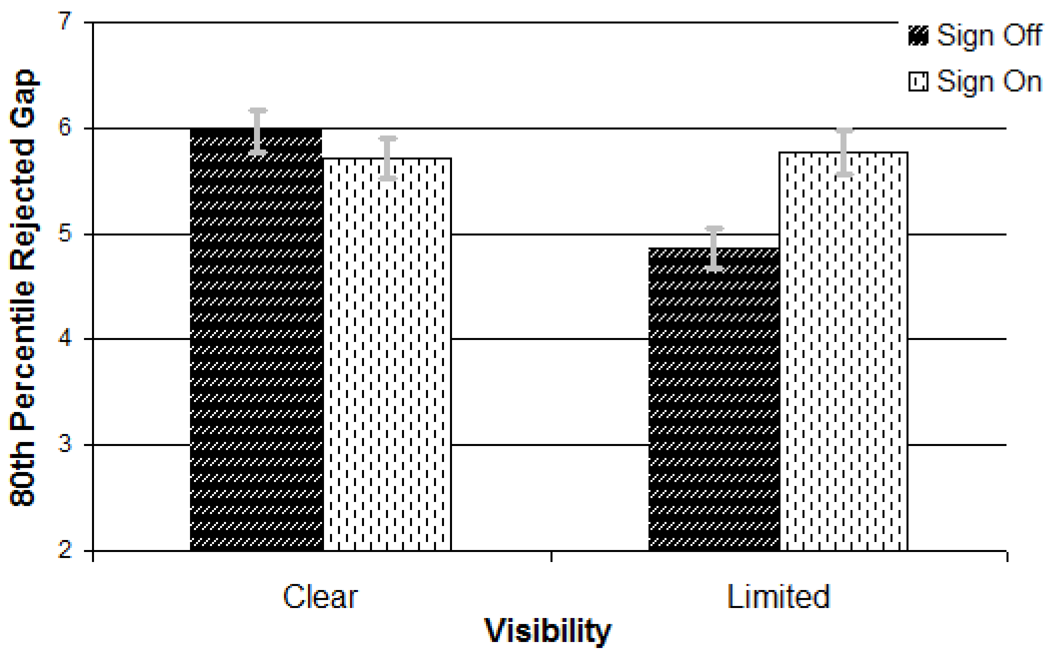


Figure 34. 80th percentile rejected gap when crossing the southbound lanes, as a function of Visibility and Sign State with standard error bars.

4.4.1.2 Location Comparison

These analyses featured a 3-way mixed model ANOVA with Sign State (Off, On) and Visibility (Good, Limited) as within-subject measures and the Location of the CICAS-SSA sign (In-Vehicle, Roadside) as the between-subject measure. Given the focus of this set of analyses on the location of the intersection crossing assist system, we reported only those findings that pertain to this factor.

4.4.1.2.1 Adjusted Time-to-Contact

Southbound. Adjusted TTC measure submitted to a 3-way mixed model ANOVA revealed a significant interaction between the Location and Visibility factors ($F(1,22) = 11.53$, $p = .003$). As depicted in Figure 35, under conditions of Good Visibility, the Location of the CICAS-SSA sign did not impact adjusted TTC measure ($p > .3$). Participants in the Roadside CICAS-SSA group accepted smaller gaps when crossing the southbound lanes under Limited Visibility conditions, compared to the participants in the In-Vehicle group ($F(1,22) = 10.03$, $p = .004$; M = 6.06 and 6.5 seconds for the Roadside and In-Vehicle groups, respectively). This finding suggests that the In-Vehicle version of the CICAS-SSA is less susceptible to the decline in driving performance under Limited Visibility conditions, compared to the Roadside version of the system.

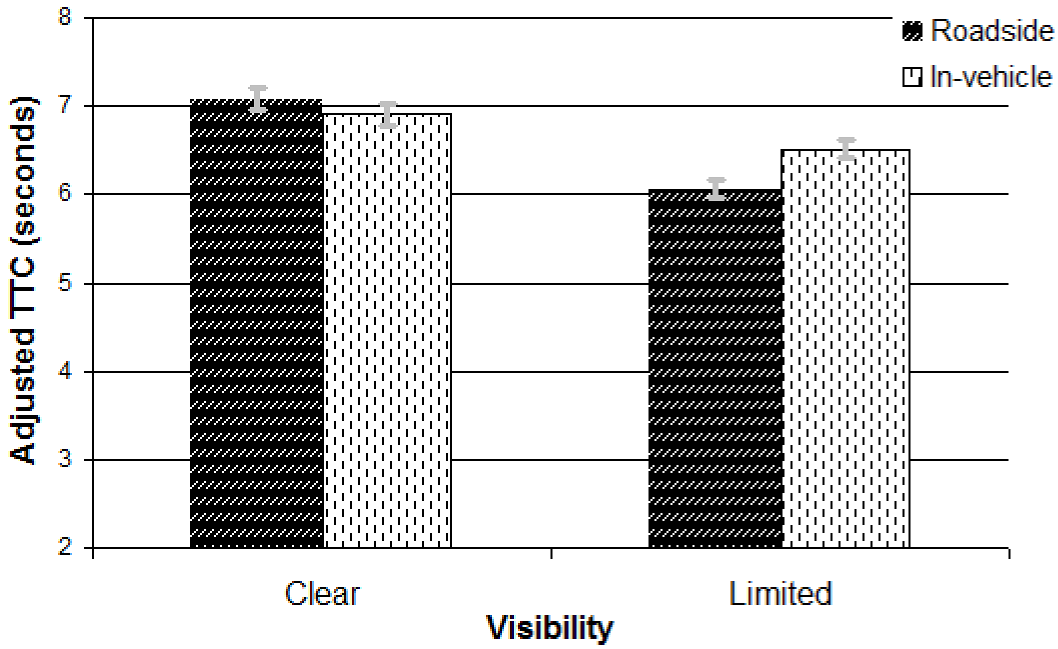


Figure 35. Adjusted time-to-contact when crossing the southbound lanes, as a function of Visibility and location of the CICAS-SSA with standard error bars.

The Visibility and Sign State interaction was significant for the adjusted TTC measure ($F(1,22) = 8.93$, $p = .007$), showing that drivers exhibited a better driving performance (i.e., accepting greater gaps) when presented with a CICAS-SSA sign, but only under Limited Visibility conditions. Because of the lack of the 3-way interaction, we can conclude that the manner in which the Visibility conditions and Sign State interacted was similar for both In-Vehicle and Roadside conditions.

Northbound. Like the finding for crossing of the southbound lanes, the analysis of adjusted TTC measure for crossing of the northbound lanes also showed a significant Visibility x Location interaction ($F(1,22) = 4.96$, $p = .036$). However, these two factors interacted in a different manner compared to their interaction for the crossing of the southbound lanes. As shown in Figure 36, participants in the Roadside CICAS-SSA group accepted smaller gaps under Good Visibility conditions compared to the participants in the In-Vehicle group ($F(1,22) = 8.48$, $p = .008$; M = 6.9 and 7.2 seconds for Roadside and In-Vehicle groups, respectively). When crossing the northbound lanes under Limited Visibility conditions, the Location of the CICSA-SSA sign did not impact adjusted TTC measure ($p > .4$).

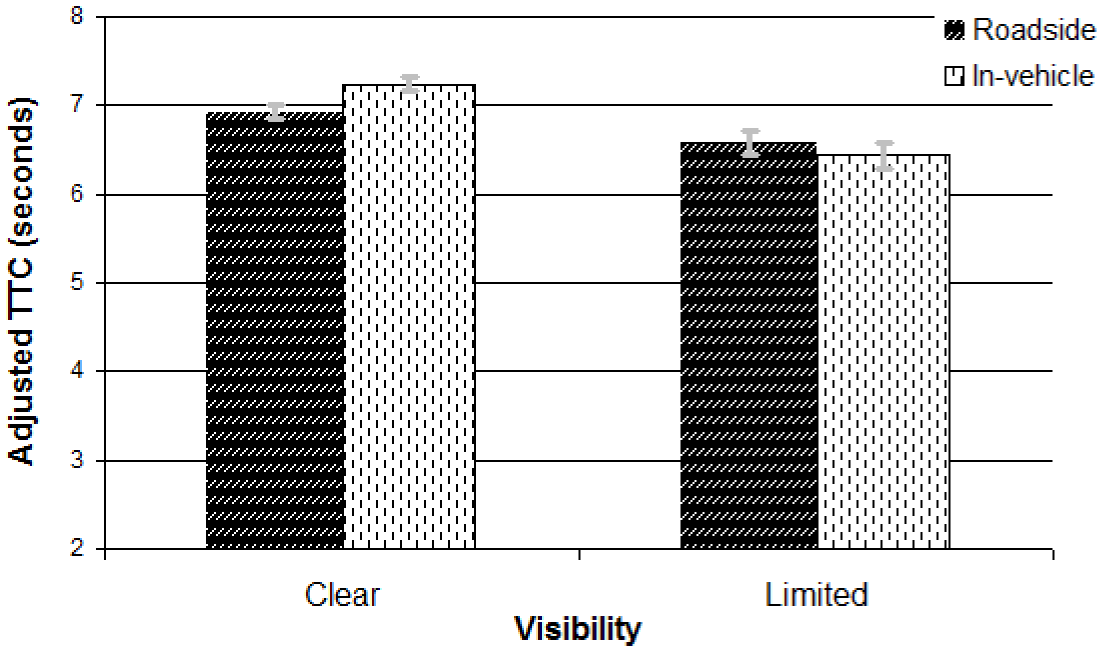


Figure 36. Adjusted time-to-contact when crossing the northbound lanes, as a function of Visibility and location of the CICAS-SSA with standard error bars.

Although an overall main effect of the Location of the CICAS-SSA sign was not present for crossing of either southbound or northbound lanes, and while the source of Visibility x Location interaction was not identical for the two sets of lanes, a common factor has emerged. Participants in the Roadside CICAS-SSA group accepted smaller gaps when crossing this rural intersection, albeit under varied Visibility condition.

4.4.1.2.2 Wait Time

Southbound and Northbound. The 3-way mixed model ANOVA performed on the wait time when crossing southbound or northbound lanes did not reveal any effects involving the Location of the sign factor. Other main effects and interactions were identical (with the same direction) to those found in comparison of In-Vehicle designs of the CICAS-SSA.

4.4.1.2.3 Likelihood of Stopping

Southbound. The 3-way mixed model ANOVA performed on the likelihood of stopping before crossing the southbound lanes revealed a significant effect of Location of the CICAS-SSA sign ($F(1,22) = 5.04$, $p = .035$). Participants in the In-Vehicle CICAS-SSA group were more likely to make a complete stop at the stop sign before crossing the southbound lanes of traffic (.9 and .77 proportion of trials for In-Vehicle and Roadside groups, respectively). Additionally, this analysis showed a significant 3-way interaction ($F(1,22) = 4.71$, $p = .041$). As depicted in Figure 37, Sign State and Visibility interaction was not significant for the participants in the In-Vehicle group ($p > .7$), while a marginally significant interaction was found for the Roadside-based sign ($F(1,11) = 5.08$, $p = .046$). For the participants in the In-Vehicle condition, the probability of making a Complete stop at the stop sign did not change regardless of the state of the CICAS-SSA sign or the Visibility conditions. However, as Figure 37 and the presence of the main effect of Location show, participants in the In-Vehicle group were overall, more likely to make a Complete stop at the stop sign.

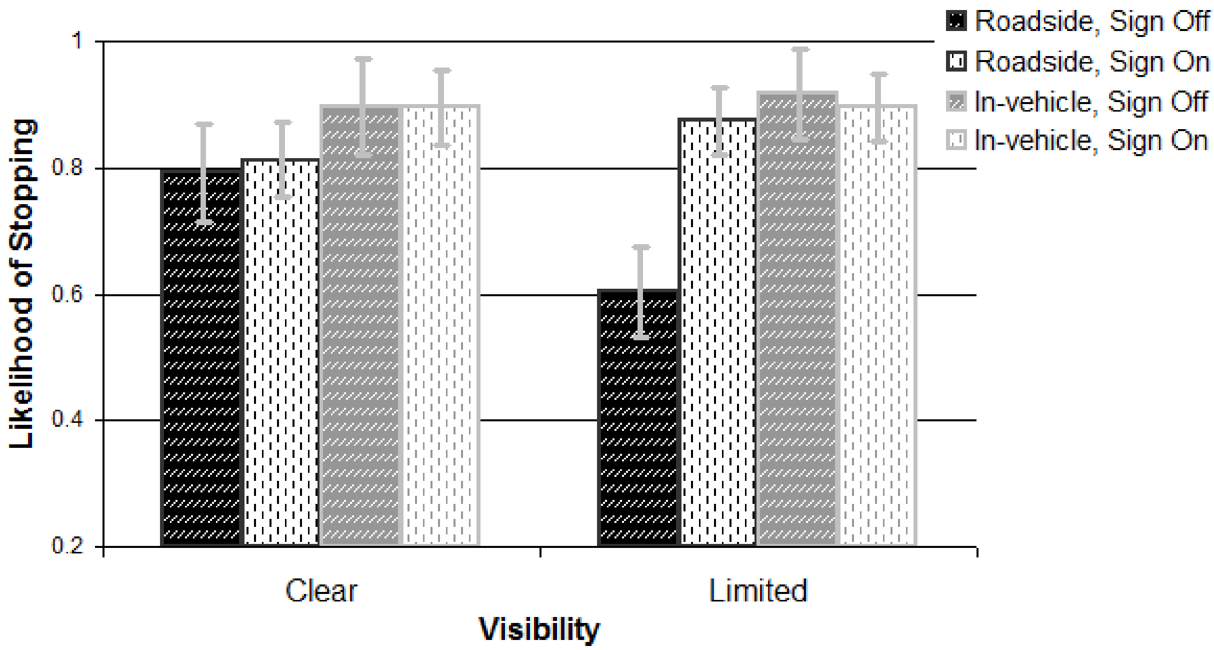


Figure 37. Proportion of complete stops when crossing the southbound lanes, as a function of Visibility, location of the CICAS-SSA and Sign State with standard error bars.

4.4.1.2.4 Movement Time

Southbound and Northbound. The 3-way mixed model ANOVA analysis of movement time did not reveal any significant effects involving the Location of the sign factor when crossing either the southbound or the northbound lanes.

4.4.1.2.5 Accepted Critical Gap

Southbound. Accepted critical gap measure that was submitted to a 3-way mixed model ANOVA revealed significant interaction between Visibility and Location of the sign factors ($F(1,22) = 11.97$, $p = .002$). As shown in Figure 38, the location of the CICAS-SSA sign did not impact the likelihood of accepting a critical gap in Good Visibility conditions ($p > .3$). However, when Visibility was limited participants in the Roadside CICAS-SSA group were more likely to accept a critical gap when crossing the southbound lanes compared to the participants in the In-Vehicle group ($F(1,22) = 7.35$, $p = .013$; M = .14 and .1 weighted proportion of trials for Roadside and In-Vehicle groups, respectively).

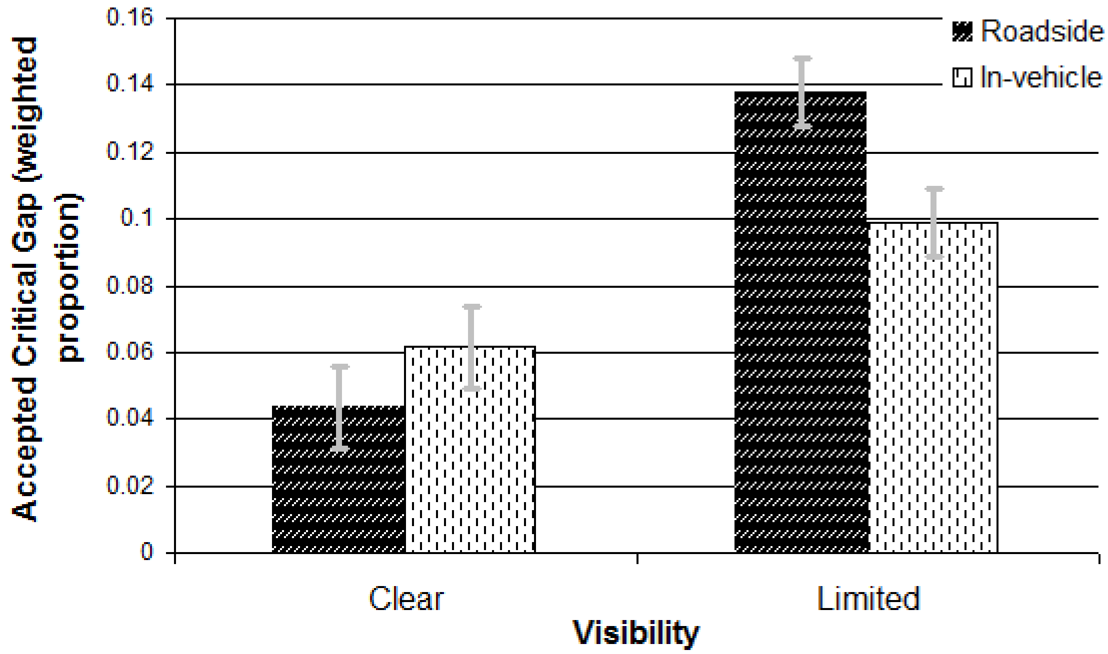


Figure 38. Proportion of critical gap acceptance when crossing the southbound lanes, as a function of Visibility and location of the CICAS-SSA with standard error bars.

Northbound. The analysis of accepted critical gap measure for crossing of the northbound lanes showed one marginal interaction involving the Location of the sign factor. The interaction between Visibility conditions and Location of the sign factor ($F(1,22) = 4.05$, $p = .057$) produced a somewhat different interaction pattern than the same interaction found for crossing of the southbound lanes. As Figure 39 depicts, the Location of the sign did not impact the likelihood of accepting a critical gap under Limited Visibility conditions ($p > .6$). When the Visibility was clear, participants in the In-Vehicle condition were less likely to accept a critical gap when crossing the southbound lanes compared to their counterparts in the Roadside condition ($F(1,22) = 8.19$, $p = .009$; $M = .03$ and .06 weighted proportion of trials for In-Vehicle and Roadside groups, respectively).

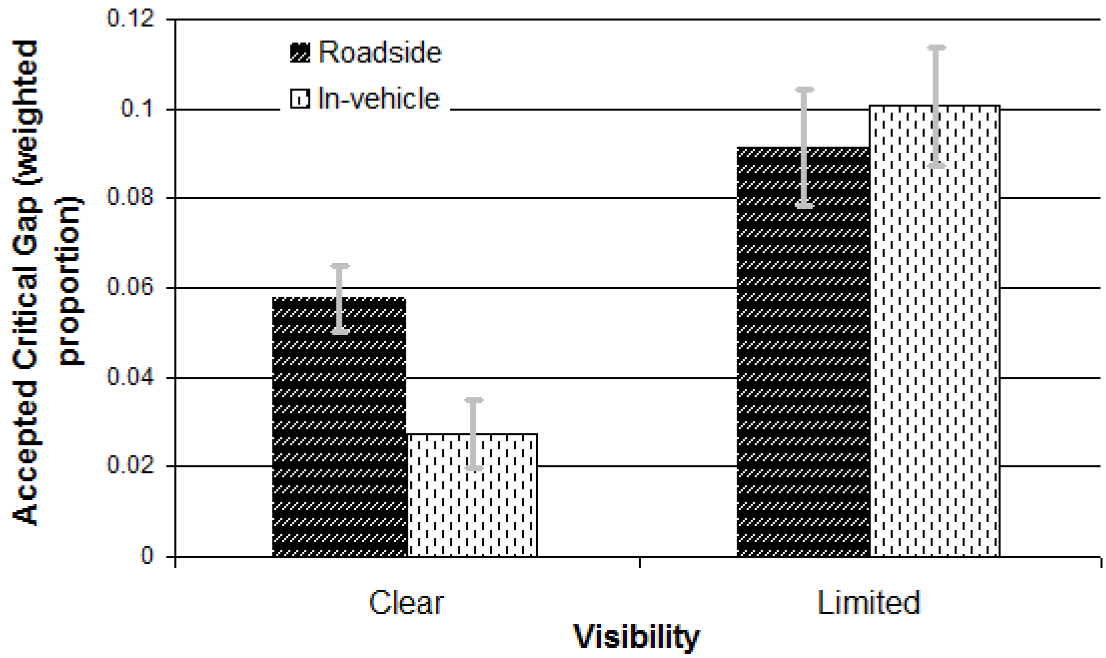


Figure 39. Proportion of critical gap acceptance when crossing the northbound lanes, as a function of Visibility and location of the CICAS-SSA with standard error bars.

The lack of Location and Sign State interaction suggests that the impact of the CICAS-SSA sign is similar between the In-Vehicle and Roadside conditions. However, the presence of Visibility x Location interactions, as well as the singular main effect of the Location factor suggest that an overall advantage of an in-vehicle based system may exist, to be found in both Control and Treatment conditions.

4.4.1.2.6 Rejected Non-Critical Gap

Southbound and Northbound. The 3-way mixed model ANOVA analysis of the rejected non-critical gap did not reveal any significant effects involving the Location of the sign factor when crossing either the southbound or northbound lanes.

4.4.1.2.7 80th Percentile Rejected Gap

Southbound and Northbound. The 3-way mixed model ANOVA analysis of the 80th percentile rejected gap did not reveal any significant effects involving the Location of the sign factor when crossing either the southbound or northbound lanes.

4.4.2 Usability Measures

The responses from both System Trust and Usability questionnaires were assigned values between 0 and 100. The value of 0 indicated that the participant strongly disagreed with a particular statement while the value of 100 indicated that the participant strongly agreed with a specific statement. The scores from the System Trust and Usability questionnaires were used to complete two sets of analyses; the in-vehicle comparison and the location comparison.

4.4.2.1 In-Vehicle Comparisons

The responses to each question in both System Trust and Usability questionnaires were submitted to a 2 x 2 between-subjects ANOVA with (Older, Younger) and design of the sign (Complete, divided, Prohibitive) as the factors.

4.4.2.1.1 System Trust Questionnaire

The specific questions/statements used in the System Trust questionnaire can be found in Appendix B. Table 11 displays the overall mean response for each question, averaged across Age and design of the sign, as well as any significant effects that were revealed by the analysis.

Questions relating to safety and reliability of the assist system (Questions 1,4,5 and 6) did not reveal any strong reactions on the part of the participants. Responses to Question 2 (i.e., "I am familiar with the operations of the system") revealed a significant main effect of Age $(1,66) = 8.07$, $p = .006$). Older participants were less likely to agree with that statement compared to Younger drivers ($M = 70$ and 91 for Older and Younger participants, respectively). As shown in Question 8, Older drivers also reported feeling less confident in their driving abilities when the assist system was not available, compared to Younger drivers ($F(1,65) = 5.88$, $p = .018$; $M = 80$ and 91 for Older and Younger drivers, respectively). None of the questions in the System Trust questionnaire revealed an effect of design of the sign.

Table 11. The average scores and significant effects for responses to questions in the system trust questionnaire.

Question	Overall Mean	Significant Effects *
1. The system enhanced my safety.	65.4	
2. I am familiar with the operations of the system.	80.5	Age (O < Y)
3. I trust the system.	73.3	
4. System is reliable.	78.1	
5. System is dependable.	77.2	
6. System has integrity.	75.6	
7. I am comfortable with the system's intent.	83.4	
8. I am confident in my driving without the system.	85.6	Age (O < Y)

* All denoted effects were significant at .05 level.

4.4.2.1.2 Usability Questionnaire

The specific questions/statements used in the Usability questionnaire can be found in Appendix C. Table 12 shows the overall mean response for each question (averaged across Age and design factors) and any significant effects that were found in the analyses.

While participants did not indicate a very strong preference (positive or negative) for the majority of questions, the responses to two questions assessing the ease of understanding of the sign (Questions 2 and 7) showed a strong reaction indicating that the In-Vehicle CICAS-SSA sign (all three designs) was easy to comprehend. The analysis of responses to questions from the Usability questionnaire revealed a significant main effect for only one question. As shown by the responses to Question 10, Younger drivers were more likely to indicate that their intersection crossing maneuver would have been the same without the use of the assist system ($F(1,66) = 8.07$, $p = .006$; $M = 67$ and 82 for Older and Younger drivers, respectively). The lack of age-related effects for response to questions that relate to the belief and trust in the system (Questions 4, 6 and) as well as the understanding of the system (Questions 2 and 7) indicate that the In-Vehicle design of the CICAS-SSA is equally understandable to both Older and Younger drivers.

Table 12. The average scores and significant effects for responses to questions in the usability questionnaire.

Question	Overall Mean	Significant Effects *
1. I felt confident using the sing.	70.8	
2. I felt it was confusing using the sign.	28.8	
3. The sign made me safer.	65.3	
4. I trusted the information provided by the sign.	73.9	
5. I like the sign.	65.6	
6. The sign was reliable.	76.7	
7. The sign was easy to understand.	81.9	
8. Sign's information was credible.	78.5	
9. Sign was useful.	71.8	
10. I would complete the maneuver the same way without the sign.	74.6	Age (O < Y)

* All denoted effects were significant at .007 level.

4.4.2.2 Location Comparisons

The responses to each question in both System Trust and Usability questionnaires were submitted to an ANOVA with the Location of the sign (Roadside, In-Vehicle) as the only factor.

4.4.2.2.1 System Trust and Usability questionnaires

Examining the differences in usability of Roadside and In-Vehicle based CICAS-SSA sign did not produce many significant effects. In fact, participants from the Roadside and In-Vehicle conditions responded differently to only one question from both System Trust and Usability questionnaires. When responding to Question 4 from the System Trust questionnaire, relating to the reliability of the system, participants from the In-Vehicle group were more likely to consider the system to be reliable compared to the participants in the Roadside CICAS-SSA group ($F(1,22) = 5.98$, $p = .023$; $M = 74$ and 89 for Roadside and In-Vehicle groups, respectively). Given the lack of any additional differences we would suggest that from the usability perspective, the In-Vehicle and Roadside-based CICAS-SSA signs both afford high levels of understanding and trust.

4.5 DISCUSSION

The primary goal of Study Two was to determine the optimal design of an In-Vehicle CICAS-SSA and assess its impact on the drivers' rural intersection crossing performance. This was accomplished through comparison of three different designs of the In-Vehicle CICAS-SSA, varying in degree of their complexity. The findings are discussed in terms of the impact of each of the In-Vehicle designs on driving performance, between-design comparisons, and the implications for the Field Study.

Study Two also had two secondary goals. One of them assessed the impact of an In-Vehicle CICAS-SSA sign under various Visibility conditions. This was accomplished by manipulating the Visibility level at the intersection during crossing. Results are discussed in terms of the impact of an In-Vehicle CICAS-SSA sign under conditions of Good and Limited Visibility. The second secondary goal of Study Two included the examination of the impact of the location of the CICAS-SSA Sign On rural intersection crossing performance. This was assessed through direct comparison of the Roadside-based CICAS-SSA and the In-Vehicle version of the same sign.

While the location of displays on which the CICAS-SSA was presented (i.e., located at the intersection or inside a vehicle) differed, the images presented on those displays were identical between the In-Vehicle and Roadside-based CICAS-SSA. The findings are discussed in terms of the impact of the location of the CICAS-SSA Sign On intersection crossing performance.

4.5.1 The Impact of an In-Vehicle CICAS-SSA and Design Differences

The design of an effective information display system located at an intersection may not be the most optimal design to be used inside a vehicle. Keeping in mind several important factors, we created three different designs of an In-Vehicle CICAS-SSA sign in an effort to successfully transition the Roadside-based CICAS-SSA to a new location, inside a vehicle. The three designs differed in terms of their complexity, that is, the amount of information that was available to the driver about the traffic on the major road. One of those designs, which provided the most extensive level of information to the driver (i.e., the Complete design), represented the direct transition from the Roadside-based CICAS-SSA. The results showed several main effects of design of the CICAS-SSA sign as well as interactions involving design and Sign State factors.

The results showed that drivers in three different groups of In-Vehicle CICAS-SSA design accepted different gaps when crossing the northbound lanes. The adjusted TTC was smallest for the participants in the Prohibitive group of CICAS-SSA design, suggesting that those drivers accepted riskier gaps when crossing. Comparatively, participants in the Complete group exhibited the greatest adjusted TTC.

Similar results were found in the accepted critical gap measure when crossing the northbound lanes. The adjusted TTC measure averages TTC for accepted gaps while limiting the ceiling value, however this measure is not sensitive enough to account for accepted gaps with small TTC (e.g., less than 3 seconds). The accepted critical gap measure, as a weighted measure places greater importance on accepted gaps with small TTC (e.g., 2 seconds) compared to those with longer TTC (e.g., 6 seconds). Participants in the Prohibitive design group were most likely to accept a critical gap when crossing the northbound lanes compared to the participants in the Complete and divided groups.

We can reasonably ascertain that larger adjusted TTC and decreased proportion of accepted critical gaps are indicators of a more conservative driving. Some other indicators of more conservative driving would be a greater 80th percentile rejected gap, as well as a greater proportion of rejected non-critical gaps. The results showed that participants in the Complete and divided design groups exhibited those precise facets of conservative driving (i.e., greater 80th percentile rejected gap, greater proportion of rejected non-critical gaps), compared to the participants in the Prohibitive design group.

Any findings of differences between different designs of an In-Vehicle CICAS-SSA would be of limited insight without exploring the possible interaction of these designs with the state of the sign (i.e., Sign On, Sign Off). Drivers in the Complete design group exhibited longer adjusted TTC when the sign was turned on compared to the Control, Sign Off condition. The participants in the Prohibitive design group, design which provided the least amount of information also improved the intersection crossing performance. Interestingly, the presence of the divided design of the In-Vehicle CICAS-SSA had no impact on adjusted TTC compared to the Control condition. This same pattern of interaction between designs of the In-Vehicle CICAS-SSA and Sign State was also found for the accepted critical gap measure. Participants in the Complete and Prohibitive groups showed improvement (i.e., reduced probability of accepting a critical gap) when the sign was turned on compared to the Control condition, while the presence of the divided design of the CICAS-SSA provided no such benefit.

The overall differences between the Complete and Prohibitive groups, to some degree appear to be due to baseline differences, although participants in the Complete design group also exhibited better driving performance in the Treatment condition as well. Based on these findings, the Complete design of an In-Vehicle CICAS-SSA appears to be the best suited for the transition from the Roadside-based to an In-Vehicle based CICAS-SSA, and thus the design to be used in the Field Study.

4.5.2 The Impact of Sign State and Visibility Factors on In-Vehicle-Based CICAS-SSA

Designs of an In-Vehicle based CICAS-SSA interacted with the State of the sign for two important measures, revealing not only the between-design differences, but also the extent to which driving performance improves compared to the Control, Sign Off state. In addition, the results also showed a consistent overall effect of Sign State. When an In-Vehicle CICAS-SSA sign was turned on (across all three in-vehicle designs), drivers accepted greater gaps (i.e., showed greater adjusted TTC) and waited longer to cross both north and southbound lanes of traffic. Furthermore, drivers were more likely to stop at the stop sign, were less likely to accept a critical gap and exhibited a larger 80th percentile rejected gap when the In-Vehicle CICAS-SSA was turned on compared to the Control condition.

These consistent effects of Sign State underlie the substantial beneficial impact of the In-Vehicle CICAS-SSA on rural intersection crossing performance. However, this impact of Sign State varied across different Visibility conditions. All main effects of Sign State were also accompanied by the interaction of Sign State with Visibility factor. The beneficial impact of the presence of an In-Vehicle CICAS-SSA, such as greater adjusted TTC, decreased likelihood of accepting a critical gap, as well as findings of a more conservative driving, such as waiting longer to cross and exhibiting greater 80th percentile rejected gap, were found only when crossing the intersection under Limited Visibility conditions. It appears that the extent to which drivers rely on the In-Vehicle CICAS-SSA is limited when weather and traffic conditions allow drivers an unrestricted and clear view of traffic.

It is possible that in situations when drivers feel confident in their perceptual judgment and motor abilities, the need to rely on assistive technology is greatly reduced. However, when the perceptual task becomes overly demanding, the extent to which drivers rely on and adhere to the assistive technology (i.e., In-Vehicle CICAS-SSA) may increase. While it appears that drivers may be able to utilize the In-Vehicle CICAS-SSA only when they deem it necessary, it is important to observe and acknowledge that the In-Vehicle CICAS-SSA does not act as a distractor in situations when drivers' reliance on the system is limited.

The usability results showed that drivers' trust in the system as well as the understanding of the same is very high. When we combine these results with the current findings showing drivers' ability to utilize the system based on the perceived need, and Study One findings showing that the use of the sign under cognitively demanding conditions (e.g., cell-phone conversation) does not result in negative consequences, we may conclude that In-Vehicle CICAS-SSA is easily understandable, beneficial and distraction-free.

4.5.3 The Impact of the Location of the CICAS-SSA Sign

The primary reason for evaluating three different designs of the In-Vehicle CICAS-SSA sign was the notion that what works on the roadside may not work inside a vehicle. The results have shown a positive impact of an In-Vehicle CICAS-SSA Sign On intersection crossing performance, but how does that performance compare to intersection crossing performance when presented with the Roadside-based CICAS-SSA? Our findings revealed only one main effect of the Location of the sign factor, showing that participants in the In-Vehicle condition were more likely to make a complete stop at the stop sign. Several interactions with Visibility factor showed that participants in the In-Vehicle condition were less likely to accept a critical gap and exhibited greater adjusted TTC. However, the simple effects of the Location factor were inconsistent, as they occurred under Limited Visibility conditions for some measures, while for others the effect was found under clear skies. One consistent component was the direction of the

Location factor. In all the interactions involving the Location of the sign factor, participants in the In-Vehicle condition exhibited better intersection crossing performance. Despite these findings we do not have enough evidence to suggest that the In-Vehicle version of the CICAS-SSA is more beneficial than the Roadside-based system. The lack of any interactions involving the Location and Sign State factors suggests a trend toward overall better driving performance for the participants in the In-Vehicle condition in both the Control (Sign Off) and the Treatment (Sign On) conditions.

4.6 CONCLUSION

The results from Study Two revealed strong and consistent findings regarding the impact of an In-Vehicle CICAS-SSA on rural intersection crossing performance. The driving performance measures also revealed important differences between different designs of an In-Vehicle CICAS-SSA, uncovering the most optimal design to be used in the Field Study. The findings from usability measures indicated high level of understanding and usability of the In-Vehicle CICAS-SSA, which was generalizable across age groups. The main findings from Study Two can be summarized in the following points:

- The use of an In-Vehicle based CICAS-SSA resulted in improved rural intersection crossing performance, such as reduced probability of accepting a critical gap.
- The benefits of an In-Vehicle based CICAS-SSA were exhibited under Limited Visibility conditions, when the perceptual task of determining an appropriate crossing gap becomes overly demanding.
- The version of the In-Vehicle CICAS-SSA that resulted in best overall intersection crossing performance was also the most informative about the traffic. The optimal In-Vehicle version of the sign was identical to the Roadside-based CICAS-SSA.
- In-vehicle based CICAS-SSA was at least as effective as a Roadside-based system, and in some cases, such as increased likelihood of stopping at the stop sign, more effective.

4.7 LIMITATIONS

Although very realistic, the simulator-based study investigating the impact of an in-vehicle based intersection crossing assist technology may not completely and accurately translate to the real world. The Field Study will test the effectiveness of the in-vehicle CICAS-SSA and thus serve as the validation for the stimulator Study.

5 FIELD STUDY

5.1 INTRODUCTION

Transitioning research from a laboratory setting into a real-world situation could be viewed as the completion stage of a research process. The laboratory setting in transportation research frequently involves a driving simulator, as was the case for the set of studies presented in this report. Due to safety concerns, experimental procedure in which a driver is being distracted, as was the case in Study One is best suited to be conducted in a simulator. Safety of a driver is obviously an important factor, but just as important is the control the researchers have to manipulate environment and visual clutter as was done in Study Two. Furthermore, interface development and usability testing can significantly reduce cost when conducted in a simulator. Driving simulators have a specific purpose and in some cases may be a preferred setting in which to carry out research; however a Field Study represents a validation of the findings and hypotheses generated from research conducted in a simulator.

Substantial research exists which compares driving performance in a simulator to performance on a road. The results of these validation studies vary depending on the nature of research, but also the sophistication of driving simulators. When comparing the results obtained in a simulator and on a road, researchers may examine *absolute validity*, for example compare the absolute velocity at which participants drove in a simulator and on a road. While absolute validity is certainly a lofty goal, good *relative validity* arguably provides sufficient validation of driving simulator research. Good relative validity is established when the direction and the strength of the effects are consistent between the simulator and field research. Many researchers have reported poor absolute validity and good relative validity in their comparisons between driving in a simulator and on a road (Törnros, 1998; Santos, Merat, Mouta, Brookhuis, de Waard, 2005; Godley, Triggs & Fildes, 2002), although some have reported opposite findings (Reed & Green, 1999).

In the first two studies described in this report we tested and evaluated different versions of an in-vehicle CICAS-SSA sign and determined the optimal design to be used inside a vehicle. The results from Study Two showed beneficial effects when using the in-vehicle CICAS-SSA, at least under Limited Visibility conditions. Findings from Study One suggested that an additional Cognitive Load did not negatively impact the use of the system when crossing rural intersections. The simulator studies allowed us to answer questions pertaining to the design of an in-vehicle CICAS-SSA and most importantly provide assurance that the use of the assist system does not result in negative consequences (i.e., worse driving performance when using the system).

The primary goal of the Field Study consisted of evaluation of the efficacy of the in-vehicle CICAS-SSA on rural intersection crossing performance at a real-world test intersection in Minnesota. As a secondary goal, we also explored age-related effects, whether the effectiveness of the system is affected by the Age of the driver.

The setup of the displays in the Field Study was identical to the setup for the in-vehicle conditions in Study Two, that is two displays were mounted on the A pillars of the instrumented vehicle (see Figure 40). The Complete version of the in-vehicle CICAS-SSA was shown to be the most effective in assisting drivers to cross the tested intersection, so that version of the system was selected as the in-vehicle CICAS-SSA design for the Field Study.

Figure 40. The location of the displays for the in-vehicle CICAS-SSA in the Field Study.

To accomplish these goals, the Field Study was conducted at the intersection of HW 52 and CSAH 9, near Cannon Falls, Minnesota. At the time when the Field Study was conducted, the Roadside version of the CICSA-SSA was activated for the general traffic at this intersection. To avoid a potential confound due to exposure and experience, only those drivers who had not had prior experience with the CICAS-SSA sign were allowed to participate. Furthermore, the Roadside CICAS-SSA signs were turned off during the testing phase, regardless of the condition (i.e., Control, Treatment).

The following are the main research issues examined in the Field Study:

- Evaluation of the effectiveness of the in-vehicle CICAS-SSA on rural intersection crossing performance at a real-world intersection.
    - Driving performance in the Control condition (i.e., no in-vehicle CICAS-SSA sign) was compared to the Treatment condition in which drivers were exposed to the in-vehicle CICAS-SSA.
- Examination of the Age-related effects on the drivers' use of the system and their driving performance.
    - Driving performance of Older drivers was compared to driving performance of their Younger counterparts.

5.2 METHODS

The in-vehicle CICAS-SSA was presented on two displays located on the bottom half of the left and right A pillars of the instrumented vehicle (see Figure 40). The displays were oriented toward the driver. The information that was presented on the displays depended on the current gap sizes of the vehicles on the major road, while the activation of the displays depended on the location of the driver. In the Treatment block of trials (i.e., the system was turned on) only one of the displays was active at any one time when crossing the intersection. The activation rules were nearly identical as those for the Complete in-vehicle interface in Study Two. When the front bumper of the subject's vehicle was within 10 meters of the stop sign, the left display turned on and started presenting information regarding the gap sizes of vehicles on the major road. The left display continued presenting information until the front bumper of the subject's vehicle was within 1 meter of the median. As depicted in Figure 41, the left screen was activated and displayed information when the subject's vehicle was located in Zone 1. At that time, the right display remained off (the screen was black). When the front bumper of the subject's vehicle crossed onto the median, the vehicle entered Zone 2 (see Figure 41), at which point the left display turned off (the screen turned black) and the right display became activated and started presenting information about the gap sizes of vehicles on the major road.

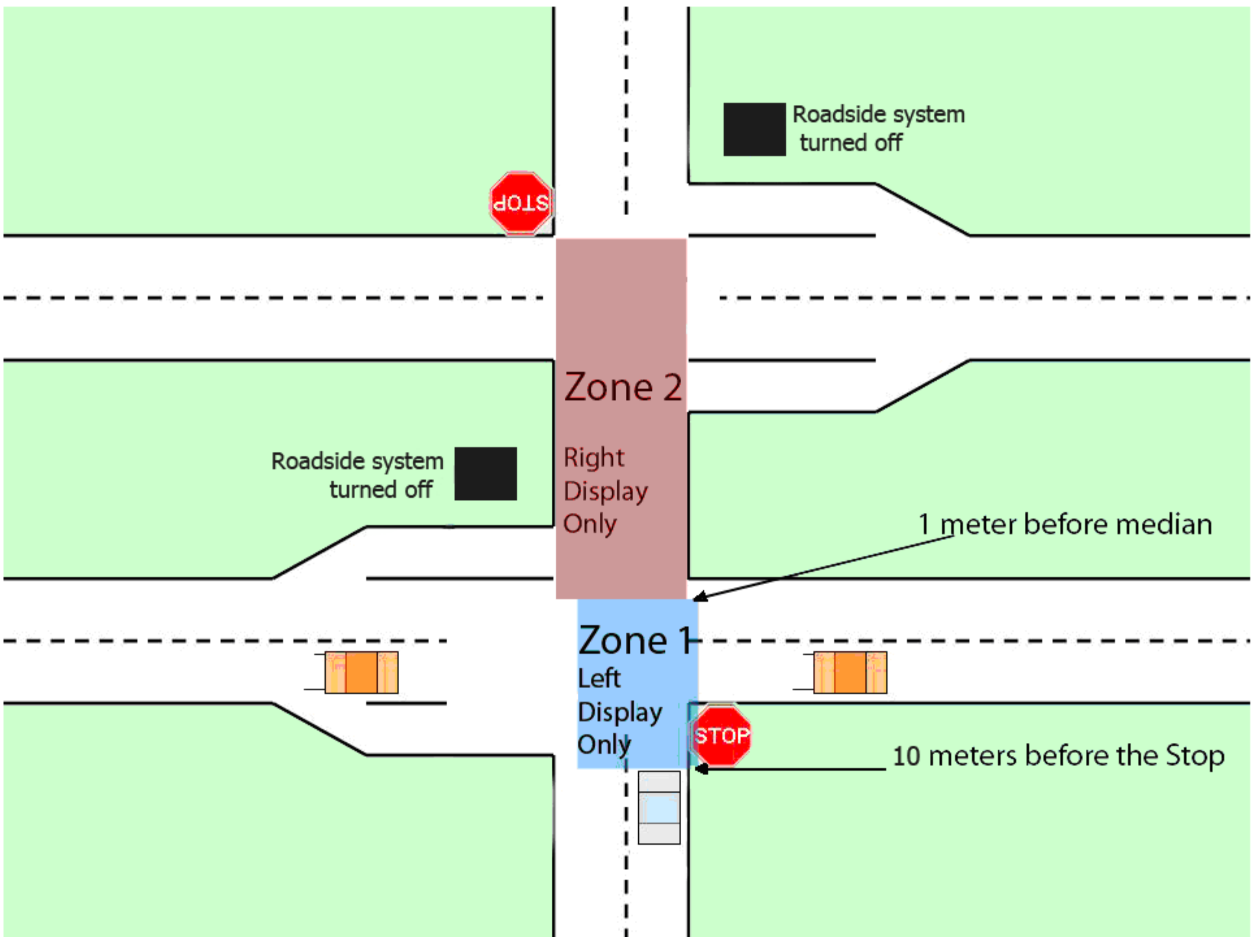


Figure 41. The rules of activation of the left and the right displays for the in-vehicle CICAS-SSA in the Field Study.

The Roadside CICAS-SSA was turned off for every trial, as well as during practice ensuring that participants were not exposed to the Roadside CICAS-SSA when driving the instrumented vehicle.

5.2.1 Participants

A total of 32 drivers participated in the Field Study. Sixteen of those participants were Older drivers between the ages of 55 and 78 (8 men, 8 women; with a mean age of 65.9 and sd = 6.7 years). Sixteen participants were Younger drivers between the ages of 19 and 29 (7 men and 9 women; with a mean age of 23.4 and sd = 3.6 years). Both groups of participants had a similar educational level with Older participants completing on average 14.9 and Younger participants completing 14.2 years of education. All the participants had normal vision (visual acuity of at least 20/40, normal color vision), possessed a valid driver's license and had no more than one accident in the last three years. Both Older and Younger participants were recruited through newspaper and online ads posted in the area of Rochester, MN. This location was selected because of the relative proximity to the location of the intersection (~30 miles away) which assured successful recruitment, but also reduced chances that the potential participants have used the intersection in the past. To avoid possible contamination of data due to experience we recruited only those drivers who had no previous exposure to the CICAS-SSA sign.

5.2.2 Materials and Apparatus

5.2.2.1 Infrastructure Data Collection System

The infrastructure data collection system was comprised of three components: sensing, computation, and an infrastructure-based driver interface (i.e., in-vehicle displays). Automotive radar sensors were placed along the major road (i.e., HW 52) and were used to determine the position, speed, and lane of travel of vehicles approaching the intersection crossroads. The automotive radar sensors were used because of their high accuracy and durability. Data collected from these sensors was then computed to calculate trajectories and velocities of the vehicles on the major road which determined the TTC of those vehicles to the center point of the intersection. Based on these computations, the appropriate state of the in-vehicle CICAS-SSA sign was then displayed.

5.2.2.2 Experimental Vehicle

A 2009 Chevrolet Impala served as the instrumented vehicle. The vehicle was outfitted with data collection equipment that included a dual frequency carrier phase differential GPS that provided position measurements at 10 Hz, a six axis Inertial Measurement Unit (three axes of rotational rates, three axes of acceleration) and a brake sensor which indicated brake actuation. Differential GPS was accurate within 2-5 cm, allowing great accuracy regarding the position of the instrumented vehicle.

Critical to the utility of the instrumented vehicle was the capability to synchronize on-board data collection with data collection at the intersection. Inter-computer synchronization was handled via the Network Time Protocol (NTP). The NTP manifested through the use of a local 802.11b wireless network located at the test intersection.

5.2.2.3 Display

The same displays that were used in Study Two were also used to present the in-vehicle CICAS-SSA in the Field Study.

5.2.2.4 In-Vehicle CICAS-SSA Sign

The left and right displays functioned in the same way as they did in Study Two; they displayed images depending on the current gap size of the vehicles on the major road. We made two modifications in the sign from the version used in Study Two that were incorporated into the in-vehicle CICAS-SSA used in the Field Study. In the Complete version of the in-vehicle CICAS-SSA, a total of six possible states of the sign could have been presented on the left display. As illustrated in Figure 42, some states of the sign presented redundant information.

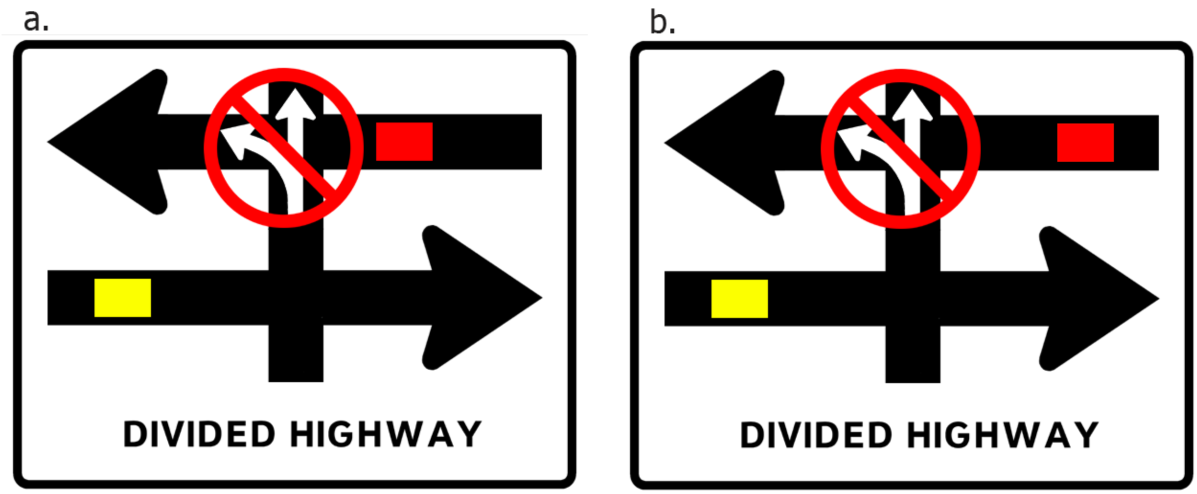
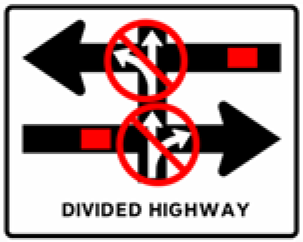
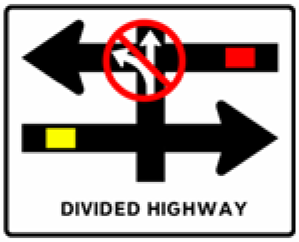


Figure 42. Different states of Complete version of the in-vehicle CICAS-SSA sign as presented on the left display in Study One.

When a driver was located at the stop sign, the red icon representing a vehicle in the far lanes of traffic had the same meaning regardless of its location (i.e., closer or farther away from the intersection). For this reason, in the Field Study we reduced the number of possible states of the sign that could have been presented on the left display to only three images. As shown in Table 13, the in-vehicle CICAS-SSA presented on the left display always showed a red icon for the far lanes of traffic (i.e., upper half of the sign).

Table 13. All display states of the in-vehicle CICAS-SSA sign as presented on the left display in the Field Study.

In-vehicle CICAS-SSA states Left Display	Message Meaning
	Do not enter the intersection; a vehicle is detected too close to the intersection travelling to the right (time-to-contact is less than 7.5 seconds).
	A vehicle is detected approaching the intersection, travelling to the right (time-to-contact is greater than 7.5 seconds). Drivers may be able to cross, but should proceed with caution.
	No vehicles are detected approaching the intersection travelling to the right that are within the sensor range. Drivers may be able to cross, but should proceed with caution.

The second modification to the in-vehicle CICAS-SSA sign that we made relates to the images that were presented on the right display. In the Complete version of the in-vehicle CICAS-SSA that was used in Study Two, a total of nine possible states of the sign could have been presented on the right display. As depicted in Figure 43, the images presented on the right display in Study Two included a dynamic update of the lanes located behind the driver. When the driver was located at the median, the Complete CICAAS-SSA dynamically updated the information about the lanes of traffic that the driver had just crossed. Since the information about the cross traffic located behind the driver is of very limited use, the in-vehicle CICAS-SSA used in the Field Study reduced the number of possible states of the sign that could have been presented on the right display to only three images. The in-vehicle CICAS-SSA presented on the right display always showed a red icon for the lanes of traffic located behind the driver (i.e., bottom half of the sign). Table 14 presents all the possible states of the system that could have been presented on the right display.

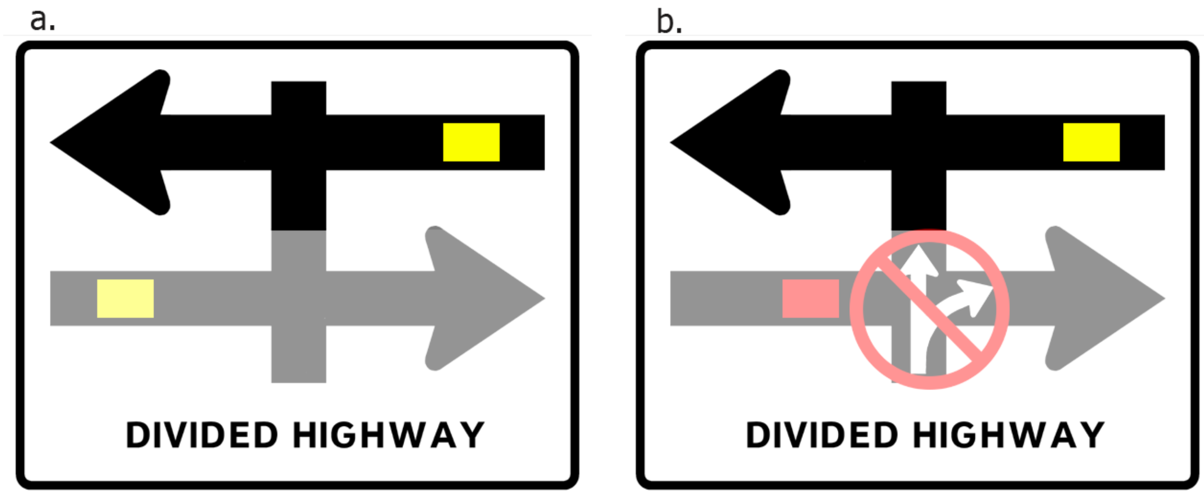
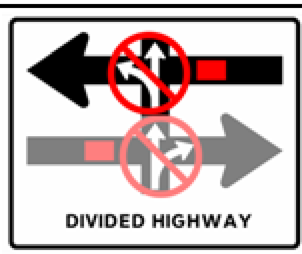
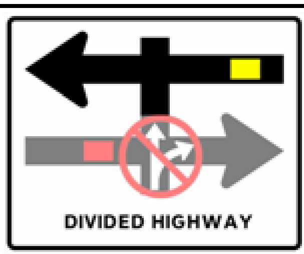
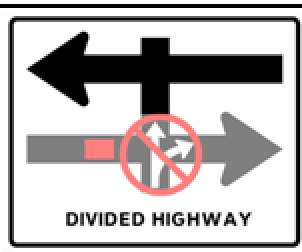


Figure 43. Different states of the Complete version of the in-vehicle CICAS-SSA sign as presented on the right display in Study Two.

Table 14. All display states of the in-vehicle CICAS-SSA sign as presented on the right display in the Field Study.

In-vehicle CICAS-SSA states Right Display	Message Meaning
	Do not enter the intersection; a vehicle is detected too close to the intersection travelling to the left (time-to-contact is less than 7.5 seconds).
	A vehicle is detected approaching the intersection, travelling to the left (time-to-contact is greater than 7.5 seconds). Drivers may be able to cross, but should proceed with caution.
	No vehicles are detected approaching the intersection travelling to the left that are within the sensor range. Drivers may be able to cross, but should proceed with caution.

5.2.2.5 Questionnaires

Participants filled out a driving history questionnaire (Appendix A) at the beginning of the study. After the completion of the driving task, participants filled out System Trust (Appendix B) and

Usability (Appendix C) questionnaires. These questionnaires inquired about participants' satisfaction, understanding and ease of use of the in-vehicle CICAS-SSA as well as any potential confusion related to the design of the system.

5.2.3 Procedure

Two experimenters met with participants near the location of the tested intersection (i.e., HW 52 and CSAW 9). The pre-testing procedures were carried out inside the instrumented vehicle. Participants completed the initial questionnaire and the consent form before they received instructions about the driving task they were required to complete as part of their participation in the study. Next, participants completed a practice drive which included one crossing of the tested intersection followed by a two-mile drive on the county road. The in-vehicle assist system was inactive during that period. Following the practice drive, participants proceeded with the driving portion of the study.

Driving performance was examined through a trial-based driving task in which participants were asked to approach the intersection, stop at the stop sign and then cross the intersection in a safe and timely manner. Each trial ended after the participant crossed the intersection. During the driving task, one of the experimenters sat in the backseat of the instrumented vehicle and instructed participants when to start each intersection crossing trial. The second experimenter monitored the traffic on the major road to determine and select an appropriately dense and long stream of traffic. When the appropriate traffic stream was determined, the second experimenter signaled (via walkie-talkie) his/her colleague in the instrumented vehicle to start an intersection crossing trial. The appropriate traffic stream was characterized as one that allowed participants an opportunity to be presented with several (at least 3) inappropriate crossing gaps (i.e., smaller than 7.5 seconds) when they reached the stop sign. Given the nature of the study (i.e., a road test), the stream of traffic that was presented to participants varied from one trial to another.

Data collection occurred on weekdays between noon and 6 p.m. These hours were selected because traffic flow was sufficiently dense to allow experimenters to obtain usable data. To avoid potential confounds due to Visibility (in case of fog or heavy rain) and traction (in case of rain), data was collected only during sunny or cloudy days.

All the participants were provided with a detailed explanation about the purpose of the in-vehicle CICAS-SSA. Participants were shown each of the possible states of the assist system and received comprehensive explanation about each state before the start of the study. These instructions mimicked the instructions participants received in Study Two.

Each participant completed 8 trials. Half the trials were Control trials in which participants were not exposed to the in-vehicle CICAS-SSA while the rest were Treatment trials in which participants completed the intersection crossing with the system activated.

5.3 EXPERIMENTAL DESIGN

5.3.1 Independent Variables

The independent variable that examined the impact of the in-vehicle CICAS-SSA on intersection crossing performance was Sign State, consisting of Control (without the in-vehicle CICAS-SSA) and Treatment (with the system) conditions. The effectiveness of the system was examined across different Age groups, exploring whether age-related differences existed with the use of the in-vehicle CICAS-SSA.

Therefore, the independent variables that were manipulated in the Field Study were:

- *Sign state* (Sign On, Sign Off)
- *Age* (Older, Younger)

5.3.2 Dependent Variables

Like in the simulator studies, data in the Field Study was collected within two measurement constructs. The Driving Performance and Usability measures were identical to those collected and analyzed in Study Two.

5.4 RESULTS

Following the same pattern when presenting the results in the simulator studies, the results section of the Field Study is also separated into two sections; the examination and the presentation of the driving performance data following by the examination of the usability data.

Both sets of measures (driving performance and usability) were submitted to a 2 x 2 mixed model ANOVA with Age (Older, Younger) as a between-subjects factor and Sign State (Sign Off, Sign On) as a within-subject factor.

5.4.1 Driving Performance

Each participant completed four intersection crossing trials in each of the Sign Presence conditions. Depending on the measure examined, participants' driving performance within a condition was either averaged across trials or combined when probabilities or percentiles were calculated.

Due to a technical issue with the data collection software, intersection traffic data was missing for one participant for a single trial (an Older driver in Sign Off condition). As a result, the data across three trials were analyzed for that particular condition for that participant.

5.4.1.1 Adjusted Time-to-Contact

Southbound and Northbound. The adjusted TTC measure was submitted to a 2-way, mixed-model ANOVA, however no significant effects were present for crossing of either the southbound or northbound lanes of traffic. The impact of Sign State approached significance when crossing the southbound lanes of traffic ($F(1,30) = 3.3$, $p = .079$), showing a trend toward acceptance of greater gaps when the system was activated (6.25 and 6.67 for the Sign Off and Sign On conditions, respectively). When crossing the northbound lanes of traffic the difference between the Sign State conditions was smaller, although in the same direction as for crossing of the southbound lanes of traffic.

5.4.1.2 Wait Time

Southbound. The mixed-model ANOVA performed on the wait time measure for crossing of the southbound lanes of traffic revealed a marginal main effect of Age ($F(1,29) = 4.05$, $p = .053$).

Contrary to expectations, Younger drivers waited longer to cross the southbound lanes of traffic compared to Older drivers (11 and 14.7 seconds for Older and Younger drivers, respectively). One potential reason for this unexpected finding could be found in the relative lack of control of traffic flow in the Field Study. Furthermore, the wait time measure was collected only for trials in which participants made a complete stop (at the stop sign or in the median) and as such the wait time measure represents only one facet of overall intersection crossing driving performance.

Northbound. The wait time measure for crossing of the northbound lanes of traffic was submitted to a 2-way, mixed-model ANOVA revealing a marginal effect of Sign State ($F(1,30) = 3.72$, $p = .063$). Drivers waited longer in the median before crossing the northbound lanes of traffic when the in-vehicle CICAS-SSA was activated compared to the Sign Off condition (8.5 and 11.4 seconds for Sign Off and Sign On conditions, respectively).

5.4.1.3 Likelihood of Stopping

Southbound. The mixed-model ANOVA performed on the likelihood of stopping measure revealed a significant effect of Sign State ($F(1,30) = 10.7$, $p = .003$). Drivers were more likely to make a complete stop at the stop sign when the in-vehicle CICAS-SSA was activated, compared to the Sign Off condition (.74 and .87 for Sign Off and Sign On conditions, respectively).

5.4.1.4 Movement Time

Southbound. The mixed-model ANOVA performed on the movement time measure revealed a significant effect of Age ($F(1,30) = 14.55$, $p = .001$). Younger drivers required more time to cross the southbound lanes of traffic, compared to their Older counterparts (2.5 and 2.7 seconds for Older and Younger drivers, respectively).

Northbound. The significant effect of Age was also found for crossing of the northbound lanes of traffic ($F(1,30) = 9.41$, $p = .005$). Again, Younger drivers (2.2 seconds) required more time to cross the lanes of traffic compared to Older drivers (1.9 seconds).

5.4.1.5 Accepted Critical Gap

Southbound and Northbound. The analyses of the accepted critical gap measure for the crossing of the southbound and northbound lanes of traffic revealed a similar pattern to that of the analyses of the adjusted TTC measure. Although the analyses did not reveal significant main effects or interactions, a trend toward decreased probability of accepting a critical gap when the assist system was activated emerged, as evidenced in a marginal effect of Sign State ($F(1,30) = 3.38$, $p = .076$). When crossing the southbound lanes of traffic, drivers were less likely to accept a critical gap in Treatment condition (.09 and .14 weighted proportion of trials for Sign On and Sign Off conditions, respectively).

5.4.1.6 Rejected Non-Critical Gap

Southbound and Northbound. The 2-way, mixed-model ANOVA performed on the rejected non-critical gap measure when crossing the southbound and northbound lanes of traffic did not reveal any significant main effects or interactions.

5.4.1.7 80th Percentile Rejected Gap

Southbound and Northbound. The 2-way, mixed-model ANOVA performed on the 80th percentile rejected gap measure when crossing the southbound and northbound lanes of traffic did not reveal any significant main effects or interactions.

5.4.2 Usability Measures Results

The responses to each question from the System Trust and Usability questionnaires were submitted to a One-Way ANOVA with Age (Older, Younger) as a single factor.

5.4.2.1 System Trust Questionnaire

The System Trust questionnaire can be found in Appendix B. Table 15 presents the average response for each question posed, averaged across age, as well as any significant effects of Age.

Overall, participants expressed a high level of comfort and familiarity with the in-vehicle CICAS-SSA, as shown in the high degree of agreement with Questions 2 and 7. Questions that deal with reliability and integrity of the system (Questions 4, 5 and 6) revealed significant effects of Age. When responding to Question 4 ("System is reliable"), Older drivers rated the assist system as more reliable than Younger drivers ($F(1,30) = 12.79$, $p = .001$; $M = 87$ and 70 for Older and Younger drivers, respectively). Older drivers also rated the assist system more dependable in Question 5 ($F(1,30) = 8.81$, $p = .006$; $M = 88$ and 75 for Older and Younger drivers, respectively), as well as having greater integrity, in Question 6 ($F(1,30) = 5.6$, $p = .025$; M == 89 and 77 for Older and Younger participants, respectively).

Table 15. The average scores and significant effects for responses to questions in system trust questionnaire.

Question	Overall Mean	Significant Effects *
1. The system enhanced my safety.	67.2	
2. I am familiar with the operations of the system.	88.9	
3. I trust the system.	79.1	
4. System is reliable.	79.1	Age (O > Y)
5. System is dependable.	81.4	Age (O > Y)
6. System has integrity.	81.9	Age (O > Y)
7. I am comfortable with the system's intent.	87.6	
8. I am confident in my driving without the system.	86.4	

* All denoted effects were significant at .05 level.

5.4.2.2 Usability Questionnaire

The Usability questionnaire can be found in Appendix C. Table 16 presents the average response for each question posed, averaged across age, as well as any significant effects of Age.

Most responses to questions in the Usability questionnaire did not elicit a strong preference, either positive or negative. Both Older and Younger participants did, however, strongly agree with the statement that the assist system was easy to understand (Question 7). Age-related effects were found only for a single question in the Usability questionnaire (i.e., Question 1). Older drivers reported having greater confidence in the assist system compared to their Younger counterparts ($F(1,30) = 6.3$, $p = .018$, $M = 89$ and 73 for Older and Younger drivers, respectively).

Table 16. The average scores and significant effects for responses to questions in the usability questionnaire.

Question	Overall Mean	Significant Effects *
1. I felt confident using the sing.	81.2	Age (O > Y)
2. I felt it was confusing using the sign.	21.9	
3. The sign made me safer.	70.3	
4. I trusted the information provided by the sign.	72.7	
5. I like the sign.	76.6	
6. The sign was reliable.	81.2	
7. The sign was easy to understand.	88.3	
8. Sign's information was credible.	82.1	
9. Sign was useful.	78.9	
10. I would complete the maneuver the same way without the sign.	73.4	

* All denoted effects were significant at .05 level.

5.5 DISCUSSION

The primary goal of the Field Study was to assess the efficacy of the in-vehicle CICAS-SSA when crossing rural intersections at a real-world test intersection. This goal was accomplished through a counterbalanced A-B design in which participants crossed the intersection without and with the assistance of the in-vehicle CICAS-SSA. Driving performance was compared between Treatment and Control conditions to examine the effectiveness of the in-vehicle CICAS-SSA on rural intersection crossing performance. Furthermore, the Field Study also examined whether the impact of the in-vehicle CICAS-SSA differs between Older and Younger drivers. The findings are discussed in terms of the impact of the in-vehicle CICAS-SSA, the recommendations for implementation, and the need for future studies.

5.5.1 The Impact of the In-Vehicle CICAS-SSA

We conducted extensive research in a driving simulator to determine the optimal design of the in-vehicle CICAS-SSA, as well as to explore potentially negative effects of extraneous factors (e.g., environmental, internal distraction) on use and adherence to the in-vehicle CICAS-SSA. The Field Study represents the final validation of the research conducted in the simulator and its results enable us to better estimate the real-world effectiveness of the in-vehicle CICAS-SSA on rural intersection crossing performance.

Unlike the findings from the simulator studies that revealed numerous significant main effects and interactions involving the Sign State factor, the results from the Field Study uncovered only one measure in which the impact of the in-vehicle CICAS-SSA system was significant. One reason for this lack of significant findings can be found in the simplistic design of the Field Study which examined only two factors, Sign State and Age. The fewer overall factors reduces the number of potential main effects and interactions. Furthermore, the impact of Sign State factor in the simulator studies was the most prominent in the interaction with the level of Visibility, a factor not examined in the Field Study.

The results of the Field Study revealed a single significant effect of the Sign State factor. Drivers were more likely to make a complete stop at the stop sign when the in-vehicle CICAS-SSA was activated. The results however, revealed several marginal effects of the Sign State factor, indicating a trend toward a more conservative driving behavior. This trend was exhibited in greater adjusted TTC, decreased probability of accepting a critical gap and longer wait time when the in-vehicle assist system was activated, compared to the Control, Sign Off condition. Figure 44 presents the pattern of results which shows a consistent trend of either better or more appropriate intersection crossing performance.

Some of the driving performance measures (e.g., wait time, rejected non-critical gaps) may suggest a more conservative/aggressive driving style, but these preferential descriptions of driving behavior do not necessarily imply safer/riskier driving performance. However, when evaluating a measure such as probability of accepting a critical gap, we can more directly infer better/poorer driving performance. The higher proportion of accepted critical gaps does represent riskier driving. The bars in Figure 44 depict a differing impact of the Sign State conditions. Although those effects were not statistically significant, the strong trend would suggest some beneficial effects of the in-vehicle CICAS-SSA on rural intersection crossing performance. The limited number of participants and especially the limited number of trials may not provide sufficient statistical power to uncover significantly different effects.

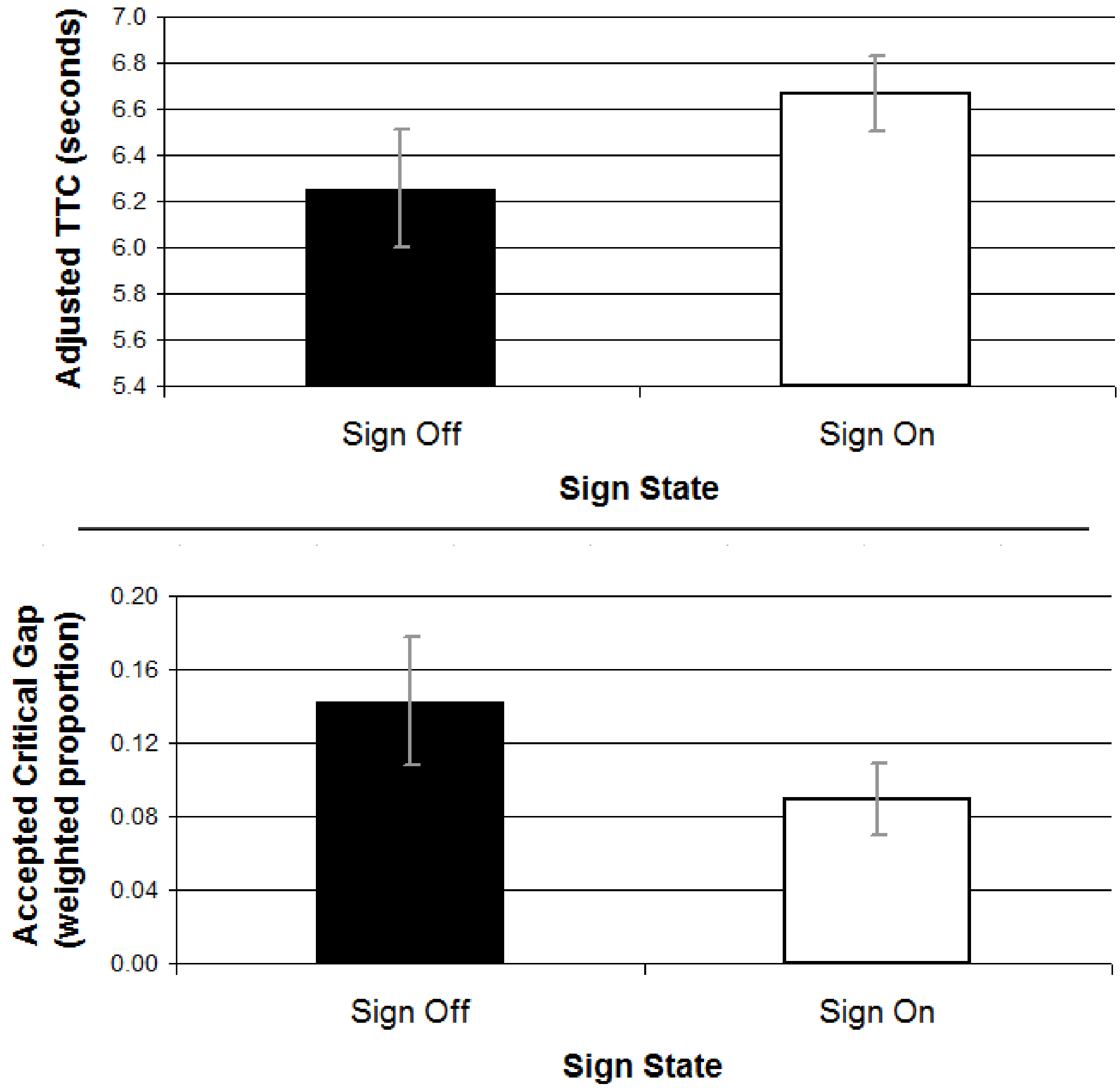


Figure 44. The impact of sign presence factor on adjusted TTC (top panel) and accepted critical gap (bottom panel) measures with standard error bars.

5.5.2. Age-Related Effects of the In-Vehicle CICAS-SSA

The main reason for the inclusion of the Age factor in the Field Study was to determine the potential age-related differences in using and adhering to the in-vehicle CICAS-SSA. A well-designed assist system should be equally effective across age groups. This is precisely what the Field Study results show. The lack of any Age x Sign Presence interactions suggests that any impact of the assist system, such as greater likelihood of making a complete stop at the stop sign, applies equally to Older as well as Younger drivers. The results, however, did show several age-related main effects. Older drivers required less time to cross both southbound and northbound lanes of traffic, as well as waited less before crossing (although this effect was only marginally significant). These are quite surprising findings, especially since they stand in contrast with the findings from the simulator studies we conducted earlier. As long as the time required to cross the intersection does not substantially impact the safety margin (TTC when driver exits the intersection), time required to cross the intersection is somewhat of a subjective preference.

Although significantly different, Older drivers were approximately 250 ms faster to cross the intersection, a difference which is small in magnitude when compared to the critical gap of 7.5 seconds. Older drivers typically drive with lower velocity in most driving environments (Owens, Wood & Owens, 2007), but the crossing of highway lanes is a somewhat atypical environment in which to measure velocity. We speculate that the perceived risk at the time of intersection crossing differed between Older and Younger drivers. The broad perceptual and cognitive decline that older adults exhibit (Salthouse, 1996), coupled with a specific tendency to perceive other vehicles as travelling at higher speeds compared to Younger drivers (Scialfa, Kline, Lyman & Kosnik, 1987), can potentially affect older drivers' estimations about the imminence of a potentially dangerous traffic situation. Although diminished perceptual abilities of older adults have not resulted in the greater acceptance of critical gaps in the Field Study, it is possible that the perceived danger of crossing was affected. In turn, this perception may have prompted Older drivers to cross the intersection in the more rapid manner. Thus, the quicker crossing of the intersection could be viewed as a more conservative driving behavior, resulting in avoidance of the potentially dangerous traffic situation, which in this case required speeding away from a potential danger (i.e., the cross traffic vehicle)

A more relevant finding relates to the equivalent impact of the in-vehicle CICAS-SSA on both Older and Younger drivers. Both Age groups benefited to the same degree, suggesting that Older drivers are just as likely to accept and use the assist system. The findings from usability questionnaires suggest that Older drivers had greater trust in the system and expressed greater level of confidence when using the assist system.

5.6 CONCLUSION

The results from the Field Study showed a consistent trend regarding the impact of the in-vehicle CICAS-SSA on rural intersection driving performance. The impact of the assist system was equally applicable to both Older and Younger drivers. The usability data suggested a high degree of trust and confidence in the assist system for both Age groups, with the degree of trust being significantly higher for Older drivers. The main findings from the Field Study can be summarized in the following points:

- The use of the in-vehicle CICAS-SSA resulted in improved rural intersection crossing performance, such as increased likelihood of making a complete stop at the stop sign and a strong trend toward a decreased probability of accepting a critical gap.
    - This impact of the in-vehicle CICAS-SSA was equivalent for Older and Younger drivers. The lack of Age x Sign State interaction indicated that both Age groups benefited from the use of the system.
- Unlike the findings from the two driving simulator studies, Older drivers crossed the intersection faster than did Younger drivers. A discrepancy in the risk assessment of the traffic situation may have influenced this finding.
- No negative effects were observed in the field assessment of the in-vehicle CICAS-SSA, suggesting that the real-world implementation of the system may not result in negative consequences.

5.7 LIMITATIONS

A trial-based study design, in which participants cross the same intersection multiple times in succession, while practical, is not a representative of a typical real-world driving pattern. Furthermore, participants completed only four trials per condition. A study with a small number of trials carries with it a risk of higher variability and potentially reduced reliability of data. On the other hand, any significant effects uncovered in such a study may also suggest very robust effects. A larger-scale study, with a greater number of participants, and more importantly, conducted over a longer period of time would provide a more complete picture of the impact of the in-vehicle CICAS-SSA on rural intersection driving performance and would address both of these issues as well as provide a more robust data set.

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APPENDIX A: DRIVING HISTORY QUESTIONNAIRE

DRIVING HISTORY QUESTIONNAIRE

This questionnaire asks you to indicate some details about your driving history and related information. Please tick one box for each question.

1. Your age: ______________ years

2. Your sex: ☐ Male
☐ Female

3. What is your highest educational level completed?
☐ High School / Vocational School
☐ Associates Degree
☐ Bachelor of Arts / Bachelor of Science
☐ Masters
☐ PhD

4. Are you currently taking any college level classes?
☐ Yes
☐ No

5. Please state your occupation:____

6. Please state the **year** when you obtained your full driving license: ___________

7. About how often do you drive nowadays?

☐ ======= ☐ ======= ☐ ======= ☐ ======= ☐

Never Hardly Sometimes Most

Every

Ever Days Day

8. Estimate roughly how many miles you personally have driven in the past year:
☐ Less than 5000 miles
☐ 5000-10,000 miles
☐ 10,000-15,000 miles
☐ 15,000-20,000 miles
☐ Over 20,000 miles

9. About how often do you drive to and from your place of work?

☐ ======= ☐ ======= ☐ ======= ☐ ======= ☐

Never Hardly Sometimes Most Every
Ever Days Day

Do you drive frequently on…	Yes	No
10. Highways?	☐	☐
11. Main Roads other than Highways?	☐	☐

12. Urban Roads? ☐ ☐
13. Country Roads? ☐ ☐
14. During the last three years, how many <u>minor</u> road accidents have you been involved in where you were at fault? A minor accident is one in which no-one required medical treatment, AND costs of damage to vehicles and property were less than $4000.

Number of minor accidents ____ (if none, write 0)

15. During the last three years, how many <u>major</u> road accidents have you been involved in where you were at fault? A major accident is one in which EITHER someone required medical treatment, OR costs of damage to vehicles and property were greater than $4000, or both.

Number of major accidents ____ (if none, write 0)

16. During the last three years, have you ever been convicted for:

	Yes	No
a. Speeding	☐	☐
b. Careless or dangerous driving	☐	☐
c. Driving under the influence of alcohol/drugs	☐	☐

17. What type of vehicle do you drive most often?

- ☐ Motorcycle
- ☐ Passenger Car
- ☐ Pick-Up Truck
- ☐ Sport utility vehicle
- ☐ Van or Minivan
- ☐ Other, briefly describe: ____________________________

18. How frequently to do drive on Highway 52?

Never ☐—☐—☐—☐—☐ Every Day

19. How frequently to do drive on County Road 9?

Never ☐—☐—☐—☐—☐ Every Day

20. How frequently to do cross or enter Highway 52 from County Road 9?

Never ☐—☐—☐—☐—☐ Every Day

21. Approximately how many times have driven through this intersection from the minor road (County Road 9) in the past 6 months? ___________

APPENDIX B: SYSTEM TRUST QUESTIONNAIRE

SYSTEM TRUST QUESTIONNAIRE

The performance of the system enhanced my driving safety.

0 Strongly Disagree — 50 — 100 Strongly Agree

I am familiar with the operation of the system.

0 Strongly Disagree — 50 — 100 Strongly Agree

I trust the system.

0 Strongly Disagree — 50 — 100 Strongly Agree

The system is reliable.

0 Strongly Disagree — 50 — 100 Strongly Agree

The system is dependable.

0 Strongly Disagree — 50 — 100 Strongly Agree

The system has integrity.

0 Strongly Disagree — 50 — 100 Strongly Agree

I am comfortable with the intent of the system.

0 50 100
Strongly Disagree Strongly Agree

I am confident in my ability to drive the car safely without the system.

0 50 100
Strongly Disagree Strongly Agree

APPENDIX C: USABILITY QUESTIONNAIRE

USABILITY QUESTIONNAIRE

Please indicate how strongly you agree or disagree with the following statements. Answer these questions in relation to the smart sign you just viewed at the intersection while driving.

1. I felt confident using this sign.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

2. I felt it was confusing to use this sign.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3. Using this sign made me feel safer.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

4. I trusted the information provided by the sign.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

5. I like this sign.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

6. The sign was reliable.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

7. I felt this sign was easy to understand.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

8. The sign's information was believable (credible).

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

9. This sign was useful.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

10. I could complete the maneuver the same way without using the sign.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree