TP 14610E

# IN-VEHICLE INTELLIGENT TRANSPORTATION SYSTEM (ITS) COUNTERMEASURES TO IMPROVE OLDER DRIVER INTERSECTION PERFORMANCE

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*by*

Cognitive Ergonomics Research Laboratory
Department of Psychology
University of Calgary

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# IN-VEHICLE INTELLIGENT TRANSPORTATION SYSTEM (ITS) COUNTERMEASURES TO IMPROVE OLDER DRIVER INTERSECTION PERFORMANCE

*by*

J.K. Caird, S.L. Chisholm, J. Lockhart,
N. Vacha, C.J. Edwards, J.I. Creaser & K. Hatch

Cognitive Ergonomics Research Laboratory
Department of Psychology

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16. Abstract

A literature review of in-vehicle intelligent transportation systems (ITS) is presented for the purposes of determining which technologies may benefit older drivers at intersections. Based on the review, three experimental studies were conducted to determine intersection behaviour of those aged 18 to 24, 25 to 35, 55 to 64 and 65+ with the assistance of a range of in-vehicle intersection signs.

The first experiment used the University of Calgary Driving Simulator (UCDS) to measure intersection performance at amber onset until drivers stopped or cleared the intersection. Older drivers approached intersections slower and stopped more accurately than younger drivers. Perception response times (PRTs) did not differ by age and varied from 0.86 s for the shortest time to stop line (1.73 s) to 1.03 s for the longest (3.58 s), indicating that drivers used more time to respond if it was available.

In the second experiment, two in-vehicle signs, presented in a head-up display format, were evaluated to determine if intersection performance improved or unwanted adaptive behaviours occurred. Overall, the advanced in-vehicle signs reduced intersection approach speed, increased the probability of stopping at the intersection, increased stopping accuracy, but also increased the likelihood that drivers would be left in the intersection when the traffic light turned red.

The third experiment tested the comprehension of 24 in-vehicle signs by older and younger drivers. Comprehension and perceived usefulness of the in-vehicle signs varied by age and context. Fixation duration and frequency to in-vehicle and traffic signs indicated that additional visual search occurred when the relationship between the sign and intersection was not understood. Signs that provided information about upcoming actions, such as stopping or changing lanes, were valued more by older drivers.

Overall, the multi-method, multi-measure approach describes older driver performance at intersections, with an innovative in-vehicle technology and design guidelines for that technology.

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16. Résumé

Le rapport présente les résultats d'une recherche documentaire sur les systèmes de transports intelligents (STI) embarqués, qui visait à déterminer les technologies les plus susceptibles de bénéficier aux conducteurs âgés aux intersections. Il rend ensuite compte de trois études empiriques qui ont examiné le comportement aux intersections de conducteurs âgés de 18 à 24 ans, de 25 à 35 ans, de 55 à 64 ans et de 65 ans et plus, avec l'appui d'une représentation, à bord du véhicule, d'un éventail de panneaux de signalisation que l'on trouve aux intersections.

Pour la première étude, les chercheurs ont utilisé le simulateur de conduite de l'Université de Calgary pour mesurer le comportement des conducteurs aux intersections, entre l'activation du feu jaune et l'arrêt ou le franchissement de l'intersection. Les conducteurs âgés s'approchaient plus lentement de l'intersection et ils s'immobilisaient avec plus de précision que les jeunes conducteurs. Les temps de perception-réaction (TPR) ne différaient pas selon l'âge et ils variaient de 0,86 s, pour le temps d'immobilisation à la ligne d'arrêt le plus court (1,73 s), à 1,03 s, pour le temps le plus long (3,58 s), ce qui dénote que les conducteurs réagissaient d'autant plus lentement qu'ils avaient du temps pour réagir (que l'intersection était éloignée).

La deuxième étude a porté sur deux panneaux de signalisation présentés en visualisation tête haute à bord du véhicule. Le but était de déterminer s'ils amélioraient la performance aux intersections ou s'ils induisaient des comportements adaptatifs indésirables. De manière générale, les panneaux de signalisation avancée à bord du véhicule avaient pour effet de réduire la vitesse d'approche et d'accroître la probabilité et la précision de l'arrêt à l'intersection; mais ils augmentaient également la probabilité que le conducteur se trouve encore sur l'intersection lorsque le feu passait au rouge.

La troisième expérience visait à vérifier le degré de compréhension de 24 panneaux de signalisation présentés à bord du véhicule, par des conducteurs jeunes et âgés. La compréhension et la perception de l'utilité de ces panneaux variaient selon l'âge et le contexte. La durée et la fréquence de fixation du regard sur les panneaux intérieurs et extérieurs ont révélé une recherche visuelle plus intense chez les conducteurs qui ne saisissaient pas le lien entre la signalisation et l'intersection. Les panneaux qui informaient de manœuvres à venir, comme un arrêt ou un changement de voie, étaient davantage appréciés par les conducteurs âgés que par les jeunes conducteurs.

Bref, cette étude, fondée sur des méthodes et mesures multiples, décrit la performance des conducteurs âgés aux intersections, ainsi qu'une technologie embarquée novatrice et des lignes directrices pour optimiser l'application de cette technologie.

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## EXECUTIVE SUMMARY

### Project Scope

This study of in-vehicle intelligent transportation system countermeasures to improve older driver performance at intersections was initiated by Transport Canada through the Transportation Development Centre.

The study had the following objectives:

- **Phase I:** Review the literature on ITS in-vehicle applications that have the greatest potential to mitigate older driver performance limitations at intersections.

- **Phase II:** Based on Phase I, develop simulation scenarios, in-vehicle prototype applications, measurement systems, experimental designs, and pilot experiments to empirically evaluate promising in-vehicle technologies.

- **Phase III:** Conduct a systematic evaluation of each technology with multiple experiments using younger and older driver samples. Determine the design strengths and weaknesses of each technology.

- **Phase IV:** Based on the results of Phase III, improve the design of prototype ITS applications. Perform additional studies with the improved designs to determine the effectiveness of the countermeasure in improving older driver performance.

- **Technical Report:** Synthesize the results into specific recommendations for the development of older driver ITS applications, generalizable design guidelines and testing approaches for efficiency and safety.

The research studies conducted are complementary to ongoing research on intersection countermeasures within the U.S. Federal Highway Administration (FHWA) and National

Highway Traffic Safety Administration (NHTSA). The research completed is unique in terms of development, evaluation and application implications.

### Technology Review

A number of possible technologies are being developed to help drivers avoid collisions at intersections. These include modifications to conventional traffic controls, collision warning systems (e.g., auditory, haptic, visual), in-vehicle information systems, and red light running camera systems. Many have not necessarily considered the older driver explicitly when a system is designed. Each system has potential advantages and disadvantages (see Caird, 2004).

Infrastructure-based solutions such as increasing the conspicuity of traffic lights and stop signs have the potential to benefit all drivers. In-vehicle technologies may be tailored to specific driver needs and information can be delivered to the driver directly. The FHWA and NHTSA have focused research efforts on infrastructure and in-vehicle intersection countermeasures, respectively. If older drivers do indeed fail to see traffic lights and stop signs, infrastructure-based solutions are more likely to be implemented and have an immediate benefit to older drivers. R&D that specifies an in-vehicle system must achieve mass marketing appeal before it is deployed. Both approaches, infrastructure and in-vehicle, are considered in this review and follow from our previous research with Transport Canada on contributing factors to older driver intersection crashes (Caird et al., 2002).

### Red Light Camera Review

Increasing the length of the yellow interval is one countermeasure reliably found to at least temporarily decrease the number of red light violations. Red light cameras are involved with a

40% reduction in violations at treated intersections (Retting et al., 1999). Right angle and rear-end collisions were estimated to decrease by 26% upon implementation of red light cameras (Flannery & Maccubbin, 2002). However, rear-end crashes increased by 40% according to one study (Golob et al., 2002). The issue of whether rear-end collisions will increase or decrease with the implementation of red light cameras has not yet been resolved. The precise effect of red light cameras on violations and crashes has not been found due to methodological issues, although research findings suggest a general trend favouring the implementation of red light cameras.

Older driver strategic choices must be taken into account when devising countermeasures to reduce collisions caused by traffic signal violations. Despite knowing that a large portion of older driver crashes occur at intersections, the prevalence with which older drivers run red lights is largely unknown (e.g., McGee & Eccles, 2003). Older drivers are more likely to be injured or killed once in a collision than a younger driver (Hauer, 1988; Preusser et al., 1998). Therefore, intersection countermeasures that potentially reduce the probability of older drivers being involved in a crash are worthwhile. Based on this study and others about older driver performance at intersections (Caird & Hancock, 2002; Staplin & Lyles, 1991), it is reasonable to suggest that if signal violations occur among this group, they are more likely to be unintentional rather than deliberate violations. The use of red-light camera enforcement does not appropriately address the potential needs of older drivers who may run signals unintentionally.

**Experiment 1: Intersection Performance at Amber Onset**

To understand why older drivers are over-represented in intersection crashes, this study sought to describe the intersection performance of older and younger drivers when traffic lights changed from green to amber. Using a moderate-fidelity driving simulator, performance was measured from amber onset until drivers stopped or cleared the intersection (see **Figure 1**). Time to stop line (TSL) at amber onset was manipulated as drivers approached intersections at 70 km/h (42 mph). Seventy-seven participants, approximately balanced for gender and age group, volunteered from the age categories of 18 to 24, 25 to 35, 55 to 64 and 65+. Driver decisions to stop or go were predicted using a logistic regression model with time to stop-line as the single significant predictor. At the longest time to stop line (3.58 s), those 55 and older were significantly less likely to stop than those in the two younger age groups. Older drivers approached intersections more slowly and stopped more accurately than younger drivers.

There were no age differences in perception response time (PRT), perception or response components. Time to stop line (TSL) significantly affected PRT and means progressively increased as TSL increased; 0.86 s at 1.73 s, 0.93 s at 2.21 s, 0.90 s at 2.61 s, 0.95 s at 2.69 s, 0.93 s at 3.1 s, and 1.03 s at 3.58 s. Thus, PRT was affected by the time constraints imposed by the time to stop line when the amber light was activated. The urgency to stop is reflected in the PRTs (Summala, 2000). In particular, drivers delayed contacting the brake, as indicated in the significant effect of TSL on response, when more time was available to stop. Perception and reaction time have not been measured in previous amber onset studies. Older driver rates of deceleration were significantly lower than younger age groups.


**A** **B**

**Figure 1.** Image A (left) shows an intersection approach with oncoming and parked vehicles at a time to stop line of 2.69 s. B shows a screen capture of the interior of the simulator with brake, accelerator, speed and steering variables overlaid.

Older drivers (65+) were significantly less likely to clear the intersection than other age groups. Initial velocity at the light change was indicative of the propensity of younger drivers to adopt higher speeds and older drivers to adopt slower speeds. When the dependent variables of velocity, stopping accuracy and intersection clearance are considered together, the adaptive strategy of a slower velocity adopted by older drivers generates benefits and costs. Those 65+ were able to come to a more accurate stop. However, clearing the intersection from a lower velocity became more problematic if they had to run the amber light. Stop line and intersection exit velocities also indicate that the oldest age group is slower than other age groups by about 4 to 5 km/h. If older drivers are more likely to be in an intersection when the all-red phase occurs, the timing of it according to the ITE formula (ITE, 1994) is clearly an important design recommendation (Staplin et al., 1998). Implications of the results for the ITE amber-phase equation and red-light running countermeasures are discussed in Section 4.

## Experiment 2: In-Vehicle Sign Effects on Intersection Performance

In the second experiment, two in-vehicle signs, presented in a head-up display format, were evaluated to determine if intersection performance improved or unwanted adaptive behaviours occurred (see **Figure 2**). Overall, the advanced in-vehicle signs reduced intersection approach speed, increased the probability of stopping at the intersection, increased stopping accuracy, but also increased the likelihood that drivers would be left in the intersection when the traffic light turned red.

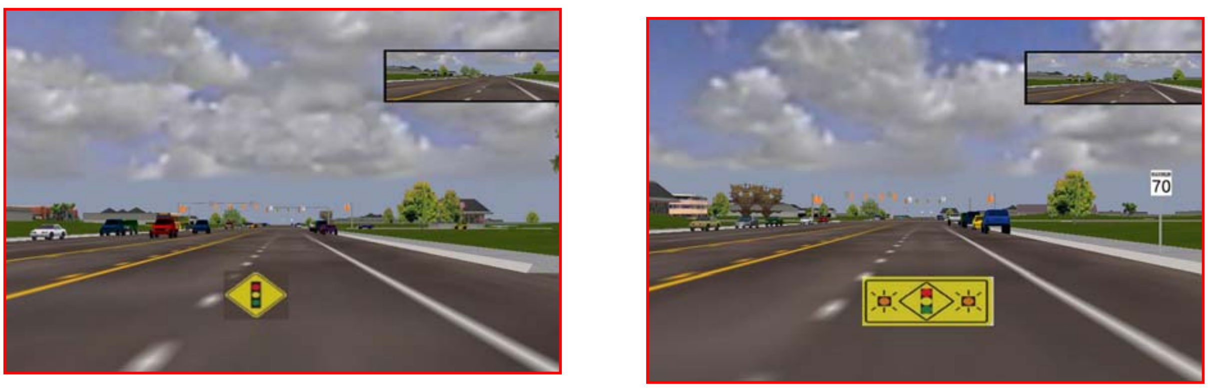


**Figure 2.** Intersection approach with oncoming and parked vehicles with the diamond advanced warning sign (left) and rectangular advanced warning sign (right).

In-vehicle signs facilitated more younger and older drivers to come to a stop at intersections with relatively short amber onsets. The net effect of the in-vehicle signs was to increase the percentage of those stopping in both age groups. At baseline, older drivers were less likely to stop and more likely to go than younger drivers. In addition, the speed of those who stopped and went through the intersection was reduced by the in-vehicle signs. Drivers decreased their speed as they approached the intersection and they were able to stop with greater accuracy than when they were not given the advanced sign. The velocity reduction produced by the in-vehicle signs was greatest at amber onset and progressively less effective at stop line and intersection exit measurement locations. The primary behavioural influence of the in-vehicle signs was on removing the driver's foot from the accelerator in advance of the light changes. Older drivers perceived, searched or processed traffic light information somewhat more slowly than younger drivers. However, once a decision was made to stop, they had faster response time and higher deceleration rates than younger drivers to compensate (cf., Vercruyssen, 1997). Like the results of Experiment 1, older drivers adopted slower intersection approach speeds, stopped more accurately and were more likely to not clear the intersection before the traffic light turned to all red.

**Experiment 3: In-Vehicle Sign Comprehension, Usefulness and Visual Behaviour**

The third experiment tested the comprehension of 24 in-vehicle signs by older and younger drivers (see **Figure 3**). Comprehension and perceived usefulness of the in-vehicle signs varied by age and context. Fixation duration and frequency of the in-vehicle and existing traffic signs were dependent on whether the information in the in-vehicle sign was understood. Search for corresponding traffic signs and contextual information was evident in the eye movement patterns (see **Figure 4**). Signs that provided information about upcoming actions, such as stopping or changing lanes, were valued more by older drivers.


**A** **B**

**Figure 3.** Examples of the 24 images tested. Image A (left) shows an intersection approach with a construction sign in the head-up display. Intersection B shows a dangerous goods route sign. A complete table of HUD signs and intersection images can be found in Appendix D.

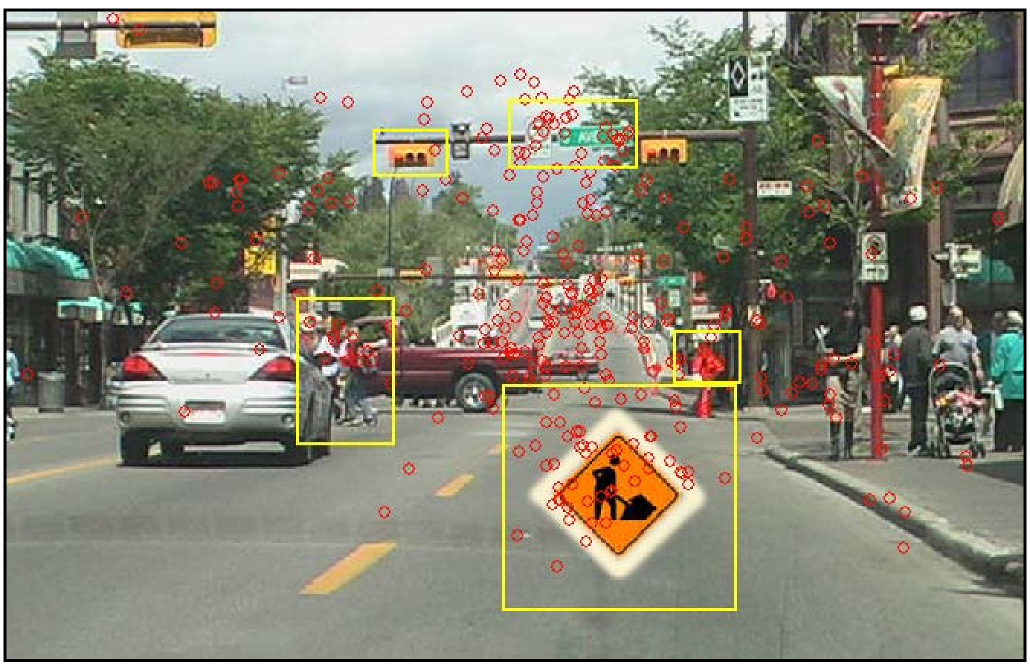

**Figure 4.** Areas of interest (yellow boxes) and fixations (red circles) for participants using the "Men at Work" sign (*MUCTD* W21-1a). Note the corresponding traffic sign just above the HUD sign.

**Conclusions**

The studies that were conducted serve to improve the safety of the older driver by developing innovative in-vehicle ITS. The in-vehicle signs developed and tested in Experiments 1 and 2 meet this objective. In addition, a number of design guidelines for in-vehicle ITS that accommodate older drivers were also applied and include:

- Target intersections as they represent an important location for reducing crash risk for older drivers.
- Increase the available time to make decisions at intersections.
- Reduce the amount of information at intersections required for making a decision.
- Do not provide explicit timing information about when traffic lights will change. Risk taking drivers may choose to run yellow and red lights.
- Take into account that traffic signs presented in the vehicle have costs and benefits. Corresponding signs in the traffic environment require the driver to scan for them when the meaning of the in-vehicle sign is poorly understood.

Additional research was identified in the following areas:

- *Timing.* The timing of the warning signs and the length of time that they are presented to the driver are several fundamental design issues that require additional research.
- *Weather.* When snow, rain and fog are present, in-vehicle signs are clearly beneficial, but require additional research.

- *Visual Search.* Search habits being what they are, drivers may be conditioned to expect the in-vehicle signs when none are presented. Conversely, the failure to search for and comply with necessary regulatory and warning signs has a cost of crash potential.

- *Expectancy.* Should any limitations be imposed on what redundant information appears in an in-vehicle sign? Should in-vehicle signs be reserved for signs with "action potential" (MacDonald & Hoffman, 1991), that is, those that are used most by drivers on a consistent basis?

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## SOMMAIRE

### Portée du projet

Cette étude des contre-mesures fondées sur les systèmes de transports intelligents embarqués pour améliorer la performance aux intersections des conducteurs âgés a été mise sur pied par Transports Canada, par l'intermédiaire du Centre de développement des transports.

L'étude poursuivait les objectifs suivants :

- **Phase I :** Revoir la littérature sur les applications embarquées des STI afin de déterminer celles qui sont le plus susceptibles d'aider les conducteurs âgés à surmonter les difficultés qui se posent aux intersections.

- **Phase II :** À partir des résultats de la phase I, élaborer des scénarios de simulation, développer des prototypes de technologies embarquées, des systèmes de mesure, des plans d'expérience et des expériences pilotes pour évaluer empiriquement quelques technologies embarquées prometteuses.

- **Phase III :** Procéder à une évaluation systématique de chaque technologie en réalisant plusieurs expériences avec des échantillons de conducteurs jeunes et âgés. Déterminer les forces et les faiblesses de chaque technologie.

- **Phase IV :** À partir des résultats de la phase III, améliorer la conception des prototypes de technologies STI. Réaliser de nouvelles études avec les prototypes améliorés pour déterminer leur efficacité à améliorer la performance des conducteurs âgés.

- **Rapport technique :** Faire une synthèse des résultats et en dégager des recommandations précises pour le développement d'applications STI destinées aux conducteurs âgés, des lignes directrices de conception généralisables, et des méthodes d'essai pour vérifier l'efficacité et la sûreté de ces applications.

Les études réalisées dans le cadre du présent projet sont complémentaires de la recherche sur les mesures de prévention des collisions aux intersections actuellement menée au sein de la Federal Highway Administration (FHWA) et de la National Highway Traffic Safety Administration (NHTSA) des États-Unis. La recherche réalisée est unique en ce qu'elle englobe les aspects développement, évaluation et application.

**Revue de la technologie**

Diverses avenues technologiques sont actuellement explorées pour aider les conducteurs à éviter les collisions aux intersections. Celles-ci comprennent des modifications aux dispositifs de signalisation classiques, des systèmes anticollision (p. ex., signaux sonores, haptiques, visuels), des systèmes d'information embarqués et des caméras de surveillance aux feux rouges. Mais les concepteurs de ces systèmes ne pensent pas toujours aux conducteurs âgés. Chaque système comporte des avantages et des inconvénients potentiels (voir Caird, 2004).

Les solutions liées à l'infrastructure, comme celle qui consiste à rendre plus visibles les feux de circulation et les panneaux d'arrêt, peuvent bénéficier aux conducteurs de tous âges. Quant aux technologies embarquées, elles peuvent être adaptées aux besoins particuliers du conducteur, et l'information peut être transmise directement au conducteur. La FHWA et la NHTSA ont concentré leurs efforts de recherche sur des contre-mesures liées à l'infrastructure et à la signalisation à bord des véhicules, respectivement. Si, de fait, les conducteurs âgés ont du mal à voir les feux de circulation et les panneaux d'arrêt, les solutions liées l'infrastructure sont les plus susceptibles d'être mises en œuvre et d'engendrer des avantages immédiats pour cette catégorie de conducteurs. Pour ce qui est des systèmes embarqués, avant que la R&D puisse passer à l'étape du déploiement, il doit exister un marché de masse. La présente revue porte sur les deux approches, infrastructure et système embarqué. Elle fait suite à notre recherche antérieure réalisée pour le compte de Transports Canada sur les facteurs contribuant aux accidents mettant en cause des conducteurs âgés aux intersections (Caird et coll., 2002).

**Caméras de surveillance aux feux rouges**

Augmenter la durée du feu jaune est une contre-mesure qui s'est révélée efficace pour réduire au moins temporairement le nombre des infractions aux feux rouges. On attribue aux caméras de surveillance aux feux rouges une diminution de 40 % des infractions aux intersections équipées d'un tel système (Retting et coll., 1999). On a de plus estimé que les collisions latérales et par l'arrière avaient diminué de 26 % après l'installation de caméras (Flannery et Maccubbin, 2002). Toutefois, selon une autre étude, les collisions par l'arrière avaient augmenté de 40 % (Golob et coll., 2002). La question de savoir si les caméras de surveillance augmentent ou diminuent les collisions par l'arrière reste non résolue. À cause de problèmes liés à la méthodologie, on ignore encore l'effet précis des caméras de surveillance sur les infractions et les accidents. Mais dans l'ensemble, les résultats des recherches indiquent une tendance en faveur de l'installation de caméras de surveillance aux feux rouges.

Il faut tenir compte des choix stratégiques faits par les conducteurs âgés lorsque l'on conçoit des mesures pour réduire les collisions causées par le non-respect des feux de circulation. On sait qu'une proportion importante des accidents mettant en cause des conducteurs âgés ont lieu à une intersection, mais on ignore dans quelle proportion les conducteurs âgés grillent les feux rouges (voir McGee et Eccles, 2003). Dans une collision, les conducteurs âgés courent davantage de risques d'être tués ou blessés que les jeunes conducteurs (Hauer, 1988; Preusser et coll., 1998). Par conséquent, les mesures susceptibles de prévenir les collisions aux intersections et de réduire le risque pour les conducteurs âgés d’être impliqués dans un accident méritent l’attention des chercheurs. Les résultats de la présente étude et ceux d’autres études sur le comportement des conducteurs âgés aux intersections (Caird et Hancock, 2002; Staplin et Lyles, 1991) donnent à penser que, dans ce groupe d’âge, le non-respect de la signalisation est plus souvent non intentionnel que délibéré. Les caméras de surveillance sont donc peu appropriées pour répondre aux besoins potentiels de conducteurs âgés qui grillent parfois les feux rouges accidentellement.

**Expérience 1 : Comportement à l’activation du feu jaune**

Pour comprendre pourquoi les conducteurs âgés sont surreprésentés dans les accidents aux intersections, les chercheurs ont examiné le comportement de conducteurs jeunes et âgés lorsque le feu passe du vert au jaune. À l’aide d’un simulateur de conduite de fidélité moyenne, ils ont mesuré le comportement des conducteurs entre l’activation du feu jaune et l’arrêt ou le franchissement de l’intersection (voir la **Figure 1**). La variable principale était le temps d’immobilisation à la ligne d’arrêt (TILA) après l’activation du feu jaune, alors que les conducteurs s’approchaient de l’intersection à 70 km/h (42 mi/h). Soixante-dix-sept participants, assez également répartis par sexe et groupe d’âge, ont volontairement pris part à l’étude; ils représentaient les catégories d’âge suivantes : 18 à 24 ans, 25 à 35 ans, 55 à 64 ans et 65 ans et plus. La décision du conducteur de s’arrêter ou de continuer était prédite à l’aide d’un modèle de régression logistique, la seule variable indépendante étant le TILA. Au TILA le plus long (3,58 s), les conducteurs de 55 ans et plus étaient significativement moins enclins à s’arrêter que ceux des deux groupes d’âge inférieur. Les conducteurs âgés s’approchaient des intersections plus lentement et s’arrêtaient avec plus de précision que les jeunes conducteurs.

On n’a pas noté de différence selon l’âge dans les temps de perception-réaction (TPR), pas plus que dans les délais de perception ou de réaction. Le TILA avait un effet significatif sur le TPR, et le TPR moyen augmentait progressivement à mesure qu’augmentait le TILA : 0,86 s à 1,73 s, 0,93 s à 2,21 s, 0,90 s à 2,61 s, 0,95 s à 2,69 s, 0,93 s à 3,1 s et 1,03 s à 3,58 s. Ainsi, les contraintes de temps imposées par le TILA à l’activation du feu jaune influaient sur le TPR. L’urgence de s’immobiliser transparaît dans les TPR (Summala, 2000). Plus précisément, lorsqu’ils avaient plus de temps pour s’arrêter, les conducteurs tardaient à appliquer les freins, comme l’indique l’effet significatif du TILA sur la réaction. Les temps de perception et de réaction n’ont pas été mesurés dans les études antérieures sur le comportement à l’activation du feu jaune. Les taux de décélération des conducteurs âgés étaient significativement plus faibles que ceux des groupes plus jeunes.


**A** **B**

**Figure 1.** L’image A (à gauche) montre l’arrivée à une intersection avec véhicules stationnés et véhicules venant en sens inverse. Le temps d’immobilisation à la ligne d’arrêt a été de 2,69 s. L’image B montre une copie écran de l’intérieur du simulateur avec, en surimposition, les données relatives aux variables freinage, accélération, vitesse et direction.

Les conducteurs les plus âgés (65 ans et plus) avaient significativement moins tendance que les autres groupes d’âge à poursuivre leur route et franchir l’intersection. La vitesse initiale, soit la vitesse au changement de feu, était un bon indicateur de la propension des jeunes conducteurs à accélérer et de celle des conducteurs âgés à ralentir. En considérant ensemble les variables dépendantes que sont la vitesse, la précision de l'arrêt et le franchissement de l'intersection, la stratégie adaptative du ralentissement, adoptée par les conducteurs âgés, se révèle être à double tranchant. En effet, les personnes de 65 ans et plus s'immobilisaient avec plus de précision. Mais s'ils «grillaient» le feu jaune, il leur était difficile, du fait qu'ils roulaient lentement, de dégager à temps l'intersection. Les vitesses enregistrées à la ligne d'arrêt et à la sortie de l'intersection confirment que les conducteurs les plus âgés roulent de 4 à 5 km/h plus lentement que les groupes plus jeunes. Si les conducteurs âgés sont particulièrement susceptibles de se trouver sur une intersection lorsque le feu passe au rouge, le chronométrage du feu rouge selon la formule de l'ITE (ITE, 1994) devient une recommandation de conception particulièrement importante (Staplin et coll., 1998). Les conséquences des résultats sur l'équation de l'ITE concernant la phase *feu jaune* et les mesures de prévention des infractions au feu rouge sont exposées à la section 4.

**Expérience 2 : Effets de la signalisation à bord des véhicules sur la performance aux intersections**

La deuxième étude a porté sur deux panneaux de signalisation présentés en visualisation tête haute à bord du véhicule (voir la **Figure 2**). Le but était de déterminer s'ils amélioraient la performance aux intersections ou s'ils induisaient des comportements adaptatifs indésirables. Dans l'ensemble, les panneaux de signalisation avancée à bord du véhicule réduisaient la vitesse à laquelle les conducteurs s'approchaient de l'intersection, ils augmentaient la probabilité et la précision de l'arrêt à l'intersection, mais ils augmentaient aussi la probabilité qu'un conducteur se trouve encore sur l'intersection lorsque le feu passait au rouge.

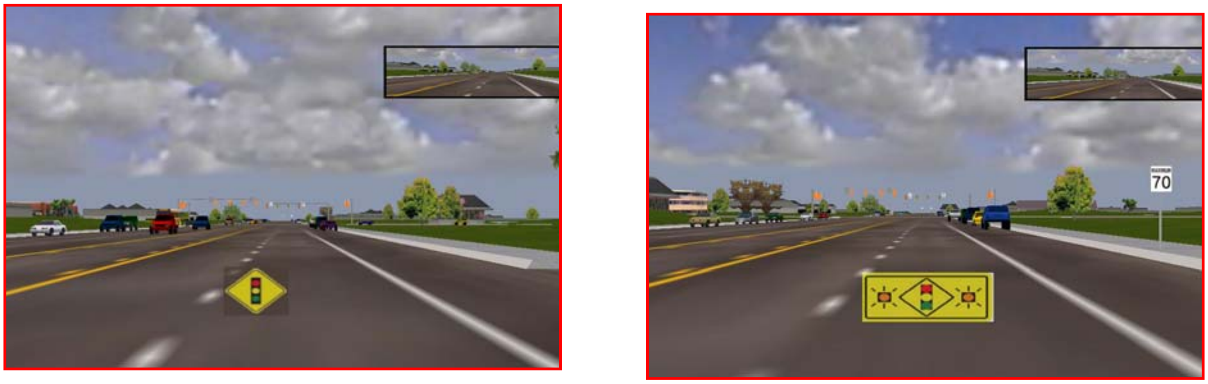


**Figure 2.** Arrivée à une intersection avec véhicules stationnés et véhicules venant en sens inverse, avec panneau d'avertissement avancé en forme de losange (à gauche) et panneau d'avertissement avancé rectangulaire (à droite).

Les panneaux de signalisation à bord des véhicules ont fait en sorte que davantage de conducteurs, jeunes et âgés, se sont arrêtés à l'intersection, malgré un feu jaune relativement serré. L'effet net des panneaux de signalisation à bord des véhicules a été d'augmenter le pourcentage des conducteurs qui s'immobilisaient, tous âges confondus. Sans cette signalisation, les conducteurs âgés avaient moins tendance à s'arrêter et étaient plus enclins à poursuivre leur route que les jeunes conducteurs. Par ailleurs, les panneaux à bord avaient pour effet de réduire la vitesse des conducteurs qui s'arrêtaient comme de ceux qui traversaient l'intersection. En effet, les conducteurs ralentissaient à l'approche de l'intersection et ils pouvaient s'immobiliser avec plus de précision que s'ils n'avaient pas accès à ces panneaux de signalisation avancée. C'est à l'activation du feu jaune que l'effet ralentisseur de la signalisation embarquée se faisait le plus sentir. Cet effet était moins marquant à la ligne d'arrêt et à la sortie de l'intersection, les deux autres endroits où la vitesse était mesurée. La principale influence de la signalisation embarquée sur le comportement des conducteurs est qu'elle les amenait à lever le pied avant même le changement du feu. Les conducteurs âgés percevaient, cherchaient ou traitaient l'information transmise par les feux de circulation un peu plus lentement que les jeunes conducteurs. Toutefois, une fois qu'ils avaient décidé d'arrêter, ils compensaient par un temps de réaction plus court et un taux de décélération plus élevé (voir Vercruyssen, 1997). Comme à l'expérience 1, les conducteurs âgés s'approchaient plus lentement de l'intersection, s'immobilisaient avec plus de précision et étaient plus susceptibles de se trouver encore sur l'intersection lorsque le feu passait au rouge.

**Expérience 3 : Compréhension des panneaux de signalisation à bord des véhicules, perception de leur utilité et comportement visuel**

La troisième expérience visait à vérifier la compréhension de 24 panneaux à bord des véhicules par des conducteurs jeunes et âgés (voir la **Figure 3**). La compréhension et la perception de l'utilité des panneaux variaient selon l'âge et le contexte. La durée et la fréquence de fixation de la signalisation intérieure et extérieure dépendaient de la compréhension de l'information contenue dans le panneau. La recherche de panneaux de signalisation et d'information contextuelle transparaissait clairement dans les mouvements oculaires (voir la **Figure 4**). Les panneaux qui informaient de manœuvres à venir, comme un arrêt ou un changement de voie, étaient davantage appréciés par les conducteurs âgés que par les jeunes conducteurs.


**A** **B**

**Figure 3.** Deux des 24 images présentées. L'image A (à gauche) montre l'approche d'une intersection avec un panneau signifiant *Travaux* en visualisation tête haute. L'intersection B montre un panneau routier avec le symbole *Marchandises dangereuses*. On trouvera à l'annexe D le tableau complet des panneaux et images d'intersection HUD (*head-up display*).

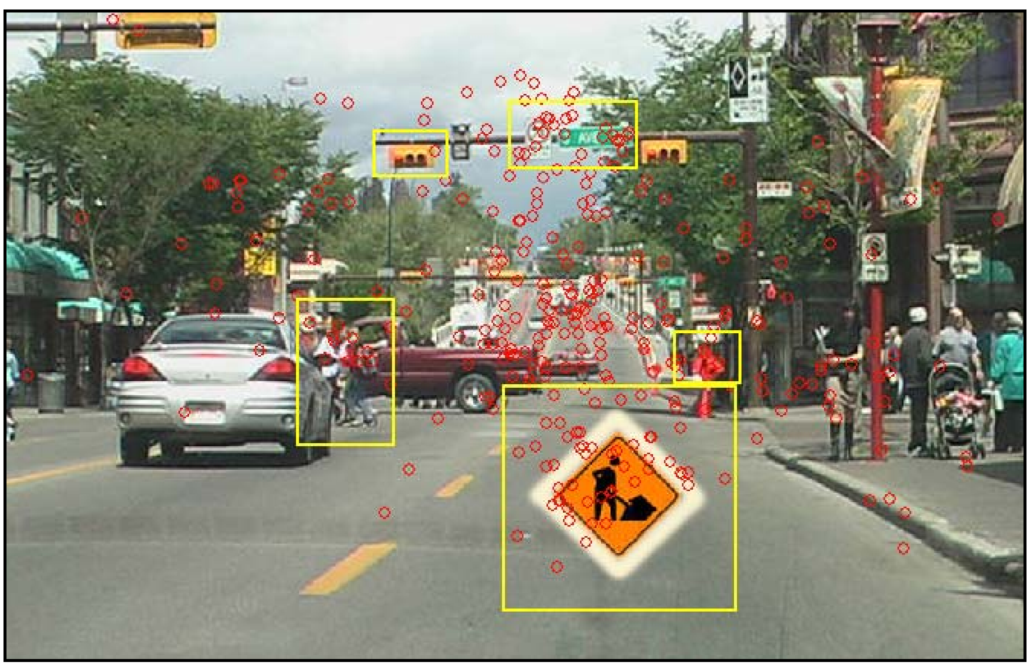

**Figure 4.** Zones d'intérêt (rectangles jaunes) et points de fixation (cercles rouges) pour les participants qui visualisaient le panneau *Travaux* (*MUCTD* W21-1a). À noter le panneau de signalisation juste au-dessus du panneau HUD.

**Conclusions**

Les études qui ont été réalisées visent à améliorer la sécurité des conducteurs âgés en développant des STI embarqués novateurs. La signalisation embarquée développée et mise à l'essai au cours des expériences 1 et 2 atteint cet objectif. De plus, certaines lignes directrices de conception applicables aux STI embarqués pour conducteurs âgés ont été mises en pratique. En voici quelques-unes :

- Cibler les intersections, car elles représentent un facteur de risque d'accident important chez les conducteurs âgés.

- Allonger la fenêtre de décision aux intersections.

- Simplifier les prises de décision en réduisant le nombre d'éléments d'information qui doivent être pris en compte.

- Ne pas donner d'indice clair sur le moment où les feux vont changer. Cela pourrait inciter les conducteurs téméraires à griller les feux jaunes et les feux rouges.

- Ne pas oublier que les panneaux de signalisation présentés à bord des véhicules peuvent engendrer des inconvénients. Ainsi, le conducteur doit faire un balayage visuel de la scène extérieure pour trouver les panneaux correspondants, lorsqu'il ne comprend pas la signification du panneau présenté à bord.

D'autres études devraient être réalisées dans les domaines suivants :

- *Choix du moment et durée.* Le moment où sont présentés les panneaux d'avertissement et la durée de leur présentation au conducteur constituent plusieurs enjeux de conception fondamentaux sur lesquels il y a lieu de se pencher plus avant.

- *Météo.* Lorsqu'il neige, qu'il pleut ou qu'il y a du brouillard, les panneaux embarqués sont nettement avantageux. Mais d'autres études s'imposent.

- *Recherche visuelle.* Les habitudes de recherche étant ce qu'elles sont (qui cherche trouve), les conducteurs peuvent être conditionnés à attendre en vain l'apparition de panneaux embarqués. À l'inverse, l'omission de chercher les panneaux de signalisation et d'avertissement et de s'y conformer, lorsqu'ils existent, pose un risque d'accident.

- *Attente.* Devrait-on fixer des normes quant au type d'information redondante que peut contenir un panneau embarqué? Les panneaux embarqués devraient-ils être uniquement des panneaux à «potentiel d'action» (MacDonald et Hoffman, 1991), soit les panneaux les plus utilisés par les conducteurs, jour après jour?

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# 1. INTRODUCTION

Turning maneuvers at intersections can be especially difficult for older drivers. They typically travel fewer miles per year, yet their turn accident risk is greater than most other age groups (Evans, 1988; McGwin & Brown, 1999). In particular, older drivers are over-represented in most types of intersection accidents (Preusser, et al., 1998). Research has found that failures of attention and perception contribute to intersection accidents and, in general, measures of divided and selective attention are predictive of older driver accidents (Caird et al., 2002; Owlsley, 2004).

The results of prior studies for the Transportation Development Centre (TDC) of Transport Canada on older driver intersection performance were used to compare performance with Intelligent Transportation Systems (ITS) countermeasures. The focus of the proposed experimental studies will be to improve specific older driver intersection difficulties (Caird, 2001; Caird, et al., 2001; Caird, et al., 2002). In-vehicle ITS technology initiatives are frequently the product of innovative fusions of telecommunications, automotive electronics, and computing. A wide variety of new driver information systems are part of extensive government and corporate telematic initiatives in the US, Europe, Japan, and Australia. In-vehicle telephones, personnel digital assistants (PDAs), on-road hazard warnings, in-vehicle signs, congestion and vehicle system monitoring, digital maps, and tourist and emergency services are just some of the products that will become commonly integrated into many vehicles. In particular, Vision Enhancement Systems (VES), In-vehicle Signing Information Systems (ISIS), and Collision Warning Systems (CWS) may provide the older driver with a means to increase their mobility and maintain safety concurrently.

Previous TDC work in this area has produced three reports:

- Department of Psychology, University of Calgary, "***A Design Guideline and Evaluation Framework to Determine the Relative Safety of In-Vehicle ITS Systems for Older Drivers***", TP 13349E, December 1998. This report describes a design guideline and evaluation framework for ITS applications by older drivers. Vision enhancement systems were used as a test case.

- Department of Psychology, University of Calgary, "***The Effects of Conformal and Non-Conformal Vision Enhancement Systems on Older Driver Performance***", TP13422E, December 2000. This work focuses on the viability of VES properties on older driver performance and preference. Implications of the results for the design of conformal and non-conformal VES were presented.

- Department of Psychology, University of Calgary, "***Contributing factors to accidents at intersections by older drivers: R&D Plan and Empirical Studies***", TP 13939E, January 2002. This research investigates older drivers' capabilities to search intersections for relevant threats such as pedestrians, light changes, and other vehicles.

## 1.1 Project Overview

The projects that are proposed will address the degree that older and younger drivers can use promising ITS in-vehicle countermeasures to improve their intersection performance. Results of the studies will be used to identify effective ITS countermeasures to reduce older driver intersection accidents.

## 1.2 Project Objectives

*1.2.1* Reduce driver fatalities and injuries.

*1.2.2* Improve the safety of travel for older drivers at intersections through the development of innovative ITS countermeasures.

*1.2.3* Contribute significantly to the knowledge of older drivers' performance at intersections with the assistance of in-vehicle ITS technologies.

*1.2.4* Create opportunities for technology transfer of ITS in-vehicle designs through government, industry and university partnerships.

*1.2.5* Disseminate research results, through a TDC technical report, conference presentations such as the Transportation Research Board and ITS America, and peer reviewed publications.

## 1.3 Scope

The work will include: an analysis of existing ITS technology (Phase I); the development of the means to test specific prototype ITS technologies (Phase 2); conduct a systematic series of driving simulation studies on promising technologies (Phase 3); improve specific technologies for additional performance testing (Phase 4); and summarize the results into design recommendations, guidelines, and test methods for wider consumption.

## 1.4 Project Phases

The first part of this project (R&D Plan, Caird et al., 2002) developed new methods to assess the contribution of motion perception, and selective and divided attention to vehicle accidents in realistic situations without putting drivers in harm's way. The second contract has the following objectives:

**Phase I:** Review the literature on ITS in-vehicle applications that have the greatest potential to aid older driver performance limitations at intersections. Such countermeasures may include: intelligent traffic lights, auditory and haptic collision warning systems, in-vehicle signing information systems, and vision enhancement systems.

**Phase II:** Based on Phase I, develop simulation scenarios, in-vehicle prototype applications, measurement systems, experimental designs, and pilot experiments to empirically evaluate promising in-vehicle technologies.

**Phase III:** Conduct a systematic evaluation of each technology with multiple experiments using younger and older driver samples. Determine the design strengths and weaknesses of each technology.

**Phase IV:** Based on the results of Phase III, improve the design of prototype ITS applications. Perform additional studies with the improved designs to determine the effectiveness the countermeasure to improve older driver performance.

**Technical Report:** Synthesize the results into specific recommendations for the development of older driver ITS applications, generalizable design guidelines and testing approaches for efficiency and safety.

The principle objective of the reported research is to determine the effectiveness of ITS technologies to reduce the performance difficulties that older drivers have at intersections. Each subsequent section of the report presents the outcome of each of these phases. Section 2 reviews the literature concerning in-vehicle technologies that may be used at intersections. A number of technologies, which have advanced considerably since a previous report (Caird et al., 1998), will be examined. Section 3 examines red light running cameras in depth to determine if older drivers are helped or hindered by the their implementation. Sections 4, 5 and 6 describe specific hypotheses, experimental designs and results of three studies to determine the effectiveness of in-vehicle signing information systems. The final section synthesizes the results of the three studies and discusses the implications of the findings for ITS countermeasures and design recommendations.

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# 2. TECHNOLOGY REVIEW

## 2.1 Introduction

A number of possible technologies are being developed to help drivers avoid collisions at intersections (Ferlis, 2001). These include modifications to conventional traffic controls, collision warning systems (e.g., auditory, haptic, visual), in-vehicle information systems, and red light running camera systems. Many have not necessarily considered the older driver explicitly when a system is designed. Each system has potential advantages and disadvantages (see Caird, 2004).

Infrastructure-based solutions such as increasing the conspicuity of traffic lights and stop signs have the potential to benefit all drivers. In-vehicle technologies may be tailored to specific driver needs and information can be delivered to the driver directly. The U.S. Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration (NHTSA) have focused research efforts on infrastructure and in-vehicle intersection countermeasures, respectively. If older drivers do indeed fail to see traffic lights and stop signs (Presseur et al., 1998), infrastructure-based solutions are more likely to be implemented and have an immediate benefit to older drivers. Research and development of in-vehicle system are likely to require mass marketing appeal before a system is deployed. Both approaches, infrastructure and in-vehicle, are considered in this review and follow from our previous research with Transport Canada on contributing factors to older driver intersection crashes (Caird, et al., 2002).

## 2.2 Red Light Running Research and the Older Driver

Red light or traffic signal violations are a significant traffic safety issue. In 2000, 106,000 crashes in the United States were caused by drivers running red lights, which resulted in 89,000 injuries and 1,036 deaths (Federal Highway Administration, 2003). Angle collisions, such as those caused by red-light running, usually result in a higher percentage of injuries than other types of accidents (Retting et al., 2001).

According to the Federal Highway Administration (FHWA) and a U.S. nationwide survey of drivers, red light running does not conform to a specific demographic and most drivers who admit to red light running usually cite “being in a hurry” as the main reason for violating the signal (FHWA, 2003; Porter & Berry, 2001). Statistics for Canada are not available overall, however, certain municipalities keep track of red light accidents. For example, there were 769 collisions in Calgary in 1999 attributed to red-light running, which resulted in five fatalities and 289 injuries (Calgary Police Service, 2003). Although young drivers (e.g., 18-35) tend to be implicated more often as red-light runners than older drivers (55+), intersections are a known problem for older drivers. Whether older drivers run red lights on purpose or inadvertently is not necessarily clear.

The nationwide survey by Porter and Berry (2001) on red-light running behaviours showed that 35.3% (N=269) of drivers surveyed over age 55 admitted to having run a red light. In this sample of 269 drivers, 12.6% also admitted to having run a red light recently (i.e., ran at least one red light in the last 10 intersections driven through). Unfortunately, the survey questions focused largely on the deliberate reasons (e.g., in a hurry) why drivers violated red lights and failed to capture any of the potential reasons that may lead to unintentional violations of traffic signals. An unintentional violation of a traffic signal occurs when a driver goes through the signal without a deliberate intention to run the signal. For example, a distracted driver might violate a signal because he or she missed the changing light. Certain intersection characteristics may also lead to unintentional violations of traffic signals. In particular, the role of the dilemma zone and the timing of lights will be discussed more extensively below. Overall, it remains unknown whether older drivers violate signals, and if they do, whether it is mostly deliberate or unintentional. Because older drivers are known to have high intersection crash rates, it is essential to investigate whether signal violations are a problem for older drivers and whether simple modifications to traffic light signal timing are an effective solution for older drivers.

### *2.2.1 The Intersection Dilemma Zone and Signal Phasing*

To effectively discuss potential older driver issues with traffic signals, it is first important to explain how signal phasing is determined at intersections. The Institute of Transportation Engineers (ITE) provides design specifications for how long yellow signal phases should be (1994). Some intersections also incorporate an all-red phase where lights in all directions are red for a brief period to provide extra time for vehicles to clear the intersection and therefore, prevent potential collisions because of red-light violators. A major problem at high-speed intersections involves an area upstream from the traffic signals known as the *dilemma zone*. The dilemma zone is the length of roadway on a high-speed intersection approach wherein drivers may be indecisive and respond differently to the onset of the yellow signal (McCoy & Pesti, 2003). That is, some drivers may choose to stop while others choose to go, even if adequate room to stop exists. “The dilemma zone is the area where the drivers find themselves if, when they see the yellow indication, they lack adequate distance to stop before the intersection but are too far away to enter the intersection before the red indication” (Bared, et al., 2003, pg. 29). Unintentional violations of a red signal may be associated with the dilemma zone (Schattler, Datta, & Hill, 2003). Depending on the length of the yellow phase (i.e., usually it is between 3-6 s long depending on intersection speed, width and other parameters), a driver in the dilemma zone might go because he is uncertain of when the light will turn to red and find that he is unable to clear the intersection during the yellow phase. In general, the shorter the yellow light phase, the more likely that a red-light violation will occur (Bonneson & Son, 2003).

Schattler et al. (2003) conducted a before and after study to determine the effectiveness of the following ITE (1992) equation for the yellow intervals at intersections using an all-red phase in Michigan:

$$\text{Length of the Change and Clearance Interval} = t + \frac{v}{(2a \pm 2Gg)} + \frac{(W+L)}{v} \qquad \textit{(Eq. 1)}$$

Where:

$t$ = driver perception-reaction time for stopping, taken as 1 second

$v$ = approach speed, feet pet second (meters per second), taken as 85th percentile speed

$a$ = deceleration rate for stopping, taken as 10 ft/s$^2$ (3.0 m/s$^2$)

$g$ = percent grade, divided by 100 (i.e., a 6% grade is entered as 0.06 into the equation)

$G$ = acceleration due to gravity taken as 32.2 ft/s$^2$ (9.8 m/s$^2$)

$W$ = width of intersection, in ft (m), measured from the upstream stop bar to the downstream extended edge of pavement

$L$ = length of clearing vehicle, taken as 20 ft (6.1 m)

The results of the study were mixed, with some intersections showing improvements and others not showing any improvement in the number of red-light runners and late exits from the intersection. This study did not focus on different age groups. The ITE calculation allows for a perception-response time of 1 s. If this equation is used to calculate the amber phase, which must be between 3-6 s, and the all-red phase for a 35 mph (~56 km/h) intersection approach where the intersection width is 30 feet, the amber phase will be 3.15 s long and the all-red phase will last 0.97 s. The minimum comfortable stopping distance is 183.09 feet (57.7 m) and the minimum distance needed to clear the intersection is 123.61 feet (37.7 m). The dilemma zone is 59.48 feet (18.1 m) (see **Figure 2.1** and **Table 2.1**).

Although the length of the dilemma zone does not change when Equation 1 is calculated for the same intersection parameters used for **Figure 2.1** using a PRT of 2 s instead of 1 s, the minimum comfortable stopping distance and the distance needed to safely clear the intersection do change appreciably. For a PRT of 2 s, the minimum comfortable stopping distance is 234.42 feet (71.5 m) and the minimum distance needed to safely clear the intersection before the light turns red is 174.94 feet (53.4 m). For older drivers, a slower response time might mean they miss the window for stopping safely at the intersection. Moreover, the length of the dilemma zone increases as the approach speed to the intersection increases. With an approach speed of 80 km/h (50 mph), the dilemma zone more than doubles to 91.51 feet (27.9 m), while the length of the all-red phase decreases to 0.68 s and the length of the amber phase increases by 1 s to 4.1s.

**Table 2.1.** Phase timing and dilemma zone calculator

| Input Parameters | | |
|---|---|---|
| $t_{prt}$ = | 2 | Perception Reaction Time (sec) |
| W = | 30 | Intersection Width (feet) |
| L = | 18 | Length of Vehicle (feet) |
| V = | 20 | Vehicular Speed (mph) = 29.33333 (ft/s) |
| d = | 10 | Deceleration rate, recommended 10ft/s^2 |
| G = | 32 | Acceleration due to gravity, 32ft/s^2 |
| g = | 0.06 | Grade of approach, in decimal form |
| $T_{yellow}$ = | | Time in amber phase (sec), **leave cell blank** to have it calculated via built in equation |

| Output Parameters | | |
|---|---|---|
| $X_s$ = | 101.69 | Minimum distance needed to comfortably stop (feet) |
| $X_c$ = | 54.14 | Minimum distance needed to clear intersection (feet) |
| $L_{dilemma}$ = | 47.55 | Length of Dilemma Zone (feet) |
| $t_{yellow}$ = | 3.23 | Time in amber phase (sec) - must range between 3-6s |
| $t_{red}$ = | 1.64 | Time for all red clearance phase (sec) |
| a = | 9.75 | Possible acceleration rate (depends on initial speed) |

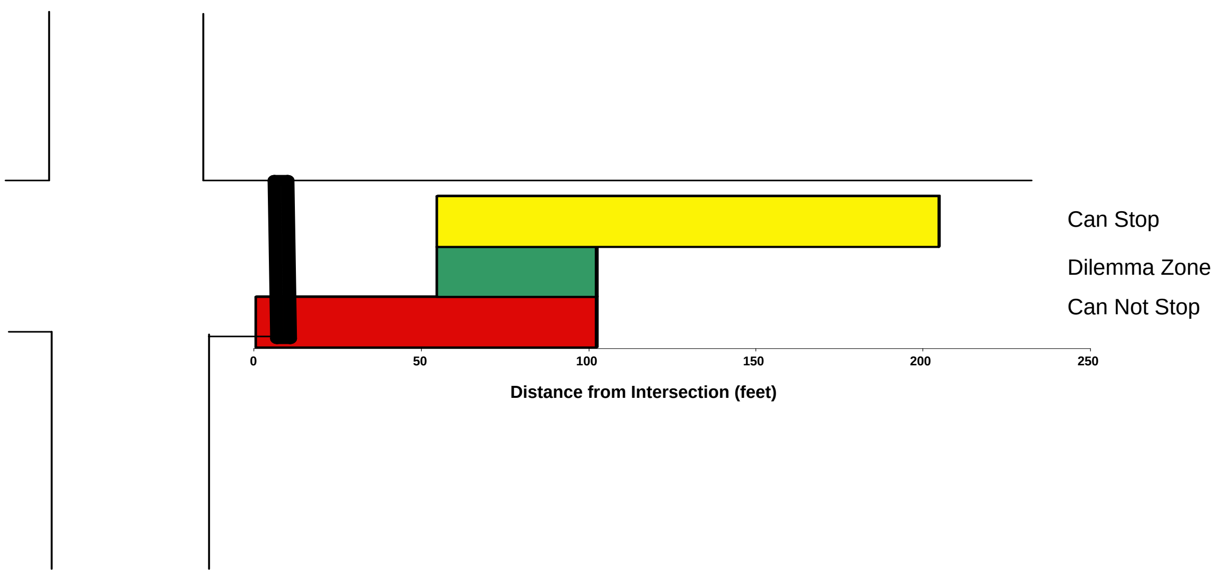


**Figure 2.1.** Dilemma zone, can stop, and can not stop based on **Table 2.1** input parameters. Table and Figure courtesy of Virginia Tech. Transportation Institute and adapted for Experiment 1.

At high-speed intersections, mechanisms are often in place to reduce the amount of time drivers spend in the dilemma zone. McCoy and Pesti (2003) investigated whether differences in red-light running frequency depended on the type of traffic control signals present at the intersection. The first control method, called advanced detection (AD), uses sensors throughout the intersection to detect traffic and extend the green phase to prevent the onset of the yellow phase while vehicles are in the dilemma zone. The locations of the advance detectors ensure that vehicles traveling at or below the design speed (i.e., 85$^{th}$ percentile speed for the intersection) will not be in their dilemma zones at the onset of the yellow phase. The presence of these vehicles extends the green phase to allow them safe travel through the intersection. One problem with this system is that the placement of sensors incorporates a long headway distance between vehicles (e.g., 2 seconds). This results in the system maxing out more often and can increase the chance that vehicles will be caught in the dilemma zone when the light is forced to turn yellow to allow cross traffic to flow (McCoy & Pesti, 2003).

Another method involves the activation of advance warning flashers (AWF) in conjunction with signs that say "prepare to stop when flashing". The flashers in this device are located upstream from the intersection and are activated at a predetermined time before the onset of a yellow light to minimize the number of drivers caught in the dilemma zone. The advantage of this design is that it does not have a green max-out scenario and, therefore, fewer vehicles may be caught in a dilemma zone. Vehicles traveling at the velocity for which the system is designed (i.e., 85$^{th}$ percentile) will reach the stop line before the light turns yellow, which means they are provided with dilemma zone protection. When comparing the AD and AWF methods, McCoy and Pesti (2003) found that there was little difference in red-light running, abrupt stops or vehicles accelerating at the onset of the yellow light. It is also unknown how these methods compare to intersections without any form of advance detection.

Inadequate signal timings and other characteristics of the intersection may encourage deliberate violations of traffic signals because driver behaviour at intersections is complex and often encompasses attitudes and beliefs about safety that interact with these intersection characteristics. For example, drivers may feel an urgency to get through the light instead of waiting for the next cycle at intersections with long signal phases that require them to wait for lengthy time periods (Porter & Berry, 2001). The probability of a driver stopping at an intersection also depends on how they view the possibility of a crash or traffic citation should they continue through the red light. Some drivers are more likely to take risks to improve their travel time or simply because they do not comprehend the probability of a crash and the consequences associated with an accident. Moreover, large groups of vehicles often promote shorter headways and drivers may be more likely to follow a vehicle through a light if they are close behind it.

### *2.2.2 Intersections and the Older Driver*

According to the U.S. Federal Highway Administration, approximately 50% of older driver (age 50+) accidents occur at intersections, compared with approximately 23% for drivers under age 50. Despite knowing that a large portion of older driver accidents occur at intersections, the prevalence with which older drivers run red lights or traffic signals is largely unknown. Based on what is known about older drivers, it is reasonable to suggest that if signal violations occur among this group, they are more likely to be unintentional versus deliberate violations. The countermeasures mentioned above, when combined with the ITE equation at high-speed intersections, may not provide enough of a safety zone for older drivers, who appear to need more time to make correct decisions in time-controlled, complex situations, such as intersections (Delorme & Marin-Lamellet, 1998; Guerrier, Manivannan & Nair, 1999; Knoblauch, et al., 1995). Older driver limitations must be taken into account when devising strategies for reducing collisions caused by traffic signal violations.

Knoblauch, et al. (1995) investigated older (65+) and younger drivers' (<65) responses to an amber signal in terms of off-gas (time from onset of amber signal to removal of foot from gas), on-brake (time from signal onset to application of brake) and decision-response time (time from when foot lifted off-gas to when pressed brake) at speeds of 48 km/h and 32 km/h on a closed course. Drivers were encouraged to maintain their speed as they approached the traffic signals and the amber light came on when the drivers were 3.0 s to 4.9 s away from the intersection and stayed on between 3 s to 4 s, which corresponded to average amber phase lengths of 3.43 s to 4.88 s for traffic lights in the area where the study was conducted.

There was a significant difference in the average number of times a participant stopped for a light when the oldest (70+) and youngest (under 60) drivers in the study were compared. Drivers over age 70 stopped only 32.1% of the time whereas drivers under 60 stopped 46.88% of the time. The younger drivers' stopping rate reflected the average stopping rate of approximately 50% expected for a light change when drivers were between 3.0 s to 4.9 s away from the intersection. Overall, there were no significant differences between older and younger driver response times for off-gas, on-brake or decision/reaction time. The authors suggested that traffic signal phasing does not need to be altered to accommodate older drivers. However, activation of the amber light when a driver was 3.0 s to 4.9 s from the intersection was determined in pilot testing because it appeared that approximately 50% of drivers stopped when the signal was activated at this distance. Neither this timing nor the experimental design takes into account issues of the dilemma zone or the interaction of other complex intersection factors, such as multiple lanes or signals that might tax an older driver's attention disproportionately compared with a younger driver.

A variety of older driver studies indicate that problems occur at intersections due to normal attention and working memory deficits associated with aging (Caird, Edwards, Creaser & Horrey, 2002; Delorme & Marin-Lamellet, 1998; Guerrier, Manivannan & Nair, 1999; Knoblauch, et al., 1995). These studies suggest that older drivers require more time to make better decisions at intersections. For example, Knoblauch, et al. (1995) found that older drivers appeared to have longer decision-response times when they were more than 4 s from the intersection at onset of amber light (i.e., had more time to assess and respond). This corresponded to later results by Guerrier at al. (1999) that showed older drivers with better working memory capacity actually took longer to make decisions at intersections. An inability to assimilate all the information needed to make a decision means older drivers with lower working memory capacity may make decisions quickly simply because they have assessed the situation to the best of their ability. That is, taking in less information results in less information to be processed, leading to shorter decision times. Unfortunately, these older drivers also made fewer correct decisions than older drivers with better working memory capacity because they were lacking important information to make good decisions. No test of working memory was made in the Knoblauch et al. (1995) study nor were decisions to stop or go categorized as "correct" or “incorrect”, therefore, it is unknown how working memory may have affected the older driver responses to the amber signal in that study.

Caird et al. (2002) found that drivers aged 65 and older were significantly less accurate than drivers aged 18 to 64 at making turn decisions while viewing intersection photographs using the flicker method to induce change blindness (see Rensink, 2002, for a review of change blindness and attention). Time in that study was limited to 5 s or 8 s for viewing. For some intersections, turn decision accuracy was predicted by available time. Older drivers tended to attend to traffic signals, such as the lights, for decision-making. For example, if the light changed from green to yellow in an intersection, they were likely to notice it and use it to make their decision about whether to go or not. They were less likely to notice changes such as a pedestrian crossing on the green light that affected their ability to turn safely. In those situations, the driver would often report that it was safe to turn due to the green light, having not noticed that a pedestrian had the right-of-way in the intersection.

Overall, countermeasures to assist older drivers in the timely detection and correct response to traffic signals must take into account the normal cognitive declines associated with aging. That includes attention and working memory limitations, as well as perceptual limitations. Older drivers suffer visual declines that can make it difficult to discriminate signs and signals. Recommendations in the *Older Driver Highway Design Handbook* (Staplin, Lococo, & Byington, 1998) suggest minimum usages for luminance and size of traffic signals to aid discrimination of signals. For example, older drivers need increased signal luminance and contrast to perceive signals in certain situations and the handbook takes these needs into account when making minimum recommendations for contrast and luminance of signals.

### *2.2.3 Countermeasures and Enforcement to Prevent Traffic Signal Violations*

The AWF (Advanced Warning Flashers) and AD (Advanced Detectors) systems already mentioned are currently in use to reduce unintentional violations of traffic signals at intersections. Used in conjunction with Equation 1 from the ITE (1992) to calculate yellow and all-red phases, they appear to be potentially useful for reducing unintentional violations at intersections. Furthermore, the presence of an all-red phase allows a grace period for potentially violating vehicles to clear the intersection before the cross traffic begins to flow. The FHWA produced highway design recommendations (Staplin, Lococo, & Byington, 1998) for aiding older drivers that includes an assumed PRT of 1 s using Equation 1 mentioned earlier. Research by Tarawneh (as cited in Staplin, Lococo, Byington, & Harkey, 2001) found that the use of a 1-second PRT in an earlier ITE equation was not sufficient for older drivers when their reaction times to signal changes was tested. However, the authors of the FHWA older driver guidelines conclude that the 1-second PRT is sufficient, basing their decision on both Tarawneh's work and the work by Knoblauch et al. (1995), which failed to turn up significant differences between older and younger drivers responses to the onset of amber lights. The use of an all-red phase in conjunction with an assumed PRT of 1 s is suggested to aid older drivers on intersection approaches.

Because Knoblauch et al. (1995) did not classify decisions as correct or incorrect, used a simple traffic signal set-up with low-speed approaches, and did not take into account the dilemma zone or other issues that affect decision-making at intersections, this assumption of a 1 s PRT may not be substantiated. An experimental design that takes into account older drivers' responses to intersections with complex factors likely to be encountered in day-to-day driving are needed to address the effectiveness of a 1 s PRT to calculate amber and all-red phase lengths in assisting older drivers decisions at intersections.

Red light cameras are the main enforcement tool in use to prevent red-light running. The cameras work using sensors in the pavement that are activated when a light turns red. If a vehicle crosses the sensors while they are activated, a camera usually takes two pictures: one of the vehicle entering the intersection and another of the vehicle in the intersection. Recent data suggests that the use of red-light running cameras may be an effective deterrent for deliberate violators. The effectiveness of automatic enforcement has been examined a number of U.S. states, including California (Retting, Williams, Farmer & Feldman, 1999) and Virginia (Ruby & Hobeika, 2003). Retting et al. (1999) found that incidences of red light running decreased approximately 42% several months after an automated enforcement program began in Oxnard, California. Furthermore, studies find that drivers support enforcement programs to reduce red light running (Porter & Berry, 2001; Retting et al., 1999).

Ultimately, the type of collision reductions that occur are important when considering red-light cameras. A reduction in red-light running should logically result in a reduction in angle crashes where a violating vehicle is struck by cross traffic or a left-turning vehicle (McGee & Eccles, 2003). However, because drivers may feel compelled to stop where the system is in place, they may do so even when it is inappropriate. Braking suddenly for a yellow light when it may be appropriate to continue through the intersection could result in a rear-end collision. Therefore, an increase in rear-end collisions might occur at camera-enforced intersections.

McGee and Eccles (2003) comprehensively reviewed the literature from North America and worldwide on the effectiveness of automated enforcement at intersections starting with an initial Australian study. Based on their analysis of the methods used in each study reviewed and the results obtained, McGee and Eccles conclude that there is considerable evidence to suggest that red-light enforcement cameras have a positive effect on reducing red-light running crashes. Most studies observed reductions in angle crashes and some also observed reductions in rear-end collisions. The long-term effect is not conclusive and studies with longer evaluation periods show less reduction in crashes as time passes.

The use of red-light camera enforcement does not appropriately tackle the potential needs of older drivers who may run signals unintentionally. The use of red-light cameras may have their biggest benefit in reducing collisions between a red-light running vehicle and that of an elderly driver legally entering an intersection. Older drivers are more likely to be injured or killed in a collision than a younger driver, therefore, any road-based countermeasures that potentially reduce their probability of being involved in a crash could be considered worthwhile. Given the cognitive limitations of many older drivers, the development of intersection countermeasures should be incorporated into an intersection’s design where possible to avoid in-vehicle technologies that may further distract or confuse a driver on the approach. A number of experimental designs can be devised in the simulator to test whether current intersection treatments will help improve older driver safety at intersections.

## 2.3 Haptic Collision Warning Devices

ITS countermeasures to avoid collision-likely situations have been the focus of recent research. Numerous collision-warning systems have been examined to assess the strengths and weaknesses of emerging technologies. A promising alternative to visual and auditory warning modalities is the use of haptic or kinesthetic warning displays. Haptic warning devices can be constructed in the form of seat shakers, accelerator or brake pulsing (or push back) methods, and torque enhanced steering wheels. Each of these techniques offers both advantages and disadvantages in warning a driver of a potential critical situation.

Haptic warnings, or mechanical devices that stimulate the skin receptors over a period of time, may be superior in stimulus-response rates compared to other modality responses. Another advantage of haptic devices is mapping the appropriate response to the intended outcome. While this is not the case for all haptic warning systems (e.g., seat shakers), other areas within the vehicle cab (e.g., foot pedals and steering wheel) show encouraging results (J. Lee, personal communication, February 27, 2003; Tijerina et al., 2000). Despite superior performance and response measures, haptic warnings systems are still in the infancy of development, implying that adequate warning frequency, amplitude, duration, and intensity have not been extensively studied for all potential warning scenarios. Empirical results on haptic devices are largely buried within the automobile manufacturers and not disseminated.

### *2.3.1 Haptic In-Seat Warning Systems*

A seat shaker, or seat vibration, is one method to warn drivers about potentially critical hazards. However, limitations on the information a vibrating seat can convey have been encountered (Tijerina et al., 2000). Moreover, stimulus-response measures for tactile seat warnings are generally slower than other haptic warning modalities and require substantially more time to learn the mappings from shaking to proper response.

Despite the drawbacks of seat vibration, Gray et al. (2002) found potential stimulus cuing applications with the use of quadrant specific vibration signals. Participants were pre-cued through the use of a vibro-tactile seat back, which vibrated the potential quadrant (e.g., upper left, lower right) that participants could expect a change in a computer image to occur. The pre-cueing, through the use of tactile senses, allowed for faster detection and greater correct identification of changes within an image. Though these results are promising for cuing individuals to changes to a hazard close to the individual, expanding the practicality of the research to the driving environment may prove more difficult. The amount of information present within the driving environment may impede the practical application of seat warning systems for specific collision likely situations such as, rear-end collisions and intersections.

Applications using in-seat warning systems are limited to drowsy driver scenarios and multi-modal warning systems (J. Lee, personal communication, February 27, 2003). Current applications for seat vibration technology include drowsy driver warnings, suggesting a "rumble-strip" type of warning when a driver violates lane parameters. The rumble-strip warning is supposed to emulate the highway rumble strips on current roadways. Thus, when a driver violates computed lane parameters or when an onboard computer detects drowsy driver symptoms, the seat is then activated. There is no research planned for assessing intensity, frequency, and duration for in-seat warning systems for older drivers. Increased intensity and duration of the warning may be required for older drivers to sense, or feel, the collision alert. Further research is needed in order to evaluate the practicalities of in-seat warning technologies for collision situations beyond run-off road situations.

### *2.3.2 Haptic Steering Wheel Warning Systems*

Another application for a haptic warning system is to use either vibration or torque force feedback mechanisms on the steering wheel. Steering wheel feedback, much like in-seat warning systems, allows for continual contact between the driver and warning system. In all driving situations, the driver is consistently holding the steering wheel.

Initial research by Enriquez et al. (2001) applied a pneumatic device to a steering wheel mock-up. The pneumatic pump system inflated pockets contained within the steering wheel. Preliminary experimental tests with the steering wheel used a simple multi-tasking situation, which produced faster response times to critical situations. Unfortunately, the experimentation did not use any real or simulated driving scenarios, but relied exclusively on simple monitoring tasks (Enriquez et al., 2001). Faster response rates indicate the potential application of a pneumatic steering wheel warning system to real-world scenarios, but in-vehicle testing is required to verify the feasibility of such a system.

Another application is the use of a torque feedback steering wheel system initiated in critical situations. The warning system has been designed to initiate a jerk or force to the steering wheel in a direction away from the potential collision (Tijerina et al., 2000). Research using torque feedback systems have focused on situations involving lane change collision warnings and roadway departure scenarios (Tijerina et al., 2000). Concerns surrounding feasibility, cost, and implementation into vehicles, and possible litigation issues have yet to be fully explored.

### *2.3.3 Brake Pulse Haptic Warning Display*

A brake pulsing haptic display shows potential as a viable collision warning system in a variety of ways. Brake displays provide a pulse or jerk to the brake pedal that indicates to drivers the need to increase pressure on the brake pedal (Lloyd et al., 1999). Moreover, the display is currently being adapted and studied in conjunction with adaptive cruise control (ACC) systems that can apply a deceleration rate according to a predefined headway time (Tijerina et al., 2000). The combination of modalities, both pedal jerk rate feedback and the force of deceleration, allows for improved stimulus-response mapping and orientation cues to the forward view (Lloyd et al., 1999). Additional safety responses by the system include activation of the brake lights to inform following drivers of the potentially rapid braking event.

Mechanical and feasibility issues have yet to be fully examined (Tijerina et al., 2000). Implementing the warning device and mechanisms to provide pedal feedback has not found optimal jerk rate settings and durations (Lloyd et al., 1999). Preliminary research found that drivers responded quickly and accurately to mono-pulse warnings that provided relatively high pedal jerk rates (e.g., 0.32 g/s), but limited (e.g., 0.65 s) warning duration (Tijerina et al., 2000). Foot position is integral for the warning system to convey the alert. Unfortunately, if the driver does not have their foot on the brake pedal during the warning time, the pulsing alert will fail to provide meaningful collision avoidance information. However, if the brake pulse is combined with an ACC system, the motion cue provided by the vehicle decelerating can act as a redundant alert to the driver. Moreover, brake pulse warning systems may have limited applications, thus only useful for rear-end collision events and intersection collision avoidance, where it's anticipated the driver will already be braking, or have their foot on the brake, for the upcoming events (Lloyd et al., 1999; Tijerina et al., 2000).

A fundamental drawback in assessing brake pulse warning systems is their utility in a simulated environment. Unfortunately, driver motion cues cannot be adequately replicated using a fixed-based simulator and current software (J. Lee, personal communication, February 27, 2003). State-of-the-art simulators (e.g., National Advanced Driving Simulator or NADS) have the potential to study brake pulse warning systems in a tightly controlled environment. In addition, liability issues have yet to be fully addressed in the event of a system failure.

### *2.3.4 Accelerator Push Back Warning Systems*

A final haptic method to warn drivers of critical collision situations involves the use of a haptic, or active, accelerator pedal. The collision warning system actively pushes the accelerator pedal back to alert the driver of an impending collision situation. The warning system relies on the driver having their foot on the accelerator pedal in order to sense the alert (Tijerina, et al, 2000). An additional mechanism is to vibrate the accelerator pedal to convey a warning. There are strengths and weaknesses for both types of accelerator-controlled warning system.

Actively pushing the pedal back involves inserting a servomotor within the accelerator control mechanism, a non-trivial procedure in current fixed-based simulators. A set of suitable visual cues has to be programmed into any scenario constructed in a simulator environment. Scaling the force of feedback (jerk rate) has not been evaluated in detail and other anthropometric measurements need to be assessed. A current accelerator feedback system on a Vection simulator (i.e., University of Iowa) is still under construction, despite extensive trouble-shooting by the manufacturer of the servomotor (J. Lee, personal communication, February 27, 2003).

A simplified version of the warning system can be installed on a fixed based simulator through the use of a simple cellular telephone vibro-tactile device. The vibration device can be easily installed onto the back of the accelerator pedal and interfaced to a PC, a dramatic cost effective measure over other methods. The disadvantage of the system is the stimulus-response reduction, or limited pulsing force of the cellular telephone vibro-tactile device to be felt by participants. The device is restricted to the frequency and amplitude of the cellular telephone vibration mechanism (J. Lee, personal communication, February 27, 2003).

#### *2.3.5 Summary*

Various haptic methods are plausible to warn drivers of potential collision critical situations. Seat vibration may be best suited for drowsy driver scenarios with the addition of an auditory warning tone. Limited research has been conducted on steering wheel haptic systems and is not currently being actively pursued by researchers. Current collision warning research has focused on brake pulsing mechanisms, which show the greatest promise in combination with ACC systems. Feasible haptic warning systems for fixed based simulators appear to be active accelerator vibro-tactile devices.

Pedal manipulations appear to be viable for collision avoidance, but are dependent on drivers actively using the correct pedal when the warning is initiated. The warning system will be ineffective if not received by the driver. Older driver research has not addressed the feasibility of haptic or tactile warning devices at all. Older drivers, because of reduced tactile sensitivity, may need increased duration and frequency of alert signals in order to sense them. Moreover, understanding and correctly interpreting what the alert is trying to convey may be problematic for older drivers with cognitive slowing. There is no current research outlining problematic situations, such as understanding, interpreting, and reacting to haptic or tactile warning systems for older drivers. Despite the lack of research for all aged drivers, the implementation of haptic warning devices will be eased as manufacturers modernize vehicles through the use of drive by wire systems.

### 2.4 Auditory Collision Warning Systems

Collision warning systems, devices which notify drivers of critical environmental events, have been pursued in human factors research for an extended period of time. Specifically, provision of important safety information to the driver in a visual format has been the central focus. Other sensory domains have been considered, but not pursued as vigorously in research. Visual warnings compete with the visual demand of driving.

Auditory warnings provide information through a different modality. Visual warning displays usually require the driver to look to a particular location, whereas auditory alerts can direct attention independent of what a driver is looking at (Edworthy, Loxely, & Dennis, 1991). Ambient road noise, car stereo systems, passengers, age related hearing loss, and other telematic devices may interfere with auditory warning perception. Moreover, presenting an array of sounds will likely just lead to driver confusion (Tan & Lerner, 1996). As a result, auditory alert research and design has focused on the frequency, amplitude, presentation time, format, meaning, and localization of sounds in order to improve driver comprehension (Belz, Winters, Robinson, & Casali, 1997; Tan & Lerner, 1996).

The technologies pursued in auditory warning research have concentrated on presentation format and meaningfulness of sounds. Tonal and speech alarms are two distinct auditory structures used for collision alerts. Examples of tonal warnings include buzzers, horns, whistles, sirens, and beeps, all of which are considered traditional alert formats. Traditional auditory alerts are defined by pitch, duration, and intensity that can be manipulated to convey urgency (Edworthy, Loxely, & Dennis, 1991). Unfortunately, tonal warnings often require learning and retention in order for a driver to match an auditory alert to a specific critical event (Edworthy & Hard, 1999; Edworthy, Loxely, & Dennis, 1991). Moreover, loud, unexpected, and confusing tonal warnings can startle a driver or promote annoyance, a negative or unwanted consequence often resulting in the operator turning it off (Edworthy & Hard, 1999; Hirst & Graham, 1997). Although tonal warnings have unfavorable components, once alarms are learned, response rates are fast (Edworthy & Hard, 1999). Meaning and retention limitations experienced with the use of a traditional tonal warning system are lessened with speech-based warning, an apparent benefit in a critical situation.

Speech based collision warning systems have been promoted as a preferred warning method, due to the ease of understanding contained in the phrase or word (Edworthy, Walters, & Hellier, 2000). To promote urgency in a critical situation, phrases or words such as “Danger”, “Danger

Ahead", "Warning", and "Caution" are used (Edworthy, Walters, & Hellier, 2000; Weedon, Hellier, Edworthy, & Walters, 2000; Hirst & Graham, 1997). Phrases or words considerably improve meaning and comprehension over traditional auditory tonal warning methods (Leung, Smith, Parker, & Martin 1997). Drivers in critical situations can relate, identify, and react appropriately on the information contained in a simple word. Moreover, speech based systems favouring specific words instead of phrases are perceived as more urgent (Hellier, Weedon, Edworthy, & Walters, 2000). Hirst and Graham (1997) tested speech and non-speech alerts in combination with visual warning displays presented prior to potential collision events. Auditory warning types consisted of a single tone, a warning phrase "Danger Ahead", and a series of tones that signified headway separation and closure to the vehicle ahead. Results indicated there were no significant differences between the speech and non-speech warning displays. In addition, the speech warning was considered more annoying compared to the other warning alerts and may not have been presented early enough. Overall, the combination of visual and auditory alerts reduced braking times to critical headway closures. Speech warnings, compared to tonal warnings, are often initialized with inadequate timing between the warning and the critical event, often leaving only a short, insufficient duration, for drivers to react appropriately. However, with recent improvements in speech technology, mapping urgency to speech-associated warnings is possible.

Edworthy et al. (2000) assessed perceived urgency levels in speech warning sounds. Results suggested the semantics associated with key words play an important role in urgency mapping. Furthermore, all of the speech warnings were synthesized, much like those that would be used for an in-vehicle warning device. Thus, the way in which words are spoken can extend the urgency rating of the alert. Further research is needed in order to assess the utility of semantically synthesized speech for in-vehicle warning alerts. Mapping the benefits of meaningfulness and retention, with the response speed of tonal warnings, has been the challenge of other collision warning research.

A compromise between a speech based warning and a tonal warning has been used in the form of auditory icons. Auditory icons, or sounds that convey meaning, are another means to indicate potential critical situations to drivers. The analogy for auditory icons was adapted from visual icons that portray pictures to indicate information. Auditory icons, conversely, are sounds that indicate meaning or information linked to the event (Belz, Winters, Robinson, & Casali, 1997). Furthermore, auditory icons are not subject to limited retention rates, as experienced with tonal warnings; a greater number of icons can be retained and understood by operators. Examples of icons used within a driving environment include tire skid, tire screech, and collision (impact) noises (Belz, et al., 1997). However, mapping an appropriate environmental sound or icon to a specific event has proved challenging. In addition, identifying varying levels of urgency for iconic sounds in complex systems has not been explored in depth (Belz, Robinson, & Casali, 1999).

For example, Belz et al. (1999) tested commercial vehicle operators with auditory icons and traditional tones that indicated potential front and side critical situations. Both auditory display conditions also used a visual iconic display. The visual display contained a representation of a semi-truck and trailer with a trapezoid surrounding it. The trapezoid flashed intermittently, indicating either side or front hazards. The traditional pure tones were constructed from 500-3000 Hz waveforms and were initiated for 0.70 s, or two pulses. Auditory icons consisted of tire skidding for the front headway incursion and a horn honk for potential side collision situations. All auditory warnings were played 13dB higher than the ambient cab noise and for the same length of time as the traditional auditory alerts. Results indicated that auditory icons elicit faster brake response times than traditional tones. Auditory icons were more readily associated with impending collision situations. Moreover, participant preferences favoured the combination of visual display and auditory icons, compared to the traditional warning tones. Iconic warnings show promise for collision warning systems, yet have only been tested for commercial vehicle applications. Further work is needed to test differences for all aged drivers, in a variety of simulated critical situations.

Extensive research as outlined has been conducted in an effort to uncover appropriate auditory warning methods for warning devices. Despite advances with urgency, auditory icon, and localization techniques, little research into the utility of in-vehicle warnings for older drivers has been conducted. Older driver limitations in cognitive and physical abilities will need to be taken into account. Intensity, frequency, duration, and timing will need to be address in order for older drivers to respond appropriately. Furthermore, warning type (e.g., traditional tones versus auditory icons) and perceived urgency of the alert will need further examination to address the utility for older drivers.

The utility of auditory alerts seems plausible for in-vehicle warning systems. Further research will need to be conducted in order to assess the utility of the warning systems for older drivers. Various research questions still need to be addressed in order to attain an appropriate warning for in-vehicle use. Questions surrounding the format of the warning have received some attention in current research, but little consensus has been attained as to the best means. More research on older driver perception of annoyance, volume requirements, and appropriate timing techniques is needed.

Potential research directions for auditory displays involve assessing the utility and perception of traditional tones, auditory icons, and speech warning systems. Traditional tones have the practicality of being perceived as more urgent than other methods (Edworthy, Walters, & Hellier, 2000). However, speech-warning research has provided evidence through synthetic semantic manipulation can likely construct similar urgency presentations (Weedon et al., 2000). A preliminary step will require an assessment by both younger and older drivers of urgencies for all alert methodologies. Intertwined with the assessment of auditory urgency alerts will be the evaluation of annoyance associated with various alarm displays (Lerner et al., 1996). Finding an appropriate warning volume and presentation format will facilitate further research with in-vehicle evaluation. Older drivers will likely need longer, or an earlier warning presentation, due to cognitive slowing and slower reaction times (Hanowski et al., 1999). Various timing conditions can address younger and older driver response limitations. Assessing different auditory alerting techniques in isolation will be valuable for future in-vehicle alerting techniques.

### 2.5 In-Vehicle Signing Information Systems

Icons are one of the oldest forms of communication and are represented in many different areas of understanding. Icons have been defined as visual representations or images that symbolize and object, action, or concept (Campbell, Carney, Monk, Granda, & Lee, 2000). In presenting drivers with in-vehicle messages, icons provide numerous advantages over text-only messages. Icons can be more recognizable, are represented in a smaller area, and can convey messages to drivers who speak many different languages. However, poorly designed icons can increase driver confusion and potential initiate more driver errors. Previously, this has been caused by the lack of guidelines and standards that are in place for the design and application of icons. It is necessary to have design guidelines that minimize icons with multiple meanings, icons that are difficult to see, and those that conflict with cultural norms.

This review examines icon comprehension and recognition for in-vehicle systems. In particular, how icons can be used in Head-Up Displays (HUD) is emphasized. A number of evaluation techniques and design principles are also reviewed.

### *2.5.1 Types of Icons*

Icons have frequently been used to minimize complex text messages. Icons are usually recognized more accurately and frequently than comparative worded designs (Campbell et al., 2000). In general, two types of icons have been described, with a continuum between them (Campbell et al., 2000). Image-related or concrete icons are often directly comprehensible. An example of an image-related icon is the fasten seat belt icon. It is a visual analog of what to do with it. Arbitrary or abstract icons are used to convey a specific meaning that is agreed upon through convention. The First Aid, Radiation and Biological Hazard symbols are examples of abstract symbols. The meaning of each must be learned.

Icons can also differ in their level of complexity relating to different situations (Nakata, Campbell, & Richman, 2002). General and specific icons have been examined in relation to their simplification, decreased memory requirements, and overall complexity. General icons provide the driver with broad and generalized messages about a particular situation (e.g., general crash warning). Specific icons provide more detail about particular driving situations. The most accurate icon type is strongly associated with its given scenario type. General icons were selected when general scenario explanations were used. These included scenarios examples such as a lane blocked, reducing speed, route guidance, food and gas, and urgent mechanical problems. Specific icons were favoured when specific situations were explained. This occurred in particular with the icon for collision avoidance.

Nakata et al. (2002) found that drivers were strongly influenced by their perception of driving situation when the situation was associated with the in-vehicle messages. This means that general or specific icons represent warnings of the possible conditions the driver is exposed to. Well-designed general icons are also quite sufficient in meeting driver's perceptions and expectations when obtaining information from in-vehicle systems. However, safety related icon messages (collision avoidance) are more effective when specific icons are used.

The development of icon components includes many of the same key characteristics. Boarders, backgrounds, elements, symbols and shapes, and text labelling are all important components in an icon (Campbell et al., 2000). These guidelines are used to establish consistency and formality for icon design and development. These components give designers key topics to address when producing icons for in-vehicle systems.

### *2.5.2 In-vehicle Sign Systems*

In-vehicle signs have been identified as a potentially beneficial ITS technology (Hanowski et al. 1999; Luoma & Rämä, 2002; Lee et al., 1999b; Regan, 2004; Staplin & Fisk, 1991), but have received only sporadic research attention. Staplin and Fisk (1991) performed a pair of laboratory studies to determine if advanced left turn information improved decision performance. One study used static signs and the other an animated sequence of slides. Younger and older drivers made more accurate decisions with less latency when upstream or advanced sign information was available, as well, younger drivers were significantly more accurate than older drivers in understanding the advanced signs. Redundant signs were interpreted significantly more accurately than non-redundant signs.

Lee et al. (1999b) examined in-vehicle messages (in the dash), presented alone and with road traffic signs in a low-fidelity driving simulator. Older drivers rated their own overall driving performance the same as younger drivers. However, while interacting with in-vehicle and roadway information, crashes per hour, lane variability, and speed variability were significantly worse for the older drivers' compared to the younger drivers. In addition, older drivers were less accurate in their responses to a range of ATIS and road information in both the auditory and visual modalities. The presentation of ATIS information alone without roadway signs produced significantly higher crash rates per hour.

Hanowski et al. (1999) investigated the benefits of signing, navigation, and warning in-vehicle information systems (IVIS) presented on the right hand portion of a vehicles dashboard using an instrumented vehicle. An auditory beep lasting 0.45 s was given to alert the driver to new information present in the IVIS. The IVIS information was available to the driver for 5 s in advance of an event. Events included a car entering from a hidden entrance, a one-lane tunnel ahead, a disabled vehicle in the roadway, an ambulance approaching the driver from behind, a crash ahead, and the trunk is open. Younger drivers responded faster to events ($M$ = 1.79 s), in the presence of the IVIS, than older drivers ($M$ = 2.57 s). Looking at the dashboard display while wearing bifocals and exercising cautiousness were presented as explanations for why older drivers responded slower to the IVIS information.

Pierowicz et al. (2000) evaluated three head-up display (HUD) signs combined with auditory warnings using an instrumented vehicle on a test track. All evaluators were employees of the company charged with performing the evaluation. Advisories were presented 7 s in advance of stop controlled intersections. Participants rated the advisories as being presented slightly too late. The stop sign HUD was rated “extremely meaningful” or nearly 5 on a 1 to 5 item scale. The signal light sign was rated somewhat less meaningful. An overhead view of an intersection icon was rated lower with comments indicating that it was difficult to interpret. The mean duration of eye glances to the HUDs was 0.13 s (SD 0.35 s) in 47% of the video observations made. In 53% of observations, glances to the HUD were not observed. Thus, glances to the HUD were relatively short. Extraction of information from the HUD may have occurred through peripheral vision as well, video based glance measures are known to have about a 10 degree spatial error rate (Green, 2002). Behavioural responses during the presentation of the HUDs were not measured in the instrumented vehicle.

Luoma and Rämä (2002) investigated driver acceptance of traffic signs presented in an in-vehicle terminal (i.e., centre column mount). Four message types were evaluated on road; namely, visual sign, visual sign and auditory message, visual sign plus auditory feedback (e.g., speeding), and visual sign with complete instructions (e.g., watch for pedestrians). In general, drivers reported that they accepted the signs, auditory alerts, and format in which they were presented. The visual sign was ranked second, after route guidance information, in terms of desirableness by participants.

Based on these studies, the use of in-vehicle signs to alert drivers to upcoming traffic light changes has the potential to benefit older drivers. The studies reviewed found that a range of in-vehicle sign systems allow drivers to anticipate upcoming events when presented in advance (Hanowski et al., 1999; Staplin & Fisk, 1991) and were generally accepted by drivers (Luoma & Rämä, 2002; Pierowicz et al., 2000). However, a number of design concerns were raised.

Display design for IVIS has been extensively investigated and similar concerns have been raised by others. The following parameters are a sample of those considered: display modality (visual, auditory, haptic), display location (HUD, dashboard, centre column), type of visual information conveyed (e.g., weather, crash ahead, pedestrian crossing, etc.), and form of the visual information (e.g., text or symbols).

Of the studies reviewed, the locations for information display were predominately in the dashboard (Hanowski et al., 1999; Lee et al., 1999b) although the centre column was also tested (Luoma & Rämä, 2002). The disadvantage of these locations is that they require the driver to glance into the vehicle to the display. Taking the eyes off the road creates an undesirable distraction potential (Green, 1999). One cause for concern for drivers was late detection of other vehicles and obstacles in the roadway if they were required to look at a display in the vehicle (Luoma & Rämä, 2002). A HUD removes the necessity to look into the vehicle for information. HUD human factors in automotive applications have been researched and design guidance provided by a number of researchers (Gish & Staplin, 1995; Gish et al., 1999; Tufano, 1998; Yoo et al., 1999). The central location of the HUD in the present study is based on Yoo et al. (1999).

Provision of useful information at the right time and in the right format is essential. When advanced information should be presented must also be systematically examined (Hanowski et al., 1999) although the 5 seconds was sufficient for the events that were encountered. Pierowicz et al. (2000) presented warnings 7 s in advance of stop controlled intersections for drivers of an instrumented vehicle, results indicated that the drivers thought the warnings were issued too late. Provision of information in advance of when it is needed so that the driver is ready to respond is the central principle of positive guidance (Alexander & Lunenfeld, 1985). The precise timing of in-vehicle information relative to external events was identified as an unaddressed question by Lee et al. (1999b). The present study used positive guidance principles to determine when to present information. Depending on the posted speed of a roadway section, 8 to 12 s in advance of where the information will be needed for a decision is commonly used for placement of traffic signs.

In addition, knowing when information changes inside the display requires drivers to look at the dash or display on a frequent basis or require an auditory prompt such as a beep to remind drivers to look at the display (Hanowski et al., 1999). Frequent occurances of an auditory prompt may become annoying to the driver and would be turned off if they had control over it. Auditory prompts for the present study were dropped from further consideration for this reason.

The form that symbols and icons should take has been the focus of a large Federal Highway Administration (FHWA, U.S.) research program. For example, Nakata et al. (2002) examined driver acceptance of general and specific icons for use in such applications as trip navigation, collision avoidance, and advanced traveler information services (ATIS). Optimization of icon or symbol comprehension for a wide range of IVIS applications has been the focus of other deliverables of the same research program (see, Cambell, 2004; Carney et al., 1998; Lee et al., 1999a). “Prepared to stop” and “signals ahead” signs were chosen after an exhaustive search of related literature (Cambell et al., 1998; Carney et al., 1998; Dewar et al., 1994; Lee et al., 1999a; Pierowicz et al., 2000).

## 2.6 Technology Summary Review

ITS systems that have the potential to aid older drivers were reviewed. The purpose of closely examining the research on red light running (RLR) countermeasures was to determine the extent that older drivers were unintentionally running red lights due to "missed detection" of traffic lights. Research conducted thus far has not addressed this question. Further elaboration of RLR systems is covered in Section 3 and Appendix A. Other epidemiological research clearly indicates that older drivers are overrepresented in intersection collisions (Preusser et al., 1998).

In-vehicle systems that may prove beneficial to older drivers include haptic collision warning systems, auditory collision warnings, and in-vehicle signing information systems. In-seat haptic systems could warn drivers of potential collisions, but are limited by the necessity to learn the mappings between stimulus and response. The use of haptic input to the driver through the steering wheel and brake are also promising. Within the scope of this research, technical and resource constraints limited pursuing this line of research. Additional research is needed that addresses older drivers who may use haptic steering and brake pulse systems.

Auditory collision warning systems alone and in combination with visual warnings also show promise for intersection collision mitigation. In particular, speech-based and auditory icons may improve response times to threats in a range of critical situations. However, a number of background noise sources including, ambient road noise, stereo systems, passengers and age-related hearing loss, may limit their eventual development and application. Age-related hearing loss for older drivers influenced our decision to exclude auditory warning systems and focus on in-vehicle signing information systems (IVSIS).

In-vehicle signs have been identified as a potentially beneficial ITS technology, but have received only sporadic research attention. Based on these limited studies, the use of in-vehicle signs to alert drivers to upcoming traffic light changes has the potential to benefit older drivers. A HUD removes the necessity to look into the vehicle for information. However, focusing attention on the HUD may still obscure or cause the late detection of other vehicles. One way to minimize this disadvantage is to present HUD information in advance of an intersection so that attention can be redirected back to signs, signals and other vehicles. The design of an in-vehicle HUD requires optimization of location, timing, form and information. These design parameters are discussed in Section 5 in the context of a study that evaluates a prototype HUD system.

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# 3. RED LIGHT CAMERAS

## 3.1 Purpose

Twenty-five papers and related academic and government materials were used to create a summary of the research findings and issues surrounding red light camera systems. This report analyzes the general findings and overall effectiveness of red light camera systems, the methodology employed, and introduces reported demographic characteristics of red light violators. Statistical issues are briefly discussed as they pertain to the limitations of the studies. Finally, red light violation data is described in terms of its relationship to yellow traffic signal timing.

Over 40 percent of all crashes occur at intersections, according to the Federal Highway Administration of the U.S. Department of Transportation. The United States experienced 6.4 million reported crashes on its roadways in 2000. Red light running accounts for more than 180,000 crashes each year, which produces approximately 1,000 deaths and 90,000 injuries annually. There is a 47 percent likelihood that red light running crashes will produce injuries, while this likelihood is only 33 percent for other crash types (47 percent vs. 33 percent, Retting et al., 1999).

One way of monitoring red light violations is by implementing red light camera systems. These systems may be used to assess how badly an intersection may need improvements to its geometry, signal timing, and signage. They may also be used to fine violators to deter to red light running. Red light camera systems measure the speed of vehicles passing through an intersection once the light has turned red. Violating vehicles are photographed if they have not sufficiently cleared the intersection in time. Conventional non-portable red light camera systems consist of buried sensors and a pole-mounted unit containing a camera and a computer. The electromagnetic sensors are embedded in the roadway preceding an intersection. These sensors detect vehicles passing over them and send the signal to the camera unit, which is synchronized with the timing of the traffic signal. There are usually two time-distance induction loop sensors under the surface of the road, so that a speed can be calculated between the two loops. Each loop consists of a rectangle of wire through which a current flows. This current, because it runs through a loop, generates a magnetic field, which induces a different electric current that alters the flow of the original current. When a vehicle passes through the magnetic field, the inductance of the loop changes and a meter detects the change in inductance. Another type of sensor, which is less common, operates similarly and is called a piezoelectric sensor. These sensors detect the presence of vehicles by converting the mechanical stress of the vehicles on the road into an electrical signal. Some jurisdictions use each type of sensor in conjunction with conventional loop detectors. For example, two time-distance loops with one piezo sensor, or alternatively one time-distance loop with two piezo sensors. Other methods for measuring violations include radar, laser, air-tube, and video loop. Radar can be used to capture the speed of a vehicle. A radar gun emits electromagnetic waves of a certain frequency, and the velocity of a vehicle can be calculated based on how the frequency of the echo (off the vehicle) differs from the emitted frequency. Lasers and air-tubes are used to measure a time differential in a similar fashion to that of induction loop sensors. A video loop involves a computer that is programmed to recognize from the video feed certain substantial changes in images indicating violating vehicles.

The pre-programmed computer calculates the speed by which the vehicles are passing over the sensors and deduces whether or not a vehicle has run the light. If a vehicle is passing over the sensors at a velocity greater than a minimum threshold velocity (commonly 24 km/h or 15 mph) while the signal is red (usually after a 0.4 second grace period), the camera will take typically two photographs of the violating vehicle. Though it is a less common practice, some jurisdictions (e.g., San Diego, CA and the state of Arizona) have had multiple cameras to take different angles of the vehicle for the purpose of more accurately identifying the violator. Ordinarily the photographs are evaluated by a police officer to verify that a violation has occurred and citations are distributed to offending drivers (or registrants of a vehicle) accordingly.

As a vehicle passes over the sensors (or triggers), each trigger recognizes a change in inductance at a different time. Taking the distance between the loops into account, the computer in the camera unit can calculate the difference in time between the changes in inductance and thus deduce the vehicular speed. However, a minimum threshold velocity is chosen so that right-turn-on-red movements can be executed without being photographed. In addition, if a driver stops for the red light but encroaches on the intersection, they have the opportunity to reverse out and not get ticketed. Usually the minimum velocity for passing over the sensors to qualify as a violation is 15mph, or 24 km/h (see **Table 3.1**). Some jurisdictions may choose to decrease the threshold to as low as 10 mph, which results in more violations.

When traffic signals turn red, an all-red interval usually precedes the opposing direction's signal turning green. Once the light has turned red, there is a grace period when vehicles in the intersection can clear it without being detected by a red light camera. Again, this length of time is chosen by each jurisdiction that chooses to employ red light cameras. Similar to threshold velocity, a smaller grace period results in more violations. **Table 3.1** illustrates how threshold velocity and grace period vary for a few areas, independent of intersection size.

**Table 3.1.** Various red light camera locations, speed thresholds, and grace periods after the red light onset.

| **Area** | **Threshold speed for detection** | **Grace period after red** |
|---|---|---|
| San Francisco, CA | 15 mph (24.5 km/h) | 0.4 s |
| Oxnard, CA | - | 0.4 s |
| Florida & Maryland (various cities) | 15 mph (24.5 km/h) | 0.5 s |
| New York City, NY | 15 mph (24.5 km/h) | 0.5 s |
| Fairfax County, VA | 18 mph (29.0 km/h) | 0.2 s |
| Calgary, AB, Canada | 10 mph (16.1 km/h) | 0.3 s |

## 3.2 Measuring the Effectiveness of Red Light Camera Systems

### *3.2.1 Data Gathering Methods*

The National Cooperative Highway Research Program (McGee and Eccles, 2003) outlined four general ways to gather data in terms of violations, conflicts, and crashes from red light camera programs. The first is termed a Before-and-After with Control Group model. This model involves the variable of interest (violations, crashes, conflicts, etc.) being measured before and after the implementation of red light cameras, which is then contrasted with a control group. While this model is appealing for statistical purposes, it is unethical to withhold treatment (like the installation of red light cameras) from intersections that may potentially benefit from treatment. Second, a Before-and-After with Comparison Group model is similar to the preceding model; although it is not as statistically sound because the comparison group of intersections is not as "needy" as the treatment group. That is, intersections are often assessed on how badly they need the employment of countermeasures (including red light cameras) based on crash rates or a similar criterion. However, both a regression-to-mean bias and a spillover effect can occur, which is explained shortly. Third, while seeming straightforward, the Simple before-and-after evaluation model is statistically weak. In this model, the same location is measured twice: before and after installation (without comparison or control group). For this model in particular, an overestimation of the effects of the red light cameras is likely, due to a high potential for the regression-to-mean bias. Problems include how the drivers may not react instantly to the installation, the possibility that drivers might behave in a random fashion, other factors (than treatment) may influence the results (such as other countermeasures employed), and the measure of effectiveness may change over time (maturation). Finally, the fourth type is the Cross-Sectional evaluation. It involves comparing the treatment intersections to similar intersections that have not been treated. Unfortunately, finding sufficiently similar intersections can be difficult. Usually in this situation, "before" data is not of good quality or even available and intersections have likely changed since installation in other ways (additional countermeasures). Other countermeasures include changes to the geometry of the lanes (addition of turning lanes, for example), optimization of signal timing, and signage.

### *3.2.2 Regression-to-Mean Bias*

The regression-to-mean bias has been widely identified as a potential source of overestimation of the effects of red light camera systems on crash and violation rates (McGee and Eccles, 2003, Datta et al., 2000, Flannery and Maccubin, 2002, Golob et al., 2003, Retting et al., 2003). The bias refers to the tendency for a typical value to be observed in the period following an extreme value for an oscillating variable. If an intersection is chosen for red light camera installation because of an observation of limited time determining that it is associated with a notable high crash frequency, it is likely that any subsequent measurement will find the intersection to have experienced a decrease in crashes. This would result in an overestimation of the effects of red light cameras on crash frequency. The statistical rigor of red light camera evaluations is threatened by regression to the mean where intersections are chosen for treatment because of their high crash frequency, unless the investigating agency demonstrates the pre-installation period crash frequency to be typical.

The regression-to-mean bias can be overcome using the Empirical Bayes method, a statistical procedure proposed by Ezra Hauer (1997). This method identifies the portion of any reduction (in crashes, violations, etc.) that should not be attributed to the treatment of the intersections (e.g., installation of red light cameras, changes to lane geometry, signage, etc.). For this technique, voluminous historical data of similar intersections are used as comparison or control sites to estimate any reductions had the study intersections not been changed.

### *3.2.3 Spillover Effect*

Where the control or comparison sites are within the same vicinity of the treatment sites, the spillover effect may limit the statistical precision in determining the effect of red light cameras on reducing red light violations or crashes. A halo effect or spillover effect refers to the occurrence found in some studies (Retting et al., 1999, Fox, 1996) where the presence of red light cameras at some intersections seems to affect driver behavior at other intersections. Other studies have challenged this attribution (Hillier et al., 1993), but intersections outside any potential influence of a red light camera program would be preferred as comparisons or controls in determining red light camera effectiveness (McGee and Eccles, 2003). The spillover effect can be observed by measuring (crashes and/or violations) at three types of intersections: one experimental group treated with red light cameras, another experimental group in the same vicinity without red light cameras, and a control group without cameras outside the influence of a red light camera program.

### *3.2.4 Other Considerations*

Determining the effectiveness of red light cameras is often complicated by the additional treatment of intersections chosen for improvement. Typically, optimization of the geometry of the lanes and signal timing (yellow and all-red interval), additional signage (which may include advanced yellow flashing lights), and other changes coincide with the implementation of red light cameras. Effectiveness may also fluctuate based on the level of fines and the degree of public awareness (McGee and Eccles, 2003, Retting et al, 1999). Regarding comparison groups, some studies used sites for comparison based on, among other factors, traffic volume (Datta et al., 2000, Ruby and Hobeika, 2003). Crash frequency is also often described in terms of traffic volume as a measure of exposure (as opposed to time, for example). However, “crashes are not necessarily linearly related to volume” (McGee and Eccles, 2003). While a commonly used scale is crashes per traffic volume, the number of crashes at an intersection is not always directly proportional to the amount of traffic passing through the intersection (Hauer, 1997). For any before-after studies, ideally both the treatment and comparison groups would have similar traffic volumes in the before and after periods. Accounting for a non-linear relationship between traffic volume and crashes can be accomplished if the relationship between the variables is known, but this complex correction may be difficult for most agencies (McGee and Eccles, 2003).

## 3.3 The Effectiveness of Red Light Cameras

Upon reviewing 15 studies pertinent to red light violation and red light cameras, four were chosen because of their relatively superior statistical practices and thus their ability to more accurately indicate the effectiveness of red light cameras. While other studies are useful in demonstrating the issues involved in measuring the effectiveness of red light cameras, the aforementioned statistical concerns shed doubt on their precision. Each one of the studies listed in **Appendix A** has its own methodological shortcomings, illustrating that measuring red light effectiveness involves many complications.

### *3.3.1 Violations*

Retting et al. (1999) found a 40% reduction in violations at camera treated intersections, and a spillover effect of 50% reduction at non-camera intersections also occurred. This resulted in an overall reduction of 42%. Golob et al. (2003) found various significant improvements at treated intersections (however, treatments were not limited to red light cameras). The most notable finding of the study was a consistent rate of decline of the reduction. The decrease in violations declined at a rate of 3.2% per month. This means that the decrease in violations is not sustained over time, the effect lessens at a somewhat constant rate.

### *3.3.2 Collisions and Crash Types*

The article by Retting and Kyrychenko (2002) reports an overall 7% reduction in collisions. Right angle crashes also decreased by 32%. For crashes involving injuries a 29% decrease occurred, while right angle crashes specifically declined by 68%. In the meta-analysis combining the findings of two meaningful studies, Flannery and Maccubbin (2003) determined that red light cameras were involved with the 26% decrease in the probability of right angle or rear-end collisions. This conservative estimate accounted for numerous threats to statistical precision. Golob et al. (2003) determined that "ran signal" and right angle crashes decreased by about 40%, while rear-end collisions increased by approximately 40%. These findings should be tempered by the methodological limitations (see **Appendix A**).

## 3.4 Demographic Characteristics of Violators

### *3.4.1 Acquisition of Demographic Data*

Two of the reviewed studies offered information regarding the demographic characteristics of red light violators. In 1999, Retting, Ulmer, and Williams utilized the Fatality Analysis Reporting System and the General Estimates System to identify red light running crash characteristics and the drivers involved. In the same year, Porter, Berry, Harlow, and Vandecar reported their findings from a nation-wide (U.S.A.) telephone survey on red light running, measuring self-reported driver behaviors. The survey involved approximately 5000 respondents, including roughly 4000 in the ten target states, and about 1000 as a comparison group from the 40 other states. From the respondents, a national sample of 880 was constructed. Neither of these studies addressed the presence of red light cameras as a factor in the violation of red lights. Future research could investigate the effect of red light cameras on driver behavior in terms of demographics, as there may be differences in compliance based on age, gender, and socioeconomic status.

### *3.4.2 Demographic Data – Retting et al. (1999) & Porter et al., (1999)*

Retting et al. (1999) found that overall, red light violators (runners) are typically younger than 30 (43% vs. 32%), male (74% vs. 70%), have had previous violations and convictions for being intoxicated, have invalid driver's licenses, and have consumed alcohol prior to the crash. Nighttime runners are more likely than daytime runners to be young, male, have deviant characteristics, and 53% of them have a high blood alcohol concentration. For drivers older than age 70, crashes happened primarily in the day, whereas the peak crash time for teenagers and ages 20 to 69 is about midnight. Regarding the typical runners, of those less than age 20, 86% were male, whereas for those greater than age 70, only 60% were male. The presence of alcohol was about the same for runners less than age 20 and ages 20 to 69, but alcohol was rarely reported for older drivers. While runners are more likely to have invalid driver's licenses, runners and non-runners do not typically differ in number of crashes in driving history. However, runners had significantly more driving while intoxicated convictions and at least two moving violation convictions. Red light runners are more likely than non-runners to be fatally injured in crashes. For runners who were killed, 72% of those age 70 or older did not survive, while only 29% of those younger than age 20 did not survive. Porter et al. (1999) found that some groups were more likely to self-report red light running. These groups include younger drivers (this likelihood seems to decrease with age), non-parents, and those in lower technology or blue-collar jobs (or unemployed).

### *3.4.3 Older Drivers and Signal Timing*

Alcohol as a factor for older drivers who run red lights is scarce, and at least 13% of fatal red light running crashes can be attributed to runners age 70 and over (Retting et al. 1999). From these findings it can be inferred that these drivers have difficulty clearing the intersection for other reasons. While Retting, Ulmer, and Williams (1999) found that older drivers have more angle collisions and higher crash involvements at stop signs than signals (where violating right-of-way is an issue), drivers age 65 and older are 3 to 4 times more likely to be seriously injured in side-impact (i.e., typical red light running) crashes. If intersections with red light cameras can be rendered safer, the older population would benefit most in this capacity. One way of potentially reducing the number of red light violations or collisions is adjusting traffic signal timing. The yellow signal and the all-red phase may be manipulated for this purpose, either independently or in combination. While both Wortman et al. (1985) and Stimpson et al. (1980) found short-term reductions in red light violation upon increasing the duration of the yellow signal, long-term effects of this increase in duration may be more meaningful. Over the course of a year, Retting and Greene (1997) monitored the change in violations as the duration of the yellow and all-red intervals were both independently then conjunctively increased (to ITE recommendations) and subsequently reduced (to their original duration). Their results demonstrated that red light violations decreased as yellow intervals were increased in length. While habituation was measured to have occurred significantly across four sites, an increase in violations was only found at one intersection. This habituation was inferred to have been confined to that site. The manipulation of the all-red interval did not seem to impact the violation of red lights; although an increase in the all-red interval may decrease the number of collisions (this would allow more violators to clear the intersection). The investigators address the possibility of the effect of an optimized yellow interval lessening over time. However, results of this study demonstrate a sustained (albeit limited) reduction in red light violations.

### 3.5 Conclusions

Increasing the length of the yellow interval is one countermeasure reliably found to at least temporarily decrease the number of red light violations. Red light cameras are involved with a 40% reduction in violations at treated intersections (Retting et al., 1999). Right angle and rear end collisions were estimated to decrease by 26% upon implementation of red light cameras (Flannery and Maccubbin, 2003). However, rear-end crashes increased by 40% according to one study (Golob et al., 2003). The issue of whether rear-end collisions will increase or decrease with the implementation of red light cameras has not yet been resolved. The precise effect of red light cameras on violations and crashes has not been found due to methodological issues, although research findings suggest a general trend favoring the implementation of red light cameras. Generally, the greater period of time for which an intersection is monitored for violation or crash frequencies, the more accurately any reductions are represented for the long-term. While some before-after studies examine the effects of red light cameras over the course of a year or more (Datta et al, 2000, Smith et al., 2000), often the data for these studies is from city-wide crash data, or the sites chosen for comparison are not sufficient as controls. In addition, studies that investigate the effects of red light cameras upon their implementation lack the necessary pre-implementation data to derive an accurate reduction in violations or crashes (Golob et al., 2003). For the studies that succeed in monitoring intersections for a sufficient time period and to a degree of specificity that the effects can be attributed to red light cameras, the criticism is that the intersections chosen for treatment may not be similar enough to other intersections that the effect can be replicated (Retting and Kyrychenko, 2002). While reductions in red light violations are associated with the presence of red light camera systems (and not always limited to the treated intersection), future research has yet to determine the permanency of the reduction and the exact impact of red light cameras on driver compliance, specifically in terms of age and other demographic characteristics.

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# 4. EXPERIMENT 1

## 4.1 Introduction

Older drivers are over-represented in most types of intersection crashes (Presser et al., 1998). According to the U.S. Federal Highway Administration (FHWA, 2003), approximately 50% of older driver (age 50+) accidents occur at intersections, compared with approximately 23% for drivers under age 50. Intersections are known to be more problematic for older drivers for a number of reasons (Hauer, 1988; Staplin & Lyles, 1991). Research has found that age-related declines of selective and divided attention may contribute to intersection accidents (Caird et al., in press; Caird & Hancock, 2002; Keskinen & Katila, 1998; Lerner, 1994; Owsley et al. 1998; Owsley, 2004; Staplin, 1995). Age-related declines in response capability may not necessarily be incorporated into the behavioral design assumptions. To reduce the frequency and severity of crashes, a number of highway design and traffic control elements have been examined to determine if they meet the needs of the older driver (Potts et al., 2004; Staplin et al., 1998). In particular, traffic light phasing for amber durations requires additional consideration given that only one study has specifically examined the limitations of older drivers to amber onsets (Knoblauch et al., 1995).

Previously, studies that have examined driver behavior in response to amber signal phasing spans more than four decades (Crawford, 1962; Gazis, Herman & Maradudin, 1960; Olson & Rothery, 1962). For example, the probability of stopping has been described based on the distance to an intersection (May, 1968; Olson & Rothery, 1972; Sheffi & Mahmassani, 1981; Williams, 1977; Wortman & Matthias, 1983) time to a stop-line (Chang et al., 1985; Mahalel, Zaidel & Klein, 1985; van der Horst & Wilmink, 1986: Williams, 1977), and as a function of approach speed (Williams, 1977; Sheffi & Mahmassani, 1981). Design values for perception response time (PRT) and deceleration rates are based in this progression of knowledge. For example, studies that have measured perception response time (PRT) to amber light onset can be found in **Table 4.1**. The mean and median PRT values across the range of study types and measurement approaches are reasonably consistent. The ITE formula specifies a 1.0 s PRT (ITE, 1994; Teply et al., 1995). Discussions have centered on the adequacy of 1.0 s in light of responses above the mean (see Range and 85$^{th}$ Percentile columns of **Table 4.1**). The necessity of drivers to respond to the amber onset increases as distance decreases and speed increases (Chang et al., 1985). It has been argued (see critiques in Olson & Rothery, 1962, Wortman & Matthias, 1983) that a 1.0 s PRT is sufficient for all drivers because it adequately approximates the necessity of an amber onset response. However, only one study has explicitly examined older drivers' PRTs to determine if the ITE specification is sufficient (Knoblauch et al., 1995), and the study has a number of technical and methodological weaknesses.

A more in-depth review of this study is provided here (also see, Staplin et al., 1998). Knoblauch et al. (1995) investigated the response time characteristics of four age categories (40-59, 60-64, 65-69, and 70+) to an amber signal onset that was varied. Responses measured were off-gas time (time from onset of amber signal to removal of foot from gas), on-brake time (time from signal onset to application of brake) and decision time (time from when foot lifted off-gas to when the brake is pressed) at speeds of 48 km/h and 32 km/h on a closed course. The terminology that was used by the authors is not consistent with the PRT literature (e.g., Olson & Farber, 2003). Drivers were encouraged to maintain their speed as they approached the traffic signals and the amber light came on when the drivers were about 3.0 to 4.9 s away from the intersection and stayed on between 3 to 4 s, which corresponded to average amber phase lengths of 3.43 to 4.88 s for traffic lights. The precise manipulation of amber onset and length is not clear due to technical difficulties, which resulted in the loss of 20% of the data, and a confusing methodological description.

There was a significant difference in the average number of times a participant stopped for a light when the oldest (70+) and middle-aged (40 to 59) drivers in the study were compared. Drivers over age 70 stopped only 32.1% of the time, whereas drivers under 60 stopped 46.9% of the time. Overall, there were no significant differences between older and younger driver response times for off-gas, on-brake or decision time. When the oldest and youngest were compared, older drivers had longer decision times ($M$ = 0.48 s) when they were more than 4 s from the intersection at amber light onset (i.e., they had more time to assess and respond) than younger drivers ($M$ = 0.33). The effect was similar for both 32 km/h (20 mph) and 48 km/h (30 mph) approach speeds. The authors concluded that when older drivers have more time and distance available to make a stopping decision, they will actually use more time to make it. That is, older drivers delayed putting their foot on the brake when they had more time to respond. Similarly, deceleration rates were lowest when more time to reach the signal was available. There were no significant differences between age groups at the 15$^{th}$, or 85$^{th}$ percentile deceleration values. Without a considered rationale, the authors concluded that traffic signal phasing does not need to be altered to accommodate older drivers.

**Table 4.1.** Summary of amber light PRT studies listed by: authors, study type, intersection and driver characteristics, number of observations or participants (N), mean PRT, range, median and 85th percentile values.

| Study (date) | Study Type | Intersection, Driver Characteristics | Mean PRT (SD) | Range | Median | 85th Percentile |
|---|---|---|---|---|---|---|
| Gazis et al. (1960) | Observational, Analytic | 3 intersections, Speed limit 40-45 mph, N = 87 | 1.14 (0.28) | 0.6–2.4 | 1.1 | 1.5 |
| Crawford (1962) | Experimental, Test Track | 3 vehicles, 6 men, 2 women, 20–60 mph, N = 650 stops | | 0.8–1.85 | | |
| Wortman & Matthias (1983) | Observational, Field | 6 intersections, N = 839, Speed limit 30-50 mph | 1.3 (0.6) | 1.09–1.55[1] | | 1.8 |
| Chang et al. (1985) | Observational, Field | 13 intersections, N = 579, Speed limit 30-55 mph | 1.3<br>0.9[2] | 0.7–1.55 | 1.1<br>0.9[2] | 1.9<br>2.5, 95th |
| Mussa et al. (1996) | Experimental, Driving Simulator | N = 41, Ages 18 to 58, 40.3 & 72.5 km/h approach speeds | 1.16 | | | |
| Knoblach et al. (1995) | Experimental, Test Track | N = 81, 40 men, 41 women, 20 & 30 mph approach speeds, 3.5 & 4.5 TSL | 0.59-0.78[3] | | | 0.74-1.26[3] |
| Caird et al. (2006) | Experimental, Driving Simulator | N = 77, 18-24,25-35, 55-64, 65+ 70 km/h limit | 0.96 (0.27) | 0.5–2.2 | 0.92 | 1.22<br>1.45, 95th |

**Notes**: [1]Range of mean times across intersections and conditions observed. [2]Value for vehicle approaches over 40 mph. [3]Range of mean times over middle-aged and older drivers, approach speeds (20, 30 mph) and time from signal (~3.5 and 4.5 s).

### *4.1.2 The Present Study*

Additional research is needed that describes the range of responses by older and younger drivers at intersections. The present study investigated seven dependent measures of driver performance, including PRTs, and sampled four age groups (18-24, 25-35, 55-64, 65+) to 6 different amber light onset times.

It was expected that older drivers would run more amber lights, depending on the amount of time available to respond before entering an intersection, than younger drivers (Edwards et al., 2003). Decisions to stop or run a yellow light were expected to be dependent on available time to respond, age and traffic presence. We also expected that older drivers would have slower response times and would choose to decelerate at a lower rate than younger drivers. Younger drivers were expected to adopt higher speeds, have faster responses and brake harder than older drivers.

## 4.2 Methods

### *4.2.1 Participants*

A total of 77 participants were in the study (36 females; 41 males), 20 in each of the age categories of 18 to 24, 25 to 35, 55 to 64, and 17 participants were in the 65+ group. Participants were recruited from the University of Calgary and the City of Calgary through newspaper advertisements and posters. Volunteers were paid $25 (Canadian) for about a 60-minute session.

To enter the study, all participants were required to have driven at least 5,000 kilometers per year and had their driver's license for a minimum of three years. In addition, they were required to report that they were in good physical and mental health, free of any visual disorders, and were not under the influence of medications or drugs that would affect their driving performance. A number of demographic, driving history and visual acuity characteristics of those who were in the study are listed in **Table 4.2**.

A brief questionnaire, called the Simulator Sickness Questionnaire (SSQ), was given on the telephone prior to participation in order to screen out those who were susceptible to motion sickness (Kennedy et al., 1993). Five potential participants reported having one or more simulator sickness risk factors and were not allowed to participate. At total of 16 participants withdrew from the study due to simulator sickness and were replaced by additional volunteers. Of the two men and fourteen women who withdrew from the study, nine were 65+, three were 55 to 65, three were 25 to 35, and one was in the 18 to 24 age group. The overrepresentation of older women (nine were 55 and older) who exhibited symptoms and/or reported simulator discomfort is a known problem (Edwards et al., 2003), but not typically reported or discussed.

**Table 4.2.** Age group categories, number of participants in each group, mean participant age (standard deviation), average kilometers driven per year, total number of crashes since licensure, moving violations, and visual acuity (minimum angle of resolution, MAR) with correction.

| **Age Group** | **N** | **Mean Age (SD)** | **Km/ Year (SD)** | **Lifetime Crashes (SD)** | **Moving Violations (SD)** | **Visual Acuity (SD)** |
|---|---|---|---|---|---|---|
| 18-24 years | 20 | 20.60 (2.5) | 25,500 (21515) | 1.2 (1.1) | 1.1 (1.3) | 1.1 (0.40) |
| 25-35 years | 20 | 27.70 (2.3) | 24,842 (24699) | 2.0 (1.5) | 3.1 (3.1) | 1.0 (0.29) |
| 55-64 years | 20 | 58.10 (3.3) | 21,677 (15091) | 2.0 (1.1) | 4.7 (4.9) | 1.1 (0.31) |
| 65+ years | 17 | 70.00 (3.7) | 21,677 (17292) | 3.0 (5.9) | 3.6 (4.1) | 1.2 (0.33) |
| Total/Means (SD) | 77 | 43.10 (20.6) | 23,494 (19704) | 2.0 (3.0) | 3.1 (3.8) | 1.1 (0.36) |

### *4.2.2 Apparatus and Materials*

#### 4.2.2.1 Driving Simulator

The University of Calgary Driving Simulator (UCDS) was integrated by KQ Corporation (now called DriveSafety) and a number of custom modifications were made in the Cognitive Ergonomics Research Laboratory (CERL). The UCDS is composed of five, networked 1Ghz SGI workstations. A NetGear FS108 Fast Ethernet switch handles the network communication between visual channels, authoring workstation, and the host computer. Three workstations with nVidia Gforce3 graphics cards are linked to three projectors. One workstation manages I/O, graphics, and audio. The fifth workstation is a development platform for traffic scenarios and experimental management. Each Epson 703C projector displays (1064 x 768 resolution and maximum lumens 1000) onto a WrapaAround Clarion Screen by Draper each of which measures 86.5” wide by 65” in height. The display refresh rate of the system is 60 Hz. The total projected forward field-of-view is 150 degrees. A Saturn SL1 is situated in front of the screens. The brake, accelerator, and steering are interfaced to the graphics by way of an A/D computer under the hood of the Saturn at 400 Hz. The steering wheel “stiffness” is controlled as a function of speed by a torque motor (Model No. SE 808). Brake and accelerator inputs are modeled in software to result in appropriate deceleration and speeds. The speedomoter (kph), interior lights (i.e., dashboard, radio, and centre console), and fan provide speed, display information, and air respectively. Road noise is presented through a Monsoon MM2000 stereo system with a base and surround speakers. Noise scales with the speed of the vehicle. Additional sounds can be attached to a range of events in the traffic environment.

The purpose of the video and audio system is for participant monitoring, communication and to create a record of participant and experimenter activities. A system of three black and white “lipstick” cameras (Model No. KPC 500) are mounted inside the Saturn and provide views of the driver’s face, hands on the steering wheel, and feet on the brake and accelerator. A fourth colour camera (Panasonic Model No. WV-CP460 with a WVLA 9C3A 9mm Panasonic lens) shows the center screen of the simulated traffic environment. All four views are displayed, using a multiplexer (Panasonic Quadsystem WJMS 424), on a 23 inch Toshiba monitor. Real-time data from the steering wheel, brake, and accelerator are overlaid on corresponding video images using a BOB-II Video Text Overlay Module. Data streams indicate deflection angle of the steering wheel and the percent depression of the accelerator. A microphone is inserted in the driver’s side visor which can pick-up all verbalizations of participants. A separate speaker (Yamaha Monitor Speaker 101) directly behind the driver can present verbal directions from the experimenter through a table-top microphone (Shure BG3.1) at the central workstation to the participant. An audio mixer (Behringer Eurorack MX802A) handles all audio to and from the vehicle and experimenter workstation. A VHS player (JVC Super VHS ET) records the multiplexed views of the driver, the forward field of view, and audio to tape.

#### 4.2.2.2 Simulation and ITS Software

HyperDrive (v. 1.6.2) provides the means to develop traffic environments and experimental scenarios for the driving simulator. The *tile* is a basic unit of a traffic environment. Tiles can be selected from an extensive pallet of intersections, freeway sections, streets, and so forth; all of which adhere to the *Manual on Uniform Traffic Control Devices* (MUCTD). Modifications to the speed limit signs were adapted for km/h by KQ. Once a tile is selected it can be placed into an environment and linked with others tiles to compose a traffic environment. Scenarios are specific situations that can be built to record driver behaviours in a specific traffic environment of interest. For example, an intersection can be built which will test the perception-response time of a driver to the change of a light or the incursion of another vehicle that runs the lights. Dependent variables that can be collected include a range of timing variables including PRT, velocity, lane position, steering deflection angles, acceleration percentage (of accelerator), deceleration percentage (of brake), heading, X-Y coordinates, lateral acceleration, longitudinal acceleration, collision detection, and a variety of derived variables. The density of the ambient traffic is controlled with a windows slider such that low, medium and high traffic flows can be introduced. Alternatively, specific flows can be established using Tcl scripting. Fog can be introduced in a similar fashion using a slider control for distance.

#### 4.2.2.3 Scenario Development

The development and iterative testing of traffic environments to test that a number of complex variables including the presence of other vehicles, the timing of lights, other vehicle vectors, pedestrian behaviours, and sign placement correspond to experimental questions. Intersection scenarios for training and experimentation will also be developed in accord with the research objectives of each project phase.

### *4.2.3 Procedure*

#### 4.2.3.1 Participant Visual Screening

Far visual acuity, far contrast sensitivity and colour vision were assessed at the beginning of the session. For the visual tests, participants wore their own visual correction if necessary. Visual acuity was measured using a Snellen Visual Acuity eye chart that requires participants to read letters in descending size at 6.1 meters (20 feet). A Snellen acuity of 20/40 or better was required to participate, which is the legal requirement to receive a license in Alberta (Casson & Recette, 2000). One person was dropped from the study because they did not bring their glasses and did not pass the visual acuity test. Contrast sensitivity was measured at 3 m using a Vistech Contrast Sensitivity Chart and participants were required to score within the normal range for at least 3 of the 5 spatial frequency functions. Colour vision was tested using an Ishihara Test for Color Blindness (plates no. 3 and 27) (Ishihara, 1993). All the remaining participants passed the contrast sensitivity and colour vision tests.

#### 4.2.3.2 Practice Drive

Participants were introduced to the simulator and drove a 5-minute practice drive to familiarize them with the roadways and vehicle control during the experiment. Drivers experienced the lights changing to amber at each intersection to allow them to practice braking in the simulator (see **Figure 4.1**). Cars were parked in the curb lanes near the intersections on the driver's approach.

Drivers were instructed to "drive as they normally would" in their own vehicles and to obey all the rules of the road, such as speed limits, lights and signs. During the practice drive, all drivers were encouraged to maintain the speed limit of 70 km/h. As well, the researcher explained the vertical traffic light layout of the simulated intersections to ensure that all drivers understood its meaning. All participants said that they understood the simulated traffic lights and their practice drive performances were consistent with their statements.


**A** **B**

**Figure 4.1.** Image A (left) shows an intersection approach with oncoming and parked vehicles at a time to stop-line of 2.69. B shows a screen capture of the interior of the simulator with brake, accelerator, speed and steering variables overlaid.

4.2.3.3 Experimental Drive

The experimental session consisted of four 5-minute drives each consisting of nine intersections. Of the 36 intersections encountered, 12 (six 4-lane; six 2-lane) had the signals change to amber. Intersections were randomized in each drive and the orders of drive presentation were counterbalanced. Participants were reminded to adhere to the 70 km/h speed limit and speed signs were present throughout. Oncoming and cross traffic was present at half of the intersections (18 intersections) and half the amber onsets (6 intersections). The traffic lights at the 24 non-changing intersections remained green when traveled through. Thus, one in three intersection lights changed during any given approach.

Each participant had the same amount of time to react to the green to amber light changes for a given experimental intersection. Ordinarily, the available time to respond to an amber onset is a function of a driver’s speed and distance from the stop line. Thus, measures of PRT introduce a confound if speed varies in a given context. A driver at a higher velocity has less time to respond, whereas a driver at a lower speed has more time available. To control these differences, velocity at amber onset can be either treated as a covariate, or the available time to respond can be experimentally controlled to give a more precise measure of PRT.

To program the TSLs, a time-to-location (TTL) script was created in Tcl/Tk. The TTL script triggered the amber light change on the approach to the 12 designated intersections. The script allowed the experimenters to enter a location where an event would approximately occur such that the triggering of the amber light was held constant in time. The TTL script polled the speed of the participant's vehicle and triggered the amber light at the appropriate time had they continued to approach the intersection at their same speed.

The six TSL values of 1.73, 2.21, 2.61, 2.69, 3.1, and 3.58 s were selected based on pilot testing, computation using the ITS amber phase formula, and the probability of stopping found in previous research (see, e.g., Chang et al., 1985; May, 1968; Olson & Rothery, 1962; Olson & Rothery, 1972; Williams, 1977; Wortman & Matthias, 1983). During pilot testing, the selection of TSLs was intended to equally challenge younger and older drivers. Using the ITE equation (ITE, 1994), the same TSLs can be computed based on PRTs of 1, 1.5, and 2.0 s and 2- and 4-lane intersections that were 33.6 m and 56.6 m wide, respectively. The formula also requires the input of a vehicle length, which was 4.72 m, the deceleration rate of 3.0 $m/s^2$ (10 $ft/s^2$) and a grade approach, which was 0%. These inputs resulted in amber phase lengths of 4.08, 4.58, and 5.08 s, although a driver never saw the entire amber phase because the TSL values placed the driver past the light prior to the end of a phase. Each participant experienced each TSL twice, once with traffic and once without.

At the conclusion of an experimental session, demographic data, such as age, gender, annual mileage, number of years driving, number of at-fault accidents, number of violations, and type of violations were collected using the Driver Experience Questionnaire (DEQ). At the conclusion of the session, participants were debriefed and remunerated for their participation.

## 4.3 Results

### *4.3.1 Experimental Design and Analysis*

A modified UNIANOVA (SPSS v. 11.5), which computes a repeated-measures ANOVA that is robust to missing values and small cell sizes, was used to analyze each dependent variable for age group (18-24, 25-35, 55-64, 65+) by time-to-stop-line (TSL) (1.73, 2.21, 2.61, 2.69, 3.1, & 3.58 s) and age group (18-24, 25-35, 55-64, 65+) by traffic presence (present, absent) factor combinations. Intersection type, 2-lane or 4-lane, was not significant, with the exception of intersection clearance, and was collapsed into the remaining factors.

To conserve space, independent variable manipulations and interactions that were not significant are not reported except when to elucidate expected or contrasting results. The statistical analysis is composed of seven sections; namely, stop/go probability, logistic regression, velocity, PRT, mean deceleration rates, stopping accuracy, and intersection clearance.

### *4.3.2 Data Reduction and Screening*

The appropriate data segments associated with each intersection where the light changed to amber were automatically cut from the raw simulator data fields using a custom C# program. Data collection flags were inserted into HyperDrive at 250 m prior to each amber intersection and 50 meters after the intersection exit point that facilitated this extraction process.

A number of PRT data values were detected as univariate outliers (SPSS 11.5 DESCRIPTIVES). Consideration of whether to substitute a lesser z-score for each was considered on a case by case basis with the understanding that PRT is not normally distributed (Olson & Farber, 2003; Toaka, 1989) and exceptional values, especially by older drivers, may naturally occur in the extreme right tail of the sample distribution.

### *4.3.3 Stop/Go Probability*

*Stop/Go Probability* is the observed likelihood of participants who stopped or proceeded through an intersection. Overall, the probability of stopping for the TSL’s of 1.73, 2.21, 2.61, 2.69, 3.0, and 3.58 was 5.8, 30.5, 42.0, 64.6, 69.0 and 83.4, respectively (see **Figure 4.2**). Between the TSL values of 2.61 and 2.69 lies the hypothetical 50:50 decision point for this sample of drivers. Four previous studies expressed the probability of stopping as a function of time to stop-line or available time as opposed to distance (Williams, 1977; Mahalel, Zaidel & Klein, 1985). The range of TSL values in this study correspond with similar probabilities of these previous studies.

Age was not significant with the exception of the TSL of 3.58. The probability of those stopping who were 18 to 24 (92.5) and 25 to 35 (92.5) was significantly different than those 55 to 64 (75) and 65+ (73.5) ($p < 0.007$).

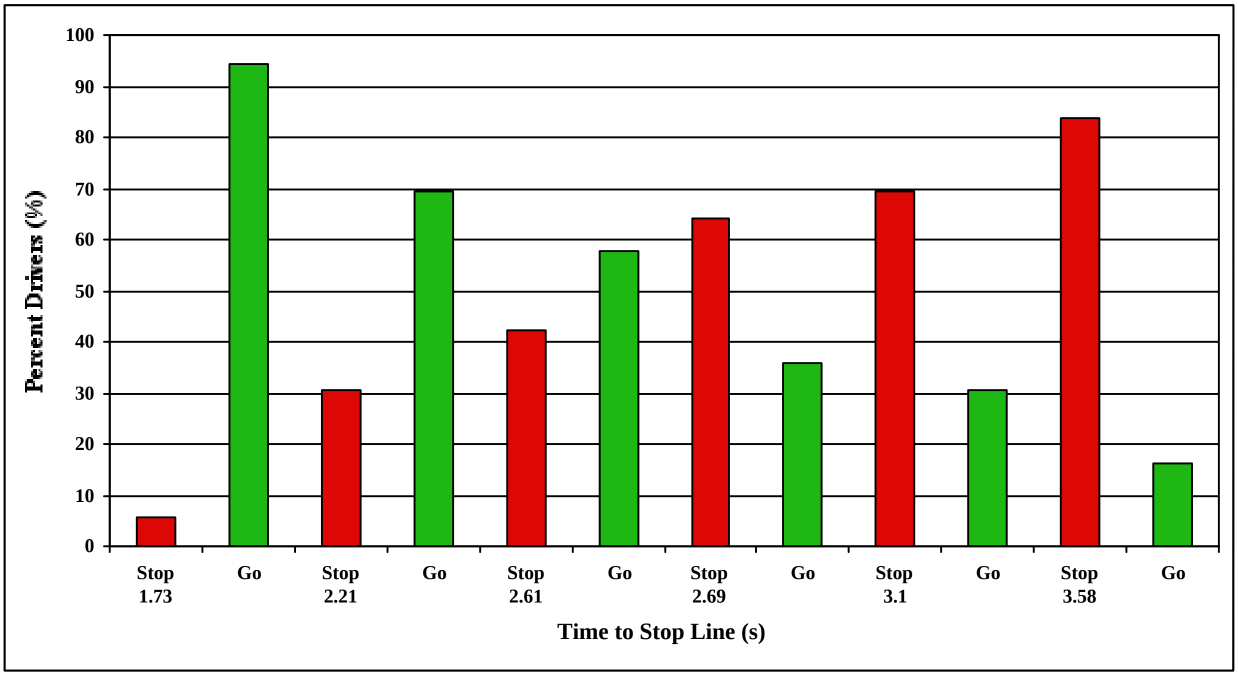


**Figure 4.2.** Time to stop line (s) by percent of participants who stopped or proceeded through an intersection.

### *4.3.4 Logistic Regression*

The purpose of conducting a logistic regression analysis was to create a model that predicted stop/ go decisions based on time to stop line (TSL), age and traffic presence variables (also see Chang et al., 1985, Cooper & Zheng, 2002). The model that contained TSL was significant as indicated by chi-squared ($\chi^2$ (5) = 286.16, $p < 0.0001$) (37). Traffic ($p < 0.215$) and age ($p < 0.282$) were not significant predictors.

Significant Wald (z-ratio) statistics (42.02, 4.52, 14.82, 22.58, 51.40) were found for the TSL values of 1.73, 2.21, 2.69, 3.1, 3.58, respectively, when compared to the reference of 2.61, which was a chosen central decision point. A value of +/- 2 is considered significant for the Wald test with a confidence interval of 95% for a standard normal distribution (Menard, 1995; Tabachnick & Fidell, 2001). The Exp(B) coefficients were 11.77, 1.66, 0.41, 0.32, 0.14 for the same ordering of TSL values above. Values less than 1 can be interpreted by 1 minus ExpB. Those who encountered the 1.73 s TSL were 11.77 times more likely to run the yellow than the 2.61 s TSL. At a 3.58 TSL, participants were 86% (1 - 0.14) less likely to run the yellow light than those at 2.61 s.

Previous studies have modeled the probability of stopping based on approach speed, distance at onset and time to stop-line assuming a constant speed (Chang et al, 1985). Distance and speed variables significantly predicted the probability of stopping. The present study examined only one speed, 70 km/h. Distance and speed were controlled such that time to stop-line was held constant for each amber onset.

### *4.3.5 Velocity at Amber Onset, Stop Line, and Intersection Exit*

*Velocity at Amber Onset* was calculated as the participant's speed, in km/h, when the light changed (Chang et al., 1985; May, 1968; Sheffi & Mahmassani, 1981). The difference in initial velocity of those who proceeded through an intersection ($M$ = 70.2 km/h) versus those who stopped ($M$ = 69.3) was significant, $F$ (1,773) = 4.47) $p < 0.035$ as was age, $F$ (3,773) 34.78, $p < 0.001$. Cell means consistently showed that those who stopped were traveling about 1 km per hour slower than those who proceeded through the intersection. In addition, speed at the light change was progressively slower with each successive age group from 18 to 24 to 65+.

For those who stopped at the intersection, the presence of traffic had a significant effect on velocity ($F$ (1, 90) = 5.7, $p < 0.019$) and age ($F$ (3, 312) = 21.36, $p < 0.0001$). Adjusted Sidak pairwise comparisons ($p < 0.05$) indicated that the two older age groups were significantly different from the two younger age groups. When cross and oncoming traffic was present, those 55 to 64 and 65+ had significantly lower speeds than the younger drivers when the light changed. The mean velocity at the light change was 71.4 km/h for those 18 to 24, 70.8 for those 25 to 35, 67.6 for those 55 to 64 and 66.7 for those 65+.

For those who went, velocity was also measured at the *stop line* and *intersection exit*. Age was significant at the stop line, $F$ (3, 185) = 22.11, $p < 0.0001$, and at the exit of the intersection, $F$ (3, 185) = 29.89, $p < 0.0001$. Sidak pairwise comparisons indicated that the oldest age group significantly differed from the age groups of 18 to 24, 26 to 35 and 55 to 64 by about 4 km/h at the stop line (66 versus 70-72 km/h) and 5 km/h at the intersection exit (68 versus 72-74 km/h). The multiplier for the linear relationship between approach and exit velocity (where approach speed = 1.08 * the exit speed) (24), was slightly less for those 65+ (1.04) than for the other age groups (1.06).

### *4.3.6 PRT Analyses*

Perception, Response and PRT were only calculated for those who stopped. Participants who lifted their foot off the accelerator in advance of the amber change were removed from the Perception and Response analyses, but were included in the overall PRT analysis. The number of times that participants lifted their foot off the accelerator in advance of the light change, increased as more time was available to stop (e.g., 2 at 1.73 s to 20 at 3.58 s). Across all levels of TSL, the number of instances that participants anticipated was 31 for those 18 to 24, 8 for 25 to 35, 23 for 55 to 64, and 30 for 65+.

#### 4.3.6.1 Perception

Perception, which is the time from the yellow light onset to accelerator release, was analyzed using a UNIANOVA for age by TSL and age by traffic. There was a significant effect of traffic presence, $F\ (1,230) = 4.04$, $p < 0.045$. Participants lifted their foot off the accelerator slightly faster when traffic was present ($M = 0.62$) than when no traffic was present ($M = 0.68$).

#### 4.3.6.2 Response

*Response Time* was measured from the foot leaving the accelerator pedal until the brake was first depressed in seconds (Olson & Farber, 2003). TSL exerted a significant difference on response time, $F\ (5, 121) = 13.55$, $p < 0.0001$, whereas age group was not significant, $p = 0.201$. The progression of response time means increased from 0.21 s for the 1.73 s TSL to 0.36 s for the 3.58 s TSL. When drivers had more time before they reached the intersection after the amber light was activated, they tended to delay moving their foot from the accelerator to the brake.

4.3.6.3 PRT

*Perception Response Time* (PRT) was the time elapsed from the amber onset until the brake was depressed (Olson & Farber, 2003). Overall PRT descriptive statistics for this study can be found in last entry of **Table 4.1** and **Figure 4.3**. TSL had a significant effect on PRT, $F$ (5,116) = 2.4, $p < 0.05$. PRT means increased from 0.86 s at 1.73 s TSL, 0.93 s at 2.21 s TSL, 0.90 s at 2.61 s TSL, 0.95 s at 2.69 s TSL, 0.93 s at 3.1 s TSL, and 1.03 s at 3.53 s TSL.

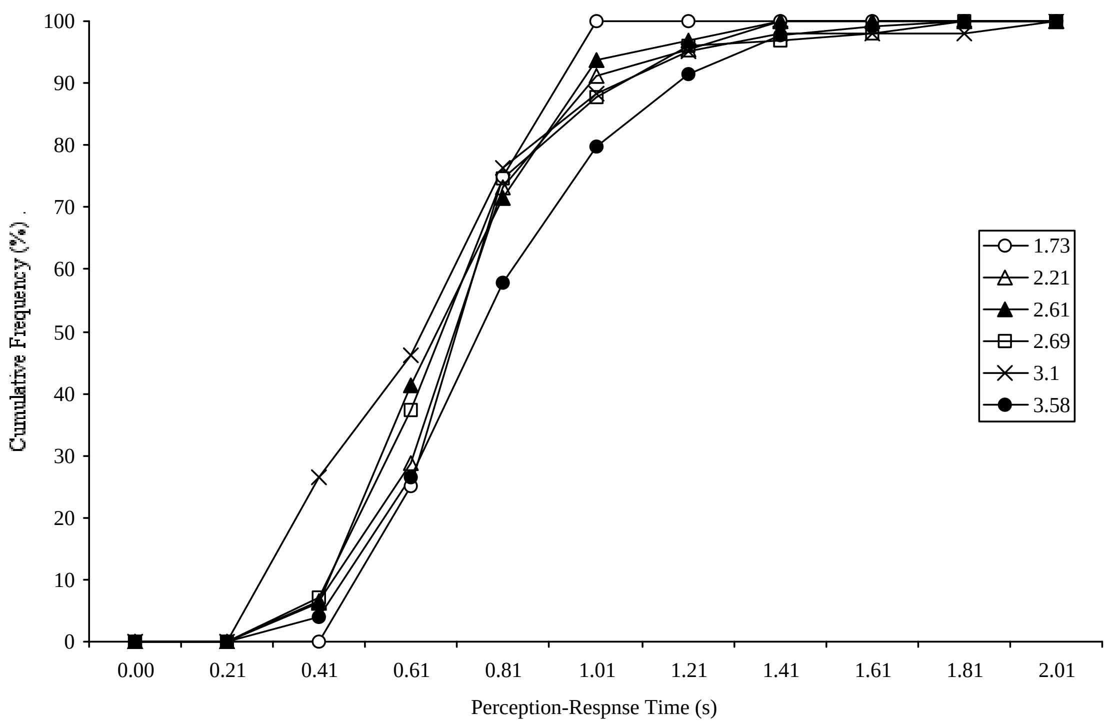


**Figure 4.3.** Cumulative PRT curves for each TSL.

*4.3.7 Mean Rate of Deceleration*

*Mean Rate of Deceleration* was calculated in $m/s^2$ from the time that the brake exceeded 5% depression until velocity was 0 (24). TSL ($F$ (5, 179) = 68.8, $p < 0.0001$) and age ($F$ (3, 179) = 7.5, $p < 0.0001$) were significant. For the range of TSLs from 1.73 to 3.58, the mean rates of deceleration decreased from 5.5 to 2.5 $m/s^2$ (18–8.2 $ft/s^2$). The mean rates of deceleration chosen by those 18 to 24 (4.4 m/s$^2$, 14.4 ft/s$^2$) and 25 to 35 (also 4.4) were significantly higher than those of the age groups 55 to 64 (3.8 m/s$^2$, 12.5 ft/s$^2$) and 65+ (3.7) ($p < 0.01$).

Rates of deceleration are typically expressed as a function of stopping probability (Chang et al., 1985; Olson & Rothery, 1962; Mahalel, Zaidel & Klein, 1985; May, 1968; Olson & Rothery, 1972; Sheffi & Mahmassani, 1981; van der Horst & Wilmink, 1986; Williams, 1977; Wortman & Matthias, 1983). For 6 intersections in Phoenix, mean decelerations were 7.0 to 13.8 ft/s$^2$ (2.1–4.2 m/s$^2$) and 85$^{th}$ percentile decelerations varied from 11.5 to 18.2 ft/s$^2$ (3.5–5.6 m/s$^2$). Comparable mean deceleration rates for older and younger drivers were 10.7 to 15.2 ft/s$^2$ (3.3–4.6 m/s$^2$) for TSLs of approximately 3.5 and 4.5 s at 20 to 30 mph (32–48 km/h) (Knoblauch et al., 1995). Thus, the decelerations from our driving simulator, which provides only visual information for deceleration, were similar to observational studies.

### *4.3.8 Stopping Accuracy*

*Stopping Accuracy* was measured in meters by using the y coordinates of the first stop line of the appropriate intersection (Hancock et al., 2003). Participant stopping accuracy was calculated by taking their initial stopping point and subtracting their y coordinates from the y coordinates of the stop line. A negative number indicated that the participant crossed the stop line and entered into the intersection.

Stopping accuracy was significantly different for age group, $F$ (3, 179) = 15.85, $p < 0.0001$. Sidak adjusted multiple comparisons ($p < 0.001$) indicated that those 65+ differed from every other age group (i.e., 18-24, 25-35, 55-64). Stopping accuracy also significantly differed by time to stop line (TSL), $F$ (5, 179) = 127.22, $p < 0.0001$. Adjusted Sidak pairwise comparisons indicated that only the 2.61 and 2.69 s TSL did not significantly differ from each other. The oldest age group (65+) was more accurate when they stopped than any other age group, probably owing, in part, to their reduced speed.

### *4.3.9 Intersection Clearance*

*Intersection Clearance* measured whether a driver was able to clear an intersection prior to the all red onset for those who ran the amber light. It was calculated from the light change until the rear end of a participant's vehicle cleared the stop line opposite the entrance to an intersection. Total clearance time from entrance to exit was subtracted from the yellow light phase calculated using the ITE equation (ITE, 1994) to determine if they were still in the intersection or not. A negative number indicated that they had not cleared the intersection before the lights changed to red.

A significant difference for age group was found, $F$ (3, 185) = 6.77, $p < 0.0001$. Sidak adjusted pairwise comparisons indicated that the older age group differed from every other age group ($p < 0.05$). The pattern of significant pairwise comparisons for the significant TSL, $F$ (5, 185) = 8.45, $p < 0.0001$, was more complicated. TSL of 1.73 differed from 2.61, 2.69, 3.1 and 3.68 s, and 2.21 differed from 3.58. Older drivers were less likely to clear the intersection, if they chose to run the light, than other age groups. This is, in part, attributable to their reduced initial speed.

## 4.4 Discussion

The results of this study fill an important descriptive gap in driver performance at intersections. In particular, the age groups sampled, the multi-measure approach, and the measurement precision of PRT extend what is known about driver behavior to amber onsets.

At the longest TSL (3.58 s), 75% of older drivers (55+) stopped while 92% of younger drivers did. The result is not unique and has been found in previous studies (Edwards et al., 2003; Knoblauch et al., 1995). A similar age split resulted in a significant age difference at approximately the same time to stop-line values (Knoblauch et al., 1995). In the present study, there were no significant age differences at the TSL values of 1.73 to 3.1. Why, at longer time to stop-line values, do more older drivers run the amber light? One plausible explanation is a desire to maintain their speed (Summala, 2000). If younger drivers decided to go, their speed profiles at amber onset, stop line and intersection exit had greater decelerations and accelerations than older drivers. Similarly, older drivers chose lesser deceleration rates than younger drivers at the same 55+ age-split. The speed maintenance hypothesis should be modified to account for age differences in willingness to tolerate changes in speed, including to yellow light changes.

Older drivers (65+) were significantly less likely to clear the intersection than other age groups. Initial velocity at the light change was indicative of the propensity of younger drivers to adopt higher speeds and older drivers to adopt slower speeds. When the dependent variables of velocity, stopping accuracy and intersection clearance are considered together, the adaptive strategy of a slower velocity adopted by older drivers generates benefits and costs. Those 65+ were able to come to a more accurate stop. However, clearing the intersection from a lower velocity became more problematic if they had to run the amber light. Stop line and intersection exit velocities also indicate that the oldest age group is slower than other age groups by about 4 to 5 km/h. If older drivers are more likely to be in an intersection when the all-red phase occurs, the timing of it according to the ITE formula (ITE, 1994) is clearly an important design recommendation (Staplin et al., 1998).

There were no age differences in PRT, perception or response components. TSL significantly affected PRT and means increased from 0.86 at 1.73 s, 0.93 at 2.21, 0.90 at 2.61, 0.95 at 2.69, 0.93 at 3.1, and 1.03 at 3.53. Thus, PRT was affected by the time constraints imposed by the time to stop-line when the amber light was activated. The urgency to stop is reflected in the PRTs (Summala, 2000). In particular, drivers' delayed contacting the brake, as indicated in the significant effect of TSL on response, when more time is available to stop. Perception and reaction time have not been measured in previous amber onset studies. Typically, the time from amber onset to brake light activation is measured to give PRT (e.g., Chang et al., 1985; Wortman & Matthias, 1983).

The PRT grand mean was 0.96 s (see Table 1, last entry), which was 0.2 to 0.4 s faster than previous studies (Chang et al., 1985; Gazis et al., 1960; Mussa et al., 1996; Wortman & Matthias, 1983), because a time critical response was required. In previous studies, the inclusion of drivers who braked further from an intersection at amber onset (i.e., longer TSLs) explains this difference. Whether or not aspects of the right tail of the PRT distribution, such as the 85$^{th}$ percentile values (see **Table 4.1**), should be considered in design, has been discussed in various contexts for some time (Chang et al., 1985; Olson & Farber, 2003; Wortman & Matthias, 1983).

Is the amber phase length sufficient to accommodate older drivers? The ITE amber phasing equation (ITE, 1994) can be used to calculate amber phase lengths and all-red phase lengths. The formula specifies a perception response time (PRT) of 1 s, among other parameters. Research by Tarawneh (as cited in Potts et al., 2004; Staplin et al., 1998) argued that the use of a 1-second PRT in the ITE equation was not sufficient and suggested that a 1.5 s PRT would accommodate older drivers to a greater degree. The authors of several important older driver design guides (Potts et al., 2004; Staplin et al., 1998) concluded that the 1-second PRT is sufficient based on a prior study (Knoblauch et al., 1995), which found a few significant age differences at the $85^{th}$ percentile levels (**Table 4.1**, second to last entry). This study, given the range of PRT values obtained across age groups, would suggest that the 1.0 s PRT is a sufficient approximation.

The use of a longer amber duration is reviewed in depth by several previous studies (Liu, Herman & Gazis, 1996; May, 1968). The shorter the amber light phase, the more likely that a red-light violation will occur (May, 1968; van der Horst & Wilmink, 1986). However, adaptive behavior to a longer amber phase may result in other intersection errors (May, 1968). Philosophical objections to longer amber phases include delays to cross traffic (Liu et al., 1996). Resolution of these issues based on field experiments has had little progress and is not mentioned in a recent AASHTO guide (Antonucci et al., 2004).

Older driver strategic choices must be taken into account when devising countermeasures to reduce collisions caused by traffic signal violations. Despite knowing that a large portion of older driver crashes occur at intersections, the prevalence with which older drivers run red lights is largely unknown (e.g., McGee & Eccles, 2003). Older drivers are more likely to be injured or killed once in a collision than a younger driver (Hauer, 1988). Therefore, intersection countermeasures that potentially reduce their probability of being involved in a crash are worthwhile. Based on this study and others about older driver performance at intersections (Caird & Hancock, 2002; Staplin & Lyles, 1991), it is reasonable to suggest that if signal violations occur among this group, they are more likely to be unintentional versus deliberate violations. The use of red-light camera enforcement does not appropriately address the potential needs of older drivers who may run signals unintentionally.

## 4.5 References


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# 5. EXPERIMENT 2

## 5.1 Introduction

The purpose of this study was to determine if in-vehicle advanced warning signs could improve both younger and older drivers' intersection performance. In-vehicle signs have been identified as a beneficial intelligent transportation systems (ITS) technology (Chugh & Caird, 1999; Hanowski et al. 1999; Regan, 2004), but have received minimal research attention. Infrastructure based advanced warning signs (AWS), which have some demonstrable crash reductions (Sayed et al., 1999), are an analog to in-vehicle signs and drivers have some familiarity with AWS in Canada. Two of in-vehicle signs were evaluated in a head-up display (HUD) format to determine if the signs were able to improve stopping performance or if they produced unwanted behavioral side effects.

## 5.2 Methods

This study used the University of Calgary Driving Simulator (UCDS) to evaluate several in-vehicle signs at a number of intersection approaches. Many of the methods are similar to those described in Section 4 and are cited as such.

### *5.2.1 Participants*

A total of 24 participants, half 18 to 24 ($M$ = 21.5) and half 65 to 76 ($M$ = 69.2), volunteered for the study. Equal numbers of men and women participated. Participants were recruited through the local newspaper and paid $40 ($CAN) for participation. As described in Experiment 1, all participants were screened for simulator sickness, visual acuity, contrast sensitivity, color deficiency, and mental and physical health as were those in the first experiment (see 4.2.3.1). The characteristics of those in this study can be found in **Table 5.1**.

Approximately 20 people were screened from participation for having one or more simulator sickness risk factors and were not allowed to participate. Four participants failed the visual acuity test and one person was blind in the left eye. Those who did not pass the eye exam were encouraged to see their eye doctor. One other participant became simulator sick and dropped out.

**Table 5.1.** Age group categories, number of participants in each group, mean participant age (standard deviation), average kilometers driven per year, total number of crashes since licensure, moving violations, and visual acuity or minimum angle of resolution (MAR) with correction.

| **Age Group** | **N** | **Mean Age (SD)** | **Km/ Year (SD)** | **Lifetime Crashes (SD)** | **Moving Violations (SD)** | **Visual Acuity (SD)** |
|---|---|---|---|---|---|---|
| 18-24 years | 12 | 21.5 (2.2) | 19,167 (13,347) | 0.6 (1.1) | 0.9 (1.2) | 0.88 (0.18) |
| 65+ years | 12 | 69.2 (3.3) | 18,167 (6,658) | 3.5 (2.5) | 3.5 (2.5) | 1.65 (0.34) |
| Total/Means (SD) | 24 | 46.35 (24.53) | 18,667 (10,327) | 2.0 (2.4) | 2.0 (2.1) | 1.43 (0.47) |

### *5.2.2 Apparatus and Materials*

#### 5.2.2.1 Driving Simulator

The UCDS was used to perform this study. A complete description of the simulator can be found in Section 4.2.2.

### *5.2.3 Procedures*

The practice drive was approximately 6 minutes in length and the posted speed was 70 km/h. Interspersed in the drive were two light changes at 2.21 s and one at 1.73 s, which were the two shortest times to stop line (TSL) intervals of Experiment 1. The experimental session consisted of four 10-minute drives each consisting of 12 intersections. All intersections had four lanes, parked cars, and oncoming and cross traffic. The first and last drives were baseline measurement drives. The order of drive presentation was counterbalanced. One drive contained a rectangular icon and another had diamond in-vehicle sign (see **Figure 5.1**).

Of the 48 intersections encountered, 24 had the signals change to amber. Half of the changes were 1.73 s and the other half were 2.21 s. The occurrence of lights that changed were randomized within each drive. In accord with positive guidance principles (see, e.g., Alexander & Lunfield, 1975; 1986; Chugh & Caird, 1999), the rectagular and diamond sign icons were displayed for 4 seconds in the HUD format from 12 s to 8 s from the intersection (see **Figure 5.1**).

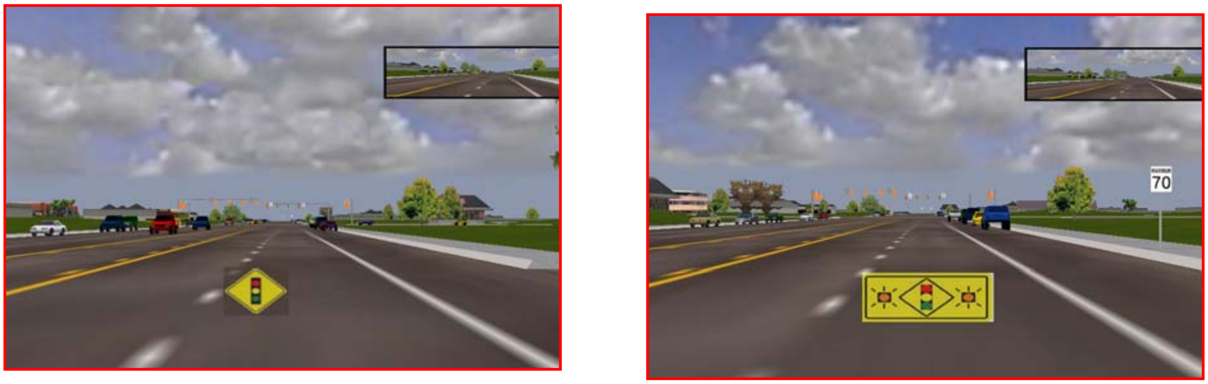


**Figure 5.1.** Intersection approach with oncoming and parked vehicles with the diamond advanced warning sign (left) and rectangular advanced warning sign (right).

Once the four experimental drives were completed, the post simulator sickness and driver behaviour questionnaires were filled out by participants. Finally, participants were debriefed and remunerated.

## 5.3 Results

### *5.3.1 Experimental Design*

A modified UNIANOVA (SPSS v. 11.5) was used to analyze the experimental design for each dependent variable. The simulator dependent variables measured included initial velocity at amber light onset, velocity at stop-line, velocity at intersection exit, perception response time (PRT), perception time, response time, stopping accuracy, rate of deceleration, and intersection clearance. These were the same variables as those analyzed in Experiment 1 (see Section 4.3.1). The independent variables were time to stop-line (TSL) (1.73 & 2.21 s), age group (18-24, 65+), and head-up display sign type (diamond and rectangular signs).

*5.3.2 Stop/Go Probability*

*Stop/Go Probability* is the observed likelihood of participants who stopped or proceeded through an intersection. Significantly fewer participants ran the amber light in the in-vehicle advanced sign conditions than those in the baseline condition ($\chi^2$ (1, 576) = 16.5, $p$ < 0.0001). The percentage of those stopping and going differed between those 18 to 24 and 65+ in the baseline ($\chi^2$ (1, 288) = 4.4, $p$ < 0.037) and in-vehicle sign ($\chi^2$ (1, 288) = 11.8, $p$ < 0.001) conditions (see **Figure 5.2**). There were no stop/go differences between the rectangular and diamond signs, $p$ = 0.48 or time to stop-line differences (i.e., 1.73 and 2.21 s). Older drivers were less likely to stop and more likely to go than younger drivers. The net effect of the in-vehicle signs was to increase the percentage of those stopping in both age groups.

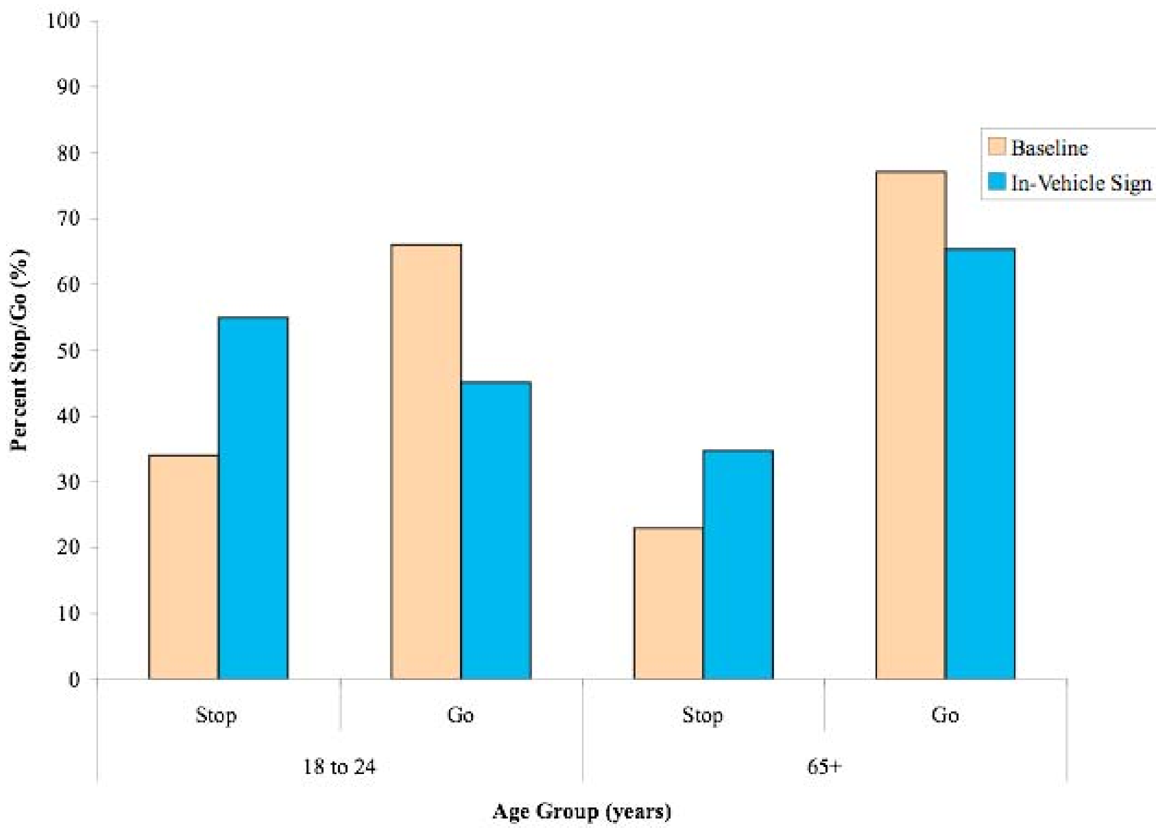


**Figure 5.2.** Percentage of those stopping and going by age group and baseline and in-vehicle sign conditions.

### *5.3.3 Initial, Stop Line and Intersection Exit Velocity*

Initial velocity (km/h) reflects the speed of a participants' vehicle when the light changed from green to yellow. For those who went through the intersection, velocity was also measured at the *stop line* and *intersection exit*.

*Initial Velocity, Stop/Go.* Overall, those who chose to stop at the intersections were traveling at a significantly lower velocity ($M$ = 48.41 km/h, $SE$ = .85) than those who ran the intersections ($M$ = 60.2 km/h, $SE$ = .78), $F(1,484) = 19.18$, $p < 0.001$. A two way interaction exist depending on drive type and Stop or Go behaviour, $F(1, 484) = 19.9$, $p < 0.001$. In the baseline condition, the velocity of those who stopped ($M$ = 57.7 km/h, $SE$ = 1.52) was no different than those who ran the yellow light (62.2 km/h, $SE$ = 0.71), $F(1, 227) = 3.24$, $p > 0.05$. Whereas, in the in-vehicle sign condition, the velocities for those who stopped ($M$ = 39.1 km/h, $SE$ = 0.80) was significantly lower than those who went (58.2 km/h, $SE$ = 1.23), $F(1, 230) = 16.9$, $p = 0.005$. The main effect of TSL was significant ($F$ (1, 484) = 6.3, $p < 0.012$) where the velocity of those in the 1.73 s TSL was slower (54.6 km/h, $SE$ = 0.70) than those in the 2.21 TSL (56.6 km/h, $SE$ = 0.71).

*Initial Velocity, Go.* Of those who went through the intersection, younger drivers were at a significantly higher velocity ($M$ = 61.8, $SE$ = 0.81) than 65+ drivers ($M$ = 59.4, $SE$ = 0.40), ($F$ (1, 227) = 7.2, $p < 0.008$). With the in-vehicle sign, those who ran the intersection were at a significantly lower velocity ($M$ = 59.7, $SE$ = 0.44) than was found for baseline initial velocity ($M$ = 62.4, SE = 0.29) ($F$ (1, 303) = 27.1, $p < 0.0001$).

*Initial Velocity, Stop.* For those who stopped, the in-vehicle sign made a significant difference on initial velocity ($F$ (1, 169 = 63.5, $p < 0.0001$) where the mean baseline velocity was 55 km/h ($SE$ = 1.93) and with the in-vehicle sign it was 37.6 km/h ($SE$ =1.19).

**Figure 5.3** shows the velocity at onset is slower for all conditions for those who stop. The in-vehicle signs reduced the speed of those who stopped and only slightly reduced those who went through the intersection.

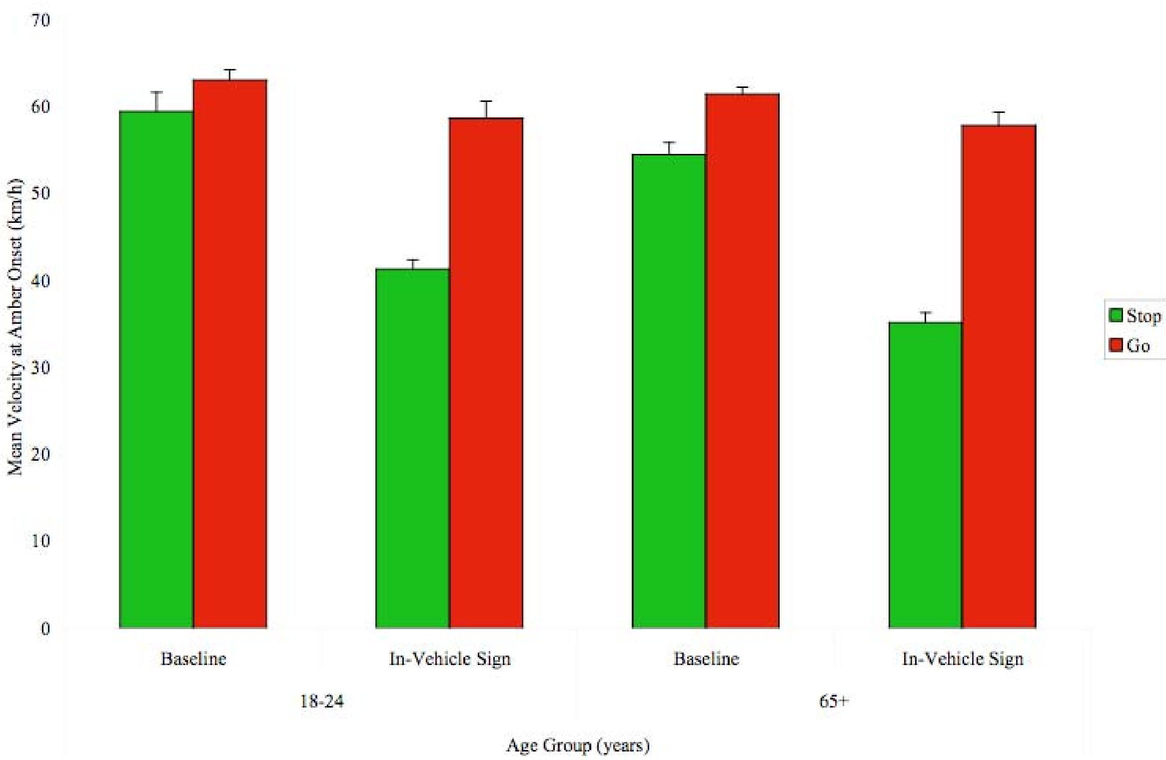


**Figure 5.3.** Mean velocity at amber onset in km/h for stop/go, age group and baseline and in-vehicle conditions. Standard error is represented in the error bars.

*Velocity at Stop Line*

For those who proceeded through the intersection, the velocity at the stop line significantly differed between those 18 to 24 ($M$ = 61.6 km/h, SE = 0.48) and 65+ ($M$ = 59.4 km/h, SE = 0.44), $F$ (1, 303) = 11.3, $p < 0.001$. The in-vehicle sign significantly reduced the speed of participants, $F$ (1, 303) = 43.5, $p < 0.0001$, over baseline drive speeds.

*Velocity at Intersection Exit*

As in Experiment 1, the velocity was also measured at the exit of the intersection to determine if drivers sped up once they decided to proceed. The same pattern of significant results was found at intersection clearance as was found at the stop line. Age ($F$ (1, 303) = 20.0, $p < 0.0001$) and baseline/invehicle sign ($F$ (1, 303) = 18.5, $p < 0.0001$) were significant and time to stop-line was not, $p = 0.23$. The mean velocity difference between young and older age group was about 3 km/h. Overall, those in the baseline and younger age groups were significantly faster then those in the in-vehicle sign condition and older age group (see **Figure 5.4**). The velocity reduction produced by the in-vehicle signs was greatest at the amber onset and progressively less at the stop-line and intersection exit (see **Figure 5.4**).

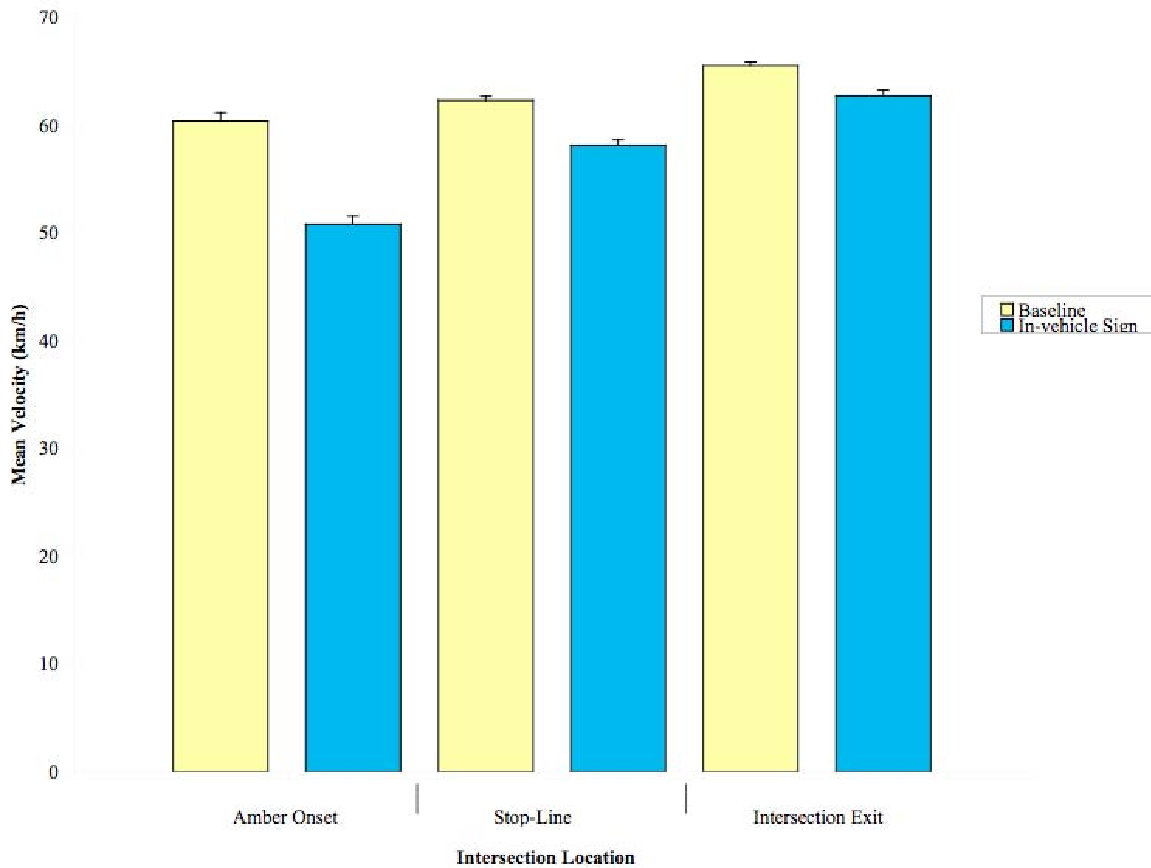


**Figure 5.4.** Mean velocity in km/h at amber onset, stop-line and intersection exit for baseline and in-vehicle conditions. Standard error is shown.

### *5.3.4 Perception Response Time (PRT)*

Perception response time (PRT) is the time from the amber light onset to the foot contacting the brake (Olson & Farber, 2003). Perception, Response and PRT were only calculated for those who stopped. Participants who lifted their foot off the accelerator in advance of the amber change were removed from the Perception and Response analyses, but were included in the overall PRT analysis.

Significantly more participants anticipated the amber onset by taking their foot off the accelerator and putting it on the brake than baseline (see **Figure 5.5**). Fewer anticipators were 65+ across drive type and TSL. Those encountering in-vehicle signs in advance of the intersection were significantly more likely to anticipate the light change by taking their foot off the accelerator than baseline. Younger drivers were almost twice as likely to do so than older drivers.

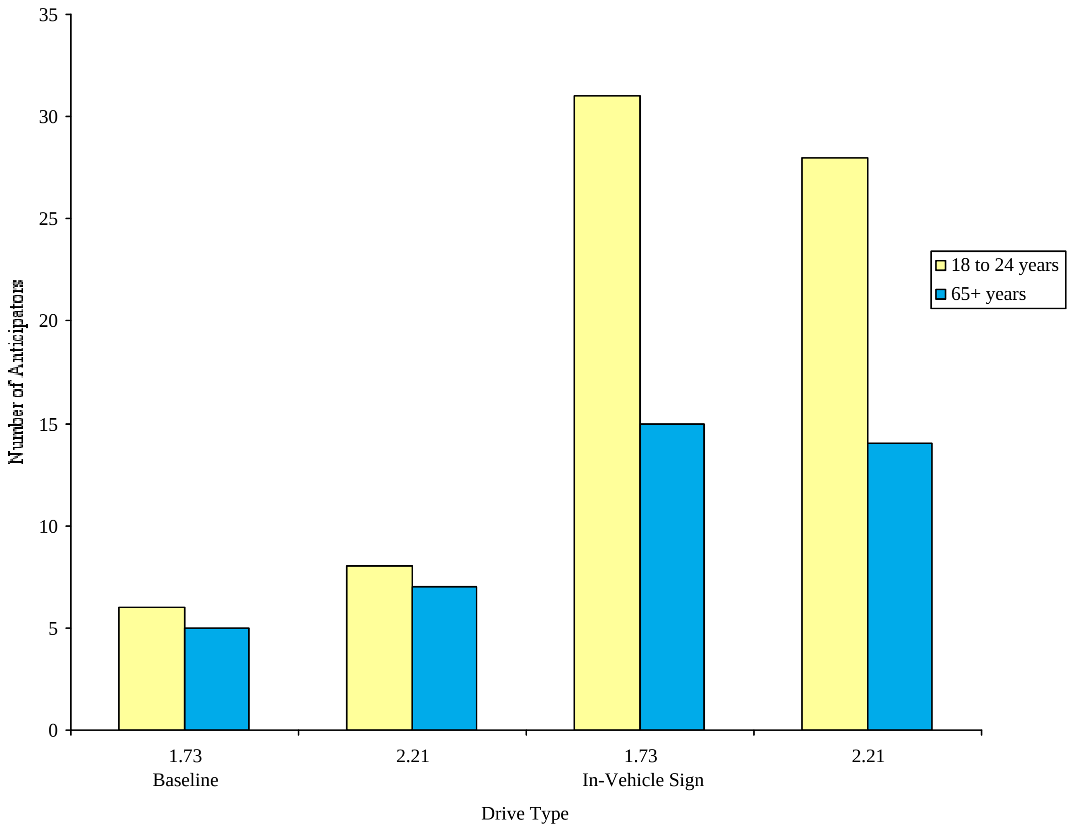


**Figure 5.5.** The number of anticipators by drive type, TSL and age.

5.3.4.1 Perception

*Perception* is the time from the yellow light onset to accelerator release. Older ($M$ = 0.48, $SE$ = 0.02) and younger ($M$ = 0.40, $SE$ = 0.02) participants significantly differed in perception time ($F$ (1, 59) = 6.6, $p$ < 0.013). The difference was more pronounced in the 2.21 TSL ($F$ (1, 32) = 10.26, $p$ < 0.003) than the 1.73 TSL ($p$ = 0.39).

5.3.4.2 Response

*Response Time* was measured in seconds from the foot leaving the accelerator pedal until the brake was first depressed (Olson & Farber, 2003). Older drivers had significantly faster response times overall ($M = 0.25$, $SE = 0.01$) than younger drivers ($M = 0.29$, $SE = 0.01$), ($F$ (1, 58) = 8.0, $p < 0.006$). In the baseline, reaction time to TSL was significant ($F$ (1, 37) = 16.8, $p < 0.0001$). In the in-vehicle sign drives, reaction time was longer than in baseline drivers ($F$ (1, 23) = 36.3, $p < 0.0001$) for both younger and older drivers.

5.3.4.3 PRT

*PRT* includes the total time elapsed from the yellow onset until brake depression. PRT did not differ between the younger and older drivers or between the baseline and in-vehicle advanced signing conditions, which was also found in Caird et al. (2005). Time to stop-line (TSL) had a significant effect on PRT ($F$ (1, 114) = 4.9, $p < 0.029$). With greater time constraints (i.e., shorter TSLs), those with a 1.73 had a faster PRT ($M = 0.58$ s, $SE = 0.02$) than when responding to the 2.21 TSL ($M = 0.64$ s, $SE = 0.02$). There were no age differences between young and old ($p = 0.14$). For the 1.73 TSL, the baseline PRTs ($F$ (1, 49) = 4.1, $p < 0.05$) were significantly faster ($M = 0.53$ s, $SE = 0.02$) than with the in-vehicle sign condition ($M = 0.60$, $SE = 0.03$).

### *5.3.5 Rate of Deceleration*

*Mean Rate of Deceleration* was calculated in $m/s^2$ from the time that the brake exceeded 5% depression until velocity was 0 (Chang et al., 1985). Older and younger drivers significantly differed in the rate of deceleration chosen, $F$ (1, 169) = 19.3, $p < 0.0001$. Drive type (baseline, in-vehicle sign) was also significant, $F$ (1, 169) = 38.7, $p < 0.0001$, but time to stop-line (TSL) was not, $p = 0.998$. Overall, mean deceleration rates for older drivers were 5.2 $m/s^2$ and 4.3 $m/s^2$ for those 18 to 24 (see **Figure 5.6**). The slightly higher rate of deceleration by older drivers contrasts with the results of Experiment 1 where older drivers had lower rates of deceleration over a larger range of time to stop-line values (i.e., 1.73 to 3.53 s).

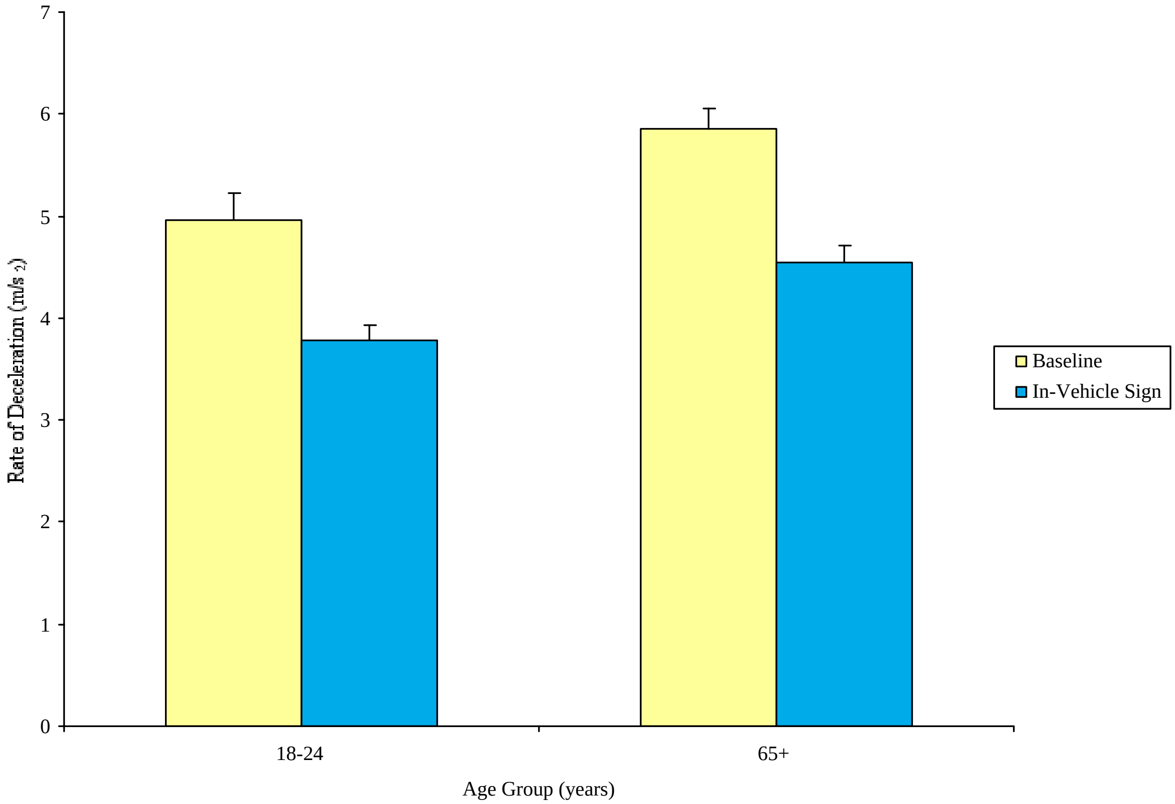


**Figure 5.6.** Mean rate of deceleration by age group and baseline and in-vehicle conditions.

### *5.3.6 Stopping Accuracy*

*Stopping Accuracy* was measured in meters by using the y coordinates of the first stop line of the appropriate intersection. Older drivers were significantly more accurate at stopping at the stop line than younger drivers ($F$ (1,169) = 268.3, $p$ < 0.0001). Whereas, younger drivers were more likely to stop in the intersection than older drivers. Older drivers may be more willing to brake harder to stop more than those 18 to 24 (see **Figure 5.7**).

In the 1.73 TSL, those with the advanced warning sign were significantly more accurate when stopping, $F$ (1, 59) = 17.1, $p$ < 0.0001. Similarly in the 2.21 TSL, those with the advanced warning sign were significantly more accurate when stopping, $F$ (1, 85) = 23.3, $p$ < 0.0001. Stopping accuracy improved over baseline for both older and younger drivers with the in-vehicle sign.

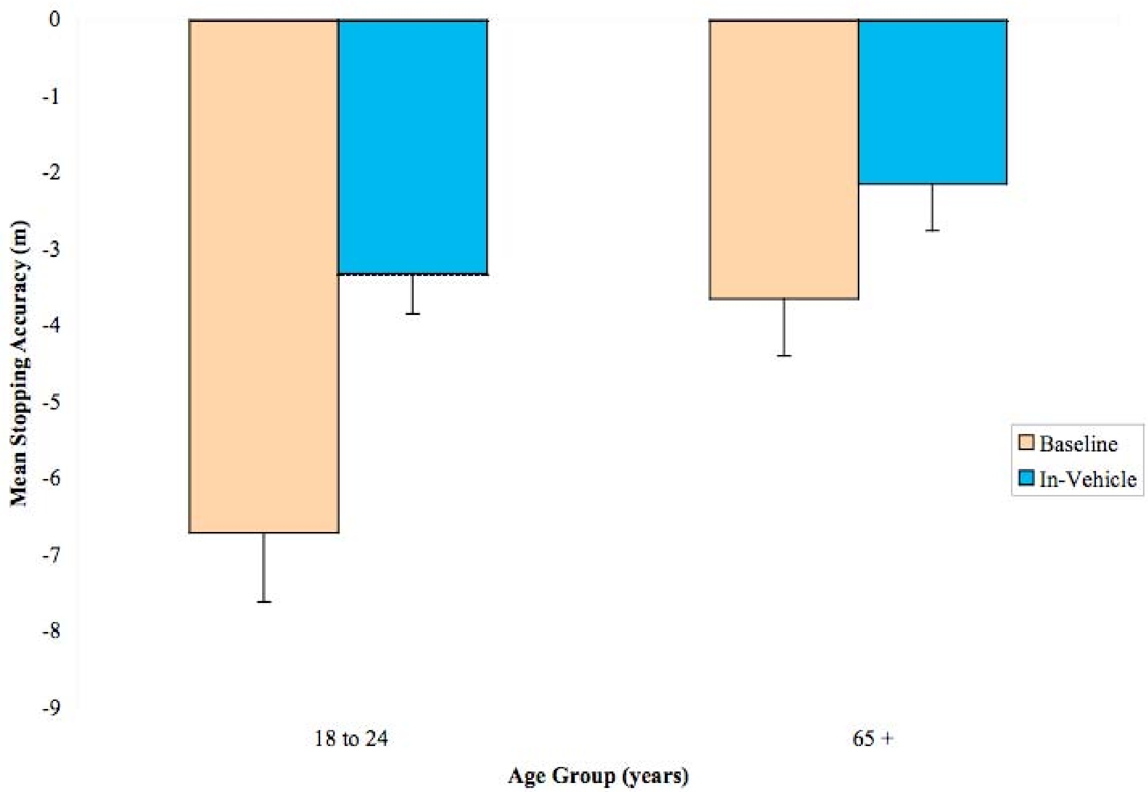


**Figure 5.7.** Mean stopping accuracy (m) to intersection stop-line for age group and baseline and in-vehicle conditions. Negative values indicate the driver is still in the intersection and error bars indicate standard error.

### *5.3.7 Intersection Clearance*

*Intersection Clearance* measured whether a driver was able to clear an intersection prior to the all red onset for those who ran the amber light. It was calculated from the light change until the rear end of a participant's vehicle cleared the stop line at the far side of an intersection. Total clearance time from entrance to exit was subtracted from the yellow light phase calculated using the ITE equation (ITE, 1994) to determine if they were still in the intersection or not. A negative number indicated that they had not cleared the intersection before the lights changed to red.

Overall, young and older groups significantly differed, $F$ (1, 303) = 21.0, $p < 0.0001$, with the older group more likely to still be in the intersection when the light changed to red. Those in the in-vehicle sign condition were significantly more likely to be in the intersection than those in the baseline condition, $F$ (1, 303) = 52.5, $p < 0.0001$. Within the in-vehicle sign conditions, young and old age groups also differed ($F$ (1, 125) = 12.5, $p < 0.001$), with the older group being further into the intersection than the younger groups (see **Figure 5.8**).

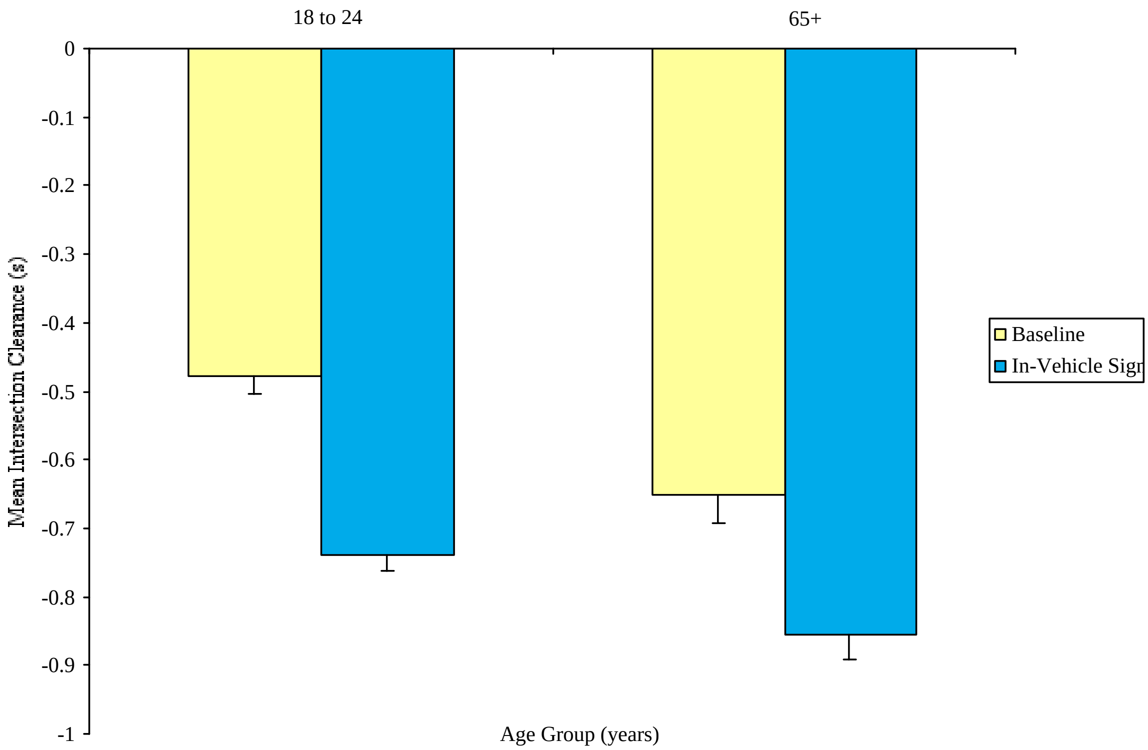


**Figure 5.8.** Mean intersection clearance (s) for time to stop-line (s), age group and baseline and in-vehicle conditions. Standard errors are shown.

### *5.3.8 Eye Movement Analysis*

Eye movement data was analyzed for the duration of the in-vehicle sign presentation, starting 12 seconds prior to the intersections, for a duration of four seconds. Comparison eye movements were also collected from the same time windows during the baseline drives.

#### 5.3.8.1 Fixation count percent

Younger drivers spent a significantly larger percent of the total number of fixations on the HUD ($M$ = 38.32, $SE$ = 1.74), when it was available, compared to the older drivers ($M$ = 23.62, $SE$ = 2.71), $F(1, 139) = 28.01$, $p < 0.0001$. In 24.6 percent of in-vehicle sign presentations, no fixations to the HUD were measured.

#### 5.3.8.2 Mean and sum of fixation duration

There were no differences between younger (*M* = 0.25, *SE* = 0.01) and older (*M* = 0.23, *SE* = 0.01) fixation durations. The frequency distribution of fixation durations to the HUD ranged from 0.1 s (the minimum fixation default), and 0.7 s. Younger driver's (*M* = 1.04, *SE* = 0.06) total fixation durations were significantly longer than older drivers (*M* = 0.59 s, *SE* = 0.07).

#### 5.3.8.3 Gaze variability

Gaze variability was calculated as the standard deviation in participant's vertical and horizontal eye positions during each presentation of the HUD sign (Recarte & Nunes, 2000; 2003). Figure 2, right panel, illustrates all fixations to the diamond sign in the time it was available to the drivers. Gaze variability was measured from 2 seconds prior to the appearance of the HUD until the lights were no longer visible (13 s). Units of eye movement variation in the horizontal and vertical planes are expressed in cm from the centre point of calibration.

#### 5.3.8.4 Vertical variability

In the baseline condition, drivers had significantly greater variability in vertical gaze than in the experimental condition with the HUD, $F(1, 322) = 4.5$, $p = 0.0001$. Overall, younger drivers had significantly greater vertical gaze variability than did those in the older age group, $F(1, 322) = 22.60$, $p < 0.001$. Older drivers had significantly less vertical gaze variability in the baseline ($F$ (1, 87) = 6.26, $p < 0.014$) and experimental drives ($F$ (1, 85) = 22.81, $p < 0.001$) compared to younger drivers.

#### 5.3.8.5 Horizontal variability

In the baseline drives, horizontal gaze variability was significantly greater compared to the experimental HUD drives, $F(1, 433) = 12.11$, $p < 0.001$. Overall older drivers exhibited significantly greater horizontal gaze variability compared to the younger drivers, $F(1, 433) = 31.71$, $p < 0.001$. Specifically, older drivers exhibited greater horizontal gaze variability than younger drivers both in the baseline ($F$ (1, 87) = 42.47, $p < 0.001$) and experimental conditions ($F$ (1, 85) = 25.84, $p < 0.0001$).

### *5.3.9 In-Vehicle Sign Preference*

At the conclusion of the study, participants were asked if the in-vehicle sign was useful or if the rectangular or diamond sign was preferred (see **Figure 5.1**). Overall, 75% of younger drivers preferred the rectangular sign, whereas 73% of older drivers preferred the diamond sign. There were no performance differences between the two signs for any intersection performance variable.

## 5.4 Discussion

This study comprehensively addressed whether older and younger drivers benefited from the in-vehicle sign when presented in a context where it can be used to inform decisions about how to proceed at an approaching intersection. In-vehicle signs facilitated an increase in both younger and older drivers stopping at intersections with relatively short yellow light onsets. During baseline drives, older drivers were less likely to stop and more likely to go than younger drivers. The net effect of the in-vehicle signs was to increase the percentage of those stopping in both age groups. In addition, the speed of approach for both those who stopped and continued through the intersection was reduced by the presence of the in-vehicle signs. The decrease in intersection approach speed resulted in greater stopping accuracy at the intersection compared to when the advanced sign was not present. The velocity reduction produced by the in-vehicle signs was greatest at yellow light onset and progressively less effective at stop-line and intersection exit measurement locations. The primary behavioural influence of the in-vehicle signs was in removing the driver’s foot from the accelerator in advance of the light changing.

Older drivers perceived, searched, and processed traffic light information somewhat slower than younger drivers. However, once a decision was made to stop, they compensated with faster response times and higher deceleration rates than younger drivers (cf., Vercruyssen, 1997). Older drivers adopted slower intersection approach speeds, stopped more accurately, and were more likely not to clear the intersection before the all red traffic light phase.

Although the mean fixation durations between younger and older groups did not differ ($M$ = 0.25 vs. 0.23, respectively), the total time fixated (sum of fixation durations) and the number of fixations (fixation count percent) did differ between age groups. Thus, younger drivers looked at the HUD signs more often and for longer overall durations than the older drivers. Several plausible explanations are possible for these results. First, older drivers may not have fixated as often or for as long of period on the HUD because they may have been less comfortable restricting their search as they approached an intersection. Visual search for signs and vehicles at intersections can be problematic for older drivers for a number of reasons (Caird, et al., in press; Ho et al., 2001; Maltz & Shinar, 1999). Second, younger drivers may have been more curious about the presence of the HUD and thus tended to look at it more often (see, e.g., Kiefer, 1991). Looking at the HUD may decrease with longer exposure to it, but determination of these longer-term effects will require a different research approach. In 24.6 percent of sign presentations, no fixations to the HUD were measured. Peripheral detection and non-use of the HUD are possible explanations. The measurement precision of the eye movement system used and precise definitions of AOIs preclude measurement error as an explanation.

Recarte and Nunes (2000; 2003) examined horizontal and vertical gaze variability as measures of attentional demand while performing secondary tasks. Decreases in gaze in either plane were attributed to increased cognitive and visual demand. In this study, when the HUD was present, gaze variability decreased in both the horizontal and vertical planes. Younger drivers had greater vertical variability than older drivers over the entire approach to the traffic lights and not just when the HUD signs were present. The younger drivers most likely used the HUD information and looked to the traffic lights more frequently during their intersections approaches. The higher number of younger anticipators and the longer total HUD fixations and frequency of fixations also support this conclusion. The greater horizontal variability of the older drivers is also consistent with retaining a more typical scan pattern, although the HUD was available. More time and experience with it may be necessary before their scan patterns change to resemble those of the younger drivers.

The in-vehicle system evaluated addresses a known problem faced by older drivers; namely, intersection negotiation. The in-vehicle signs presented in a HUD format facilitated an increase in both younger and older drivers stopping at intersections with relatively short yellow light onsets. As older drivers have more difficulty searching for and using road signs, an in-vehicle sign system may assist in intersection negotiation. Drivers who look but do not see the traffic lights and drivers who are inattentive or distracted as they approach an intersection may benefit from in-vehicle intersection sign systems (IVISS).

A number of questions still require additional research. How do drivers adapt to in-vehicle signs over the long term? Do younger drivers use the HUD information to run red lights? Do fixations fall back to road signs once the novelty of the HUD wears off (Kiefer, 1991)? Typically, as drivers become more familiar with a route, the less they fixate on roadway signs (MacDonald & Hoffman, 1991; Mourant et al., 1969). Over prolonged exposure to in-vehicle signs, perception of them may decline because they are redundant with the traffic lights and may be viewed as irrelevant to the needs of the driver (Drory & Shinar, 1982). If signs are in unexpected locations such as to the left in North America, in-vehicles signs may benefit drivers because they would provide redundancy (Theewes, 1996). Over time, does speed and willingness to proceed through a yellow light increase?

A number of HUD sign design attributes were not addressed by this study, specifically, control over whether drivers would like to receive the advanced signs was not explored. Understanding the context in which an in-vehicle sign is critical to the choice of presentation format and specific sign. Drivers' reliance on external information, when presented with new information inside the vehicle, was identified as another potential problem. In particular, the relationship between the in-vehicle signs and existing roadway signs requires consideration (Lee et al., 1999b). Other beneficial applications of in-vehicle signs include weather, day and night, and differences in spoken language (Regan, 2004). Novice drivers and tourists may also benefit from other applications.

A number of ITS infrastructure projects that provide collision avoidance information to the driver at intersections using roadside sensors, processors, warning devices, roadside communication systems, and modified traffic signals (Ferlis, 2002). These systems, which is often referred to as cooperative ITS have been the focus of a number of research and development programs in the U.S. Infrastructure based advanced warning signs (AWS) are an analog to in-vehicle signs. Drivers in Canada have some familiarity with AWS and AWS have been found to produce measurable crash reductions (Sayad et al., 1999). Prior familiarity with infrastructure AWS may have benefited the participants' interpretation and responses to the in-vehicle signs presented in the HUD. A driving population that is less familiar with the meaning and correct response to these signs may cause difficulties in interpretation (Pant & Xie, 1995). HUDS can be used, not just to provide advisory or alerts while approaching an intersection, but in a warning mode where the information is made more imperative because a signal is about to be violated or another vehicle struck. The late presentation of precise information about a potential collision suffers from the problems of false alarms, distraction, and time to respond.

Many within the field of human factors operate with the belief, which is often dependent on familiarity with a certain method, that on-road or driving simulation provide the best means to test in-vehicle systems. The statistical argument is usually cast in terms of control over a variety of extraneous or confounding variables, which may contribute to systematic error variance. More control is possible in the simulator and less on-road. Whether laboratory, driving simultion, or field studies yield results that are more reliable or valid is highly debatable. From a practical viewpoint, Santos et al. (2005) concluded that laboratory set-ups may provide a reasonable first approximation of the impact of a new IVIS design. However, when more precise descriminations of the degree that interactions effect safety is needed, driving simulation and/or on-road studies may be required.

Based on meta-analysis which combines effects sizes across studies (Rosenthal & DiMatteo, 2001), the impact of cell phone use on driving performance has been measured in numerous studies in the laboratory, driving simulation and on-road. Horrey and Wickens (in press) found larger effect sizes for field studies (0.66) than using driving simulation (0.42). Similarly, Caird et al. (2004) found that laboratory studies had the highest effect sizes (0.89) followed by on-road (0.64) and then driving simulation (0.36). These meta-analyses indicate that no single methodological approach necessarily yields definitive results with respect to driver distraction. Further, laboratory studies afford a cost effective means to address a range of IVIS questions ordinarily thought to be only attainable using driving simulation and field studies.

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# 6. EXPERIMENT 3

## 6.1 Introduction

The purpose of this study was to determine the degree to which an array of in-vehicle signs were understood by both younger and older drivers. Like Experiment 2, the in-vehicle signs were presented in the UCDS. However, the presentation format was designed to determine the level of comprehension of the HUD signs that were embedded in the static pictures of intersections filmed in Calgary.

## 6.2 Methods

The University of Calgary Driving Simulator (UCDS) was used to evaluate the comprehensibility, utility, preference and visual behaviour to 24 in-vehicle signs embedded in 24 intersection scenes filmed in Calgary.

### *6.2.1 Participants*

The participants of Experiment 3 were the same as those in 2 (see **Table 6.1**). A total of 24 participants, half 18 to 24 ($M$ = 21.5) and half 65 to 76 ($M$ = 69.2), volunteered for the study. Equal numbers of men and women participated. As described in Experiment 1 (see 5.2.3), all participants were screened for simulator sickness, visual acuity, contrast sensitivity, color deficiency, and mental and physical health. Three older participants' eye movement data was lost due to a loss of calibration. Reflections from the frames and lenses of their glasses caused the loss of calibration.

**Table 6.1.** Age group categories, number of participants in each group, mean participant age (standard deviation), average kilometers driven per year, total number of crashes since licensure, moving violations, and visual acuity or minimum angle of resolution (MAR) with correction.

| **Age Group** | **N** | **Mean Age (SD)** | **Km/ Year (SD)** | **Lifetime Crashes (SD)** | **Moving Violations (SD)** | **Visual Acuity (SD)** |
|---|---|---|---|---|---|---|
| 18-24 years | 12 | 21.5 (2.2) | 19,167 (13,347) | 0.6 (1.1) | 0.9 (1.2) | 1.1 (0.40) |
| 65+ years | 12 | 69.2 (3.3) | 18,167 (6,658) | 3.5 (2.5) | 3.5 (2.5) | 1.2 (0.33) |
| Total/Means (SD) | 24 | 43.10 (20.6) | 23,494 (19704) | 2.0 (3.0) | 3.1 (3.8) | 1.1 (0.36) |

### *6.2.2 Signs and Intersection Images*

The selection of intersection images was based on a process of reviewing a 2500 digital-image archive of intersections from Calgary, Winnipeg and Montreal (Caird, et al., in press). Additional images from Calgary were also filmed. Signs were selected from the *Manual of Uniform Traffic Control Traffic Control Devices* and a number of sources listed in Carney et al. (1998). The fusion of each sign and intersection was performed in Photoshop. The development of each image sought to balance the information within an intersection, the head-up display sign, vehicle position and distance to the intersection. The construction of the 5 incongruent signs was based on potential logical confusions between sign and context. The 24 signs embedded in the tested images can be found in Appendix D.

The images were presented on the centre channel of the UCDS, which includes an Epson 710C projector. Images were displayed at a resolution of 1024 x 768 pixels on a WrapAround Clarion Screen by Draper, which measured 2.18 m wide by 1.35 m high. The distance from the centre of the screen was 2.3 m. A custom software program was developed in C# to present the images and synchronize data collection with the ASL 501 eye movement system. The mean visual angle of all 24 images was 6.7 degrees in height by 6.9 degrees in width.

### 6.2.3 *Eye Movement System*

Participants' eye movements were measured using an Applied Science Laboratory (ASL) 501 system. A near infrared beam illuminated the participants' left eye and the reflected image was captured by a video sensor, or eye camera (see **Figure 6.1**). The illumination beam and image of the eye was reflected off of a headband-mounted monocle located just below the participants' left eye. A forward-view scene camera mounted on the headband showed what the participant saw. The illuminator, optics, camera, and monocle were integrated into Head Mounted Optics Module or HMO. To capture head movements in conjunction with eye movements, a small rectangular device mounted on the headband monitored the position of the head with respect to the Magnetic Head Tracking Hardware (MHT), which was mounted in the vehicle near the participant. The MHT is connected to the Flock of Birds® control unit which measured the position and orientation of sensors by transmitting a magnetic field (ASL Manual Version 2.0, 2001).


**Figure 6.1.** Eye movement head-mounted optics, magnetic head tracking, and video camera on participant (left) and calibration and monitoring software (right).

Output from the eye, scene camera, and magnetic head tracker was processed through a Model 5000 control unit. Eye movements were sampled at a rate of 60 Hz. The control unit tracked the pupil and cornea reflection using a proprietary algorithm and computed pupil diameter and line of gaze from it with adjustments for head position. Gray scale pupil and corneal outlines were displayed on a Sony black-and-white 9-inch monitor (Model SSM-930). A set of cross hairs were superimposed onto the scene video display (see **Figure 6.1**, right).

Calibration commands and set up procedures were processed through the ASL Eye-Tracker interface software which was called E5Win™. Head-tracking information from the MHT was processed through EYEHEAD™ integration software and was combined with the eye position information to determine a participants' point of gaze on the forward screen. ASL (2001) reports that the spatial error rate is less than one degree between true eye position and computed measurement, but the error rate may increase up to two degrees in the periphery of the visual field. The eye tracker hardware communicates at a baud rate of 57,600 Kbps over the serial port of the PC.

### *6.2.4 Procedures*

#### 6.2.4.1 Eye Movement Calibration

After the visual testing, participants were seated in the Saturn and the eye movement system was adjusted to their heads. The eye movement system was calibrated to each participant in a number of steps. First, the position of the monocle was adjusted to capture the participant's left eye. Second, the illumination beam brightness was scaled to resolve the pupil outline and corneal reflection. Third, the participant fixated on nine circles, in order, each with a number from 1 to 9 inside it. The circles formed a square 3 x 3 matrix on the centre screen in front of the participant. The calibration steps were performed at the beginning of each session and at various points during the experimentation if the eye tracking was lost. Participants' calibration was monitored throughout their session.

#### 6.2.4.2 Procedures

Participants were shown 5 images to practice the procedure. After viewing each image, they were asked, "what would you do if you saw this intersection with this sign?" Their verbal answers were recorded by the experimenter. After answering this question, they were asked to rate the sign, in combination with the intersection, as being useful, where 1 was "not at all useful" and 10 was "extremely useful."

Prior to the intersection being shown, a grey screen with a dot at the center of it was shown. Two examples are shown in **Figure 6.2** and all images are shown in Appendix D. They were asked to fixate on the dot until the intersection scene appeared with the sign in a HUD format. Then they were instructed to scan the intersection image as they normally would when driving to gather relevant information for their answers.

Five practice images were shown to start. The five practice HUD signs were one way to the left, left turning lane, no left turns, only right turning lane, and dual left turning lane. Participants were able to answer the meaning of each sign and were comfortable with proceeding to the experimental set of images. A total of 24 experimental images were then shown. Two experimental orders were used to present the images and participants were randomly assigned to the two orders.

Once the participants completed the experimental portion, they filled out the post simulator sickness questionnaire and the in-vehicle sign preference questionnaire. Once the questionnaires were filled out, participants were debriefed and remunerated.


**A** **B**

**Figure 6.2.** Examples of the 24 images tested. Image A (left) shows an intersection approach with a construction sign in the head-up display. Intersection B shows a dangerous goods route sign. A complete table of HUD signs and intersection images can be found in Appendix D.

## 6.3 Results

### *6.3.1 Experimental Design and Variables*

Age group (18-24, 65+) was a between-subjects factor for all analyses. A total of 24 intersection images were analyzed for comprehension, perceived usefulness and preference. Nineteen images were classified as congruent, meaning that the information within the HUD, environment and vehicle position were inter-related and made sense. Five HUD/image combinations were classified as incongruent, meaning that the HUD traffic signage and/or vehicle position information did not make sense.

### *6.3.2 Comprehension and Usefulness*

#### 6.3.2.1 Comprehension

Answers to the comprehension questions were scored using a correct (2), partially correct (1) and incorrect (0) system (Dewar, Kline & Swanson, 1994). Appendix D shows each intersection image and HUD sign that was evaluated. The mean comprehension and usefulness of each in-vehicle sign and intersection is listed by the primary between-subjects variable, age (18-24, 65+).

There were no significant differences for age for any particular sign/image. Younger participants had greater comprehension than the older group on 10 of the 24 signs evaluated. Another 10 signs had about an equal level of comprehension for both age groups (i.e., within 5% of each other). The older participants had a higher level of comprehension on four signs than the younger group. Verbal comments of note are listed in Appendix E to serve as qualitative information about the interpretation made by participants.

#### 6.3.2.2 Usefulness

There was a significant difference between incongruent and congruent signs for perceived usefulness $F\ (1, 570) = 34.9$, $p < 0.0001$. As might be expected, incongruent signs had a mean of 5.8, whereas congruent signs had a mean rating of 7.6. Age was not significant, $p = 0.171$.

A number of in-vehicle signs were rated as highly useful by older drivers (i.e., having a rating of 8 or higher). These included: pedestrian crossing (#2, Appendix D), left turn (5), traffic lights (6), right turn (7), no turns (8), one-way (9), work zone (10), left turn, 2-lanes (13), bicycles in roadway (14), pedestrian crossing (18), and no right turn, restriction (19). The younger age group rated the same signs as highly useful with the exception of (i.e., less than a rating of 8) left turn (5), traffic lights (6), left turn, 2-lanes (13), and bicycles in roadway (14).

### *6.3.3 Eye Movement Variables and Data Reduction*

Eye movement dependent variables included sum of fixation durations, mean fixation duration, total number of fixations, fixation frequency, and area of interest analyses to the head-up display, and corresponding traffic information.

EYENAL™ (Version 1.59), a Windows based data analysis program, was used to process the eye movement data. Specifically, the number of eye fixations, fixation durations, pupil size, areas of interest, and scan pattern statistics were calculated using EYENAL. The fixation algorithm and default parameters provided in EYENAL™ were used to define fixations. Fixations were defined as follows: a fixation started when six consecutive recorded samples of eye movements had no more than 0.5º standard deviations of visual angle from a centroid. A fixation ended when three consecutive recorded samples exceeded 1º of visual angle from the average of all samples of a fixation. A fixation was defined as a minimum of 6 consecutive, 16.66 ms samples or into a fixation time of about 100 ms. If the eye tracker was unable to sample data for less than 12 consecutive recordings, it was considered a blink and did not affect the calculation of a fixation. If recording loss exceeded 12 consecutive samples, then this was considered lost data (ASL, 2001). Other researchers have used different sampling rates and definitions, which were somewhat hardware and data dependent (see, e.g., Recarte & Nunes, 2000; 2003).

Each intersection image generated a data file that had to be passed through EYENAL. Thus, 504 raw eye movement files (24 images x 21 participants) were processed through EYENAL. exported to Excel and to SPSS (version 12.0). FIXPLOT was used to generate the coordinates of areas of interest (AOI) for EYENAL and to create figures with the fixations plotted on each intersection (see **Figure 6.3** and Appendix F).

### *6.3.4 Eye Movement Analysis*

6.3.4.1 Overall Analyses

The mean number of fixations was 13.0 fixations over 5 seconds of observation for those 18 to 24 and 15.1 for those 65+. The overall mean fixation duration was 0.22 s for those 18 to 24 and for those 65+ it was 0.24 s, and did not differ by age (*p* = 0.141) or congruency (*p* = 0.231).

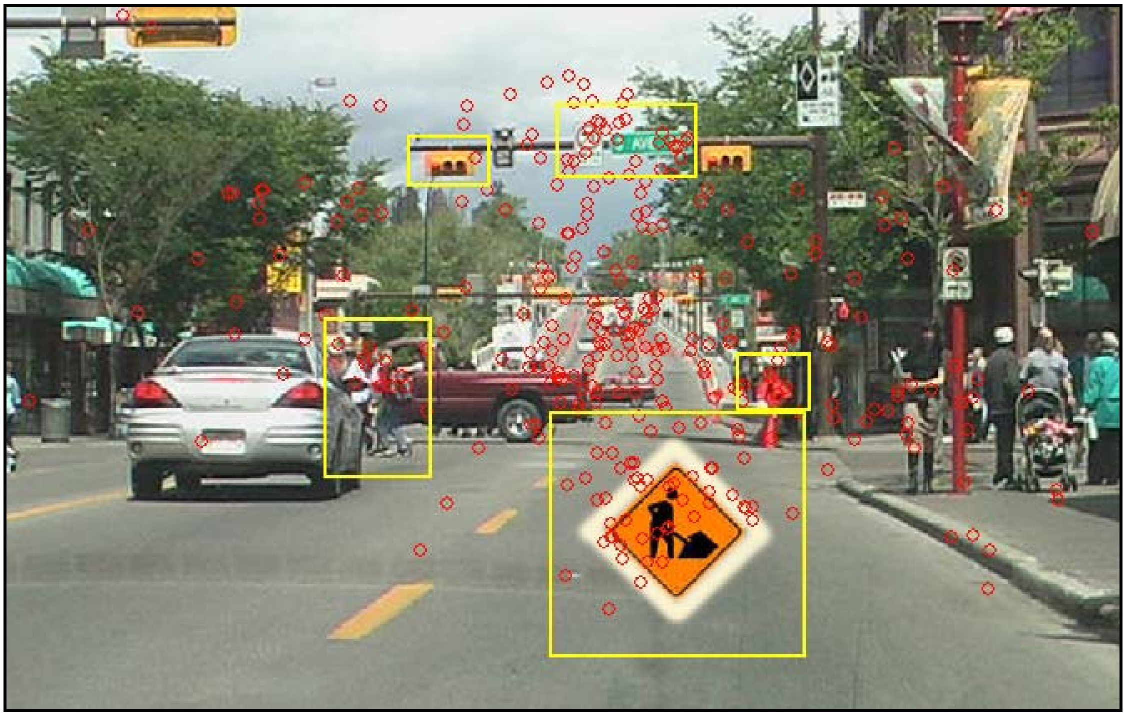

**Figure 6.3.** Areas of interest (yellow boxes) and fixations (red circles) for participants using the "Men at Work" sign (*MUCTD* W21-1a). Note the corresponding traffic sign just above the HUD sign.

6.3.4.2 In-Vehicle Sign or HUD Measures

The sum of fixation durations to the HUD signs significantly differed between young (*M* = 0.8 s, SE = 0.06) and old (*M* = 1.1, SE = 0.07) groups, $F$ (1, 379) = 9.7, $p < 0.002$. A significant difference was found between congruent and incongruent signs for sum of fixation durations ($F$ (1, 379) – 18.7, $p < 0.0001$) (see Figure 6.4). In-vehicle signs received more total fixations (*M* = 1.2 s) than incongruent signs (*M* = 0.8 s). The interaction between age and congruency was not significant (*p* = 0.147). Similarly, the total number of fixations to the HUD significantly differed between age groups ($F$ (1, 379) = 7.2, $p < 0.008$), where those 65+ made an average of 4.7 (SE = 0.3) fixations to the HUD signs, whereas those aged 18 to 24 made 3.7 (0.3) fixations.

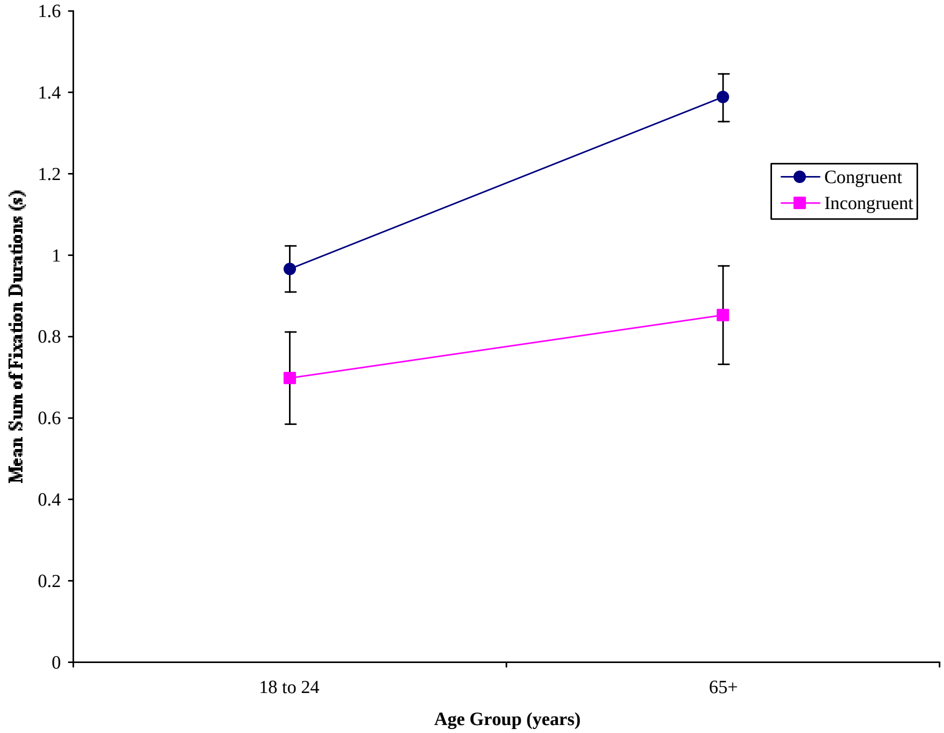


**Figure 6.4** Mean sum of fixation durations to the secondary traffic light and sign information.

The sum of fixation durations to the head-up display signs significantly differed by age for congruent image 5 (left turn) (see Appendix F) ($F$ (1,13) = 8.8, $p$ <0.111). Significant age differences for total mean fixation duration, total mean fixation frequency and percent comprehension are also listed in Appendix F. In addition, right turn arrows (#7, $F$ (1, 15) = 5.2, $p < 0.038$), green light ahead (#16, $F$ (1, 17) = 8.4, $p < 0.01$) and restricted right turn (#19, $F$ (1, 15) = 11.0, $p < 0.005$) were significantly different by age. No turns (#8) approached significance, $p < 0.072$.

The mean fixation frequency to the in-vehicle signs was signficant for age ($F$ (1, 379) = 7.2, $p < 0.008$) and congruency (F (1, 379) = 17.7, p < 0.0001). The interaction of age and congruency approached significance (p = 0.097) (see **Figure 6.5**). Those 65+ made more fixations to the HUDs (M = 4.7) than those 18 to 24 (M = 3.7). More fixations were made to congruent HUDs (M = 5.0) than to incongruent in-vehicle signs (M = 3.4).

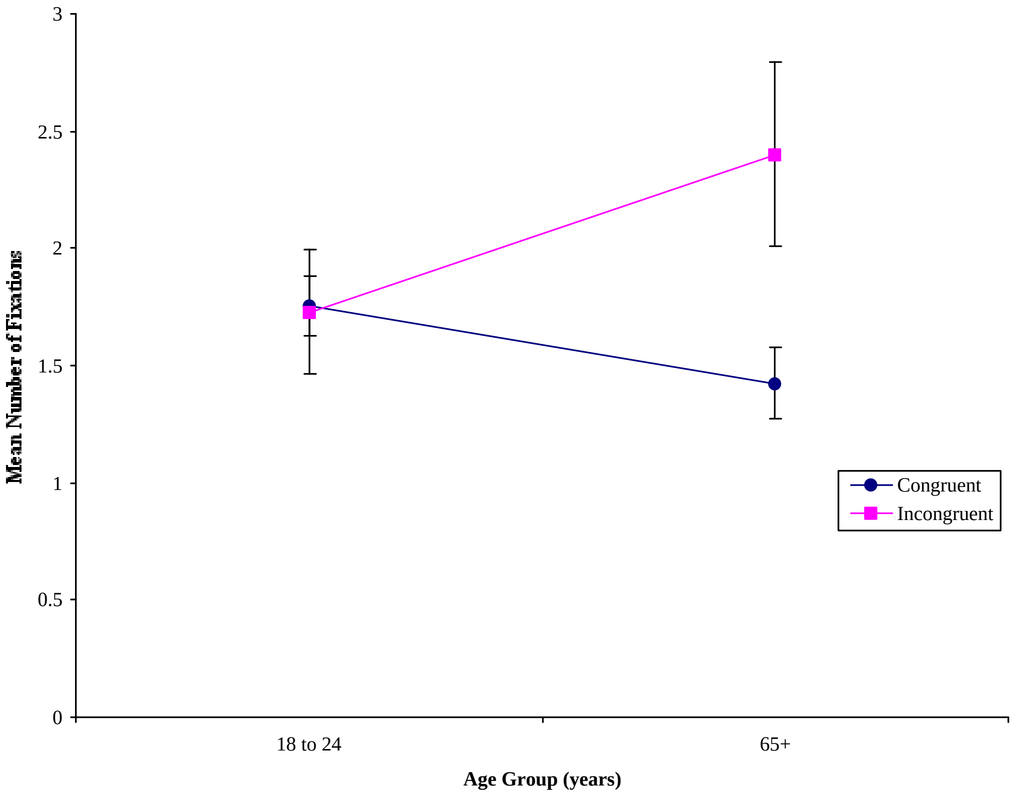


**Figure 6.5.** Mean fixation frequency to congruent and incongruent HUD signs.

6.3.4.3 Corresponding Traffic Information

The second area of interest that was analyzed was the traffic information that the in-vehicle sign or HUD corresponded with. These were categorized as either traffic light or traffic sign and analyzed accordingly. Age and congruence were not significant for the sum of fixation durations ($p$ = 0.5), $p$ = 0.6, respectively) for traffic lights or traffic signs ($p$ = 0.03, $p$ = 0.9, respectively). The means and standard errors indicated that for both traffic lights and signs, for those 18 to 24, the sum of fixation durations was longer to both congruent and incongruent signs and lights than those 65+. For both age groups, the sum of fixation durations was highly variable to the incongruent signs.

A significant age by congruency interaction for the corresponding sign was found, $F\ (1, 94) = 3.8$, $p < 0.05$ (see **Figure 6.6**). The total number of fixations was nearly the same for younger participants ($M$ = 1.8, congruent, $M$ = 1.7, incongruent), but for those 65+ more fixations were made to the corresponding incongruent traffic sign. For lights, age group approached significance ($p$ = 0.071). The younger age group tended to look more frequently at the lights ($M$ = 2.2) than those 65+ ($M$ = 1.5).

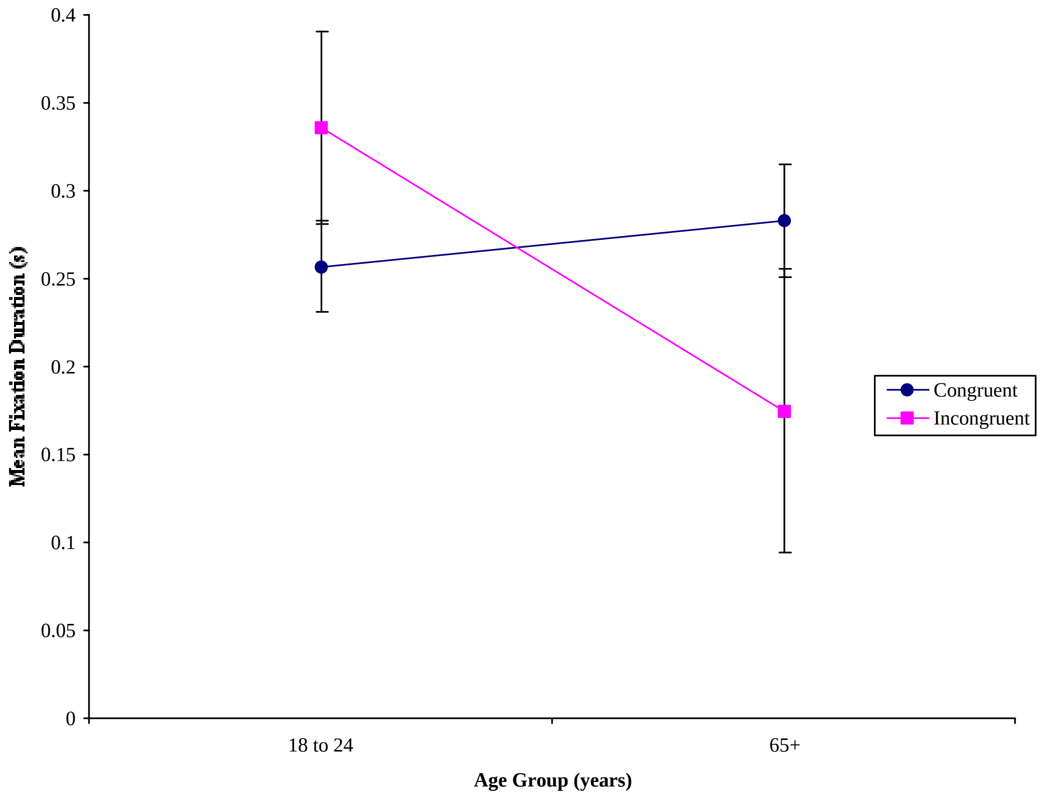


**Figure 6.6.** Mean fixation duration to secondary traffic signs by age and congruency.

## 6.4 Discussion

The comprehension of the 24 in-vehicle signs varied from well to not understood. Dewar, Kline and Swanson (1994) tested a wide range of traffic signs for comprehension using a range of age groups. Four signs were common between their study and the present study. Comprehension in the present study was somewhat lower than percentages previously reported. The presentation of signs as an in-vehicle sign in the context an intersection represents the primary difference between the studies. Context or where the sign is viewed may add or subtract to the intepretation of a sign's meaning (Wogalter et al., 1999).

A few signs differed by age on perceived usefulness. Signs that were congruent with the intersection context were perceived as more useful than incongruent signs. Signs that provided information about upcoming actions, such as stopping or changing lanes, appeared to be more valued by participants.

A limited number of previous studies have examined eye movements to traffic signs (see Green, 2002 for review). In the methods used in this study, older participants had more total cumulative fixations (total dwell) on the in-vehicle signs than those 18 to 24, which is consistent with prior research on sign search that found that older drivers made more fixations and for longer durations (Ho et al., 2001).

Congruent signs had a higher sum of fixation durations and total number of fixations than incongruent signs. The need to confirm or check corresponding traffic signs with the in-vehicle sign is implicated by this result. Top-down search for corresponding lights and signs would logically follow (Theewes, 1996).

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# 7. CONCLUSIONS AND RECOMMENDATIONS

The research reviewed and studies that were conducted are complementary to ongoing research on intersection countermeasures within the Federal Highway Administration (FHWA) and National Highway Traffic Safety Administration (NHTSA). However, the specific research agenda is unique from the standpoints of technology chosen, evaluation processes, and results implications. Each of these research phases is summarized.

## 7.1 Technology Review

ITS systems that have the potential to aid older drivers were reviewed. Epidemiological research clearly indicates that older drivers are overrepresented in intersection collisions (Preusser et al., 1998). In-vehicle systems that may prove beneficial to older drivers include haptic collision warning systems, auditory collision warnings, and in-vehicle signing information systems. In-seat haptic systems could warn drivers of potential collisions, but are limited by the necessity to learn the mappings between stimulus and response. The use of haptic input to the driver through the steering wheel and brake are also promising. Within the scope of this research, technical and resource constraints limited pursuing this line of research. Additional research is needed that addresses older drivers who may use haptic steering and brake pulse systems.

Auditory collision warning systems alone and in combination with visual warnings also show promise for intersection collision mitigation. In particular, speech-based and auditory icons may improve response times to threats in a range of critical situations. However, a number of background noise sources including, ambient road noise, stereo systems, passengers and age-related hearing loss, may limit their eventual development and application. Age-related hearing loss for older drivers influenced our decision to exclude auditory warning systems and focus on in-vehicle signing information systems (IVSIS).

In-vehicle signs have been identified as a potentially beneficial ITS technology, but have received only sporadic research attention. Based on these limited studies, the use of in-vehicle signs to alert drivers to upcoming traffic light changes has the potential to benefit older drivers. A HUD removes the necessity to look into the vehicle for information. However, focusing attention on the HUD may still obscure or cause the late detection of other vehicles. One way to minimize this disadvantage is to present HUD information in advance of an intersection so that attention can be redirected back to signs, signals and other vehicles. The design of an in-vehicle HUD requires optimization of location, timing, form and information.

### 7.2 Empirical Research

To understand why older drivers are over-represented in intersection crashes, Experiment 1 sought to describe the intersection performance of older and younger drivers when traffic lights changed from green to yellow. Using the UCDS, time to stop-line (TSL) at yellow onset was manipulated as drivers approached intersections at 70 km/h (42 mph). Seventy-seven participants, approximately balanced for gender and age group, volunteered from the age categories of 18 to 24, 25 to 35, 55 to 64, and 65+. Driver decisions to stop or go were predicted using a logistic regression model with time to stop-line as the single significant predictor. Older drivers approached intersections at a lower velocity and stopped more accurately than younger drivers. For those who chose to go through the yellow light, speed profiles across the intersection and intersection clearance indicate that older drivers are more likely to be in the intersection when the light changed to red. The results of this study fill an important descriptive gap in driver performance at intersections. In particular, the age groups sampled, the multi-measure approach, and the measurement precision of PRT extend what is known about driver behavior to yellow onsets.

Experiment 2 determined if intersection behaviour benefited from advanced in-vehicle signs presented to older and younger drivers in a head-up display (HUD) format. The UCDS was again used to evaluate intersection performance. Measures of those who were able to stop or ran the yellow light, speed over the span of the intersection, perception response time, and eye movements were analyzed to determine if performance improved or whether undesirable adaptive behaviours occurred. In-vehicle signs facilitated an increase in the frequencies of stopping for both younger and older drivers at intersections with relatively short yellow onsets. The speed at the yellow light onset for both those who stopped and those who proceeded through the intersection was reduced by the presence of the in-vehicle signs. The primary behavioural influence of the in-vehicle signs was to cause the drivers’ to remove their foot from the accelerator in advance of an intersection. Eye movement analyses indicated that younger drivers looked at the in-vehicles signs more often and for longer overall durations than older drivers. Older drivers had slower intersection approach speeds, stopped more accurately, and were more likely to not clear the intersection before the traffic light turned to an all-red phase than younger drivers. The in-vehicle signs presented in a HUD format facilitated an increase in both younger and older drivers stopping at intersections. As older drivers have more difficulty searching for and using road signs, an in-vehicle sign system may assist in intersection negotiation. Drivers who look but do not see the traffic lights and drivers who are inattentive or distracted as they approach an intersection may benefit from in-vehicle intersection sign systems (IVISS).

The purpose of Experiment 3 was to determine the degree to which an array of in-vehicle signs presented in a head-up display (HUD) format were understood by both younger and older drivers. Comprehension and perceived usefulness ratings of the 24 in-vehicle signs varied by sign, age, and intersection. Signs that provided information about upcoming actions, such as stopping or changing lanes, appeared to be more valued by participants. In each instance, older participants had more total cumulative fixations (total dwell) on the in-vehicle signs and longer fixation durations than younger drivers. Fixation duration and frequency to the in-vehicle and corresponding intersection traffic signs roughly paralleled the need to understand the relationship between the two and the ease of search for existing signs. The intelligent transportation system (ITS) design implications of the comprehension, usefulness, and visual behavior results are elaborated next.

## 7.3 Design Guidelines

Overall, countermeasures to assist older drivers in the timely detection and correct response to traffic signals must take into account the normal cognitive declines associated with aging. That includes attention and working memory limitations, as well as perceptual limitations. Older drivers suffer visual declines that can make it difficult to discriminate signs and signals. Recommendations in the *Older Driver Highway Design Handbook* (Staplin, Lococo, & Byington, 1998) suggest minimum usages for luminance and size of traffic signals to aid discrimination of signals. For example, older drivers need increased signal luminance and contrast to perceive signals in certain situations and the handbook takes these needs into account when making minimum recommendations for contrast and luminance of signals.

The studies that were conducted serve to improve the safety of the older driver by trying to understand the difficulties older drivers face at intersections and to develop innovative in-vehicle ITS to assist them. The in-vehicle signs developed and tested here achieve this objective and are quite promising. During the course of development and evaluation, number of design guidelines for in-vehicle ITS, which accommodate older drivers, were also developed and include:

- Increasing the available time to make decisions at intersections will benefit drivers of all ages.

- Reducing the amount of information at intersections, will simplify required decisions.

- Provision of explicit timing information about when traffic lights will change may be used by risk taking drivers to run yellow and red lights.

- Traffic signs presented in an in-vehicle HUD have costs and benefits. Less visual search for salient signs is required of the driver. However when an in-vehicle sign is poorly understood, the driver is required to search for corresponding signs in the traffic environment.

Additional research needs were identified in the following areas.

- *Timing.* The timing of the warning signs and the length of time that they are presented to the driver are several fundamental design issues that require additional research.

- *Weather*. When snow, rain and fog are present, in-vehicle signs are clearly beneficial.

- *Visual Search*. Once a driver becomes reliant on in-vehicle HUD signs, drivers may be conditioned to expect the in-vehicle signs. What will they do when none are presented? The failure to reliably search for and comply with necessary regulatory and warning signs in the traffic environment may also increase crash risk.

- *Expectancy*. Should any limitations be imposed on what redundant information appears in a in-vehicle sign? Should in-vehicle signs be reserved for signs with "action potential", that is, those that are used most by drivers on a consistent basis?

## 7.4 References

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# APPENDICES