Modifying Driver Following Behaviour with a Real-Time Headway Evaluation System

by

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ABSTRACT

MODIFYING DRIVER FOLLOWING BEHAVIOUR WITH
A REAL-TIME HEADWAY EVALUATION SYSTEM

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Tailgating (maintaining an inadequate headway) is a major road safety concern that emerges because drivers tend to misperceive their following distance. Drivers seldom receive enough feedback to correct this error, leaving them vulnerable to rear-end collisions. While there have been attempts to address this issue through vehicle automation and warning systems, these approaches have not been sensitive to the needs of young drivers. The present investigation sought to implement a headway evaluation system: an in-vehicle display designed to provide motorists with real-time as well as aggregate headway feedback. This system was designed to teach drivers to recognize safe headways and to motivate adherence. Compared to drivers selecting their own headway or those attempting to count a two second headway, drivers using the headway evaluation system maintained longer headways that would be conducive to collision avoidance. This system may be beneficial as a training device for new drivers.
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Introduction

The World Health Organization has estimated that 1.3 million people are killed in car accidents every year (WHO, 2011). This figure is even more devastating when you consider that among these victims there is a vast overrepresentation of young people. Today, car accidents are the leading cause of death for people between the ages of 15 and 29 (WHO, 2009). While these accidents can be attributed to various factors, it has been estimated that up to 93% of collisions involve some form of human error (Connolly, 2009; Stanton & Marsden, 1997). Among these errors, one of the most noteworthy is drivers following one another too closely or maintaining short headways (Stanton & Salmon, 2009). Most commonly known as tailgating, drivers leaving an inadequate gap between themselves and a lead vehicle has been cited as one of the primary contributors to rear-end collisions (Taieb-Maimon, 2007; Ben-Yaacov, Maltz, & Shinar, 2002). This is a major concern as up to 15% of fatal car accidents involve rear-end collisions (Taieb-Maimon, Shinar, & Gurion, 2000; Stanton, Young, & McCaulder, 1997). In response, manufacturers are placing increasing emphasis on vehicle automation technologies designed to mitigate tailgating, among other driver errors (Hoc, Young, and Blosseville, 2009, Armingol et al., 2007; Connolly, 2009). One such technology is ACC or Adaptive Cruise Control (Connolly, 2009).

ACC detects lead vehicles and calculates their speed and trajectory. It then regulates the host vehicle's speed in order to maintain a safe following distance (Armingol, 2007). When the system is active it can reduce the throttle or, if necessary, apply the brakes (Connolly, 2009). While the aim is to reduce rear-end collisions, vehicle automation technology may increase driver risk in some critical dimensions. A growing body of literature has indicated that vehicle automation can lead to behavioural adaptation, overdependence, and skill deterioration.
(Parasuraman & Manzey, 2010; Rudin-Brown & Parker, 2004; Stanton & Marsden, 1997; Hjalmdahl & Varhelyi, 2004; Summala, 2000; Sagberg, Fosser, & Saetermo, 1996). These factors can leave drivers highly vulnerable to situations in which the technology fails to intervene due to a malfunction or circumstances that exceed its design limitations (Parasuraman & Manzey, 2010; Stanton & Marsden, 2004). For those reasons, we were interested in investigating an alternate approach to the problem of driver tailgating. Instead of using technology to automate longitudinal vehicle control, we developed a headway evaluation system that gave the driver real-time feedback pertaining to their headway. In addition to immediate headway measurements, drivers were presented with a long-term representation of their performance designed to reinforce their efforts to maintain a safe headway and to motivate adherence. Our ultimate objective was to encourage drivers to maintain safe following distances in order to reduce the likelihood of rear-end collision involvement.

The following literature review will consider the motivation behind automation technology, along with the negative influence it can wield over driver safety and performance. The focus will then turn to the factors that contribute to tailgating and we will consider prior attempts to provide the driver with headway feedback through warning devices. That will carry the discussion into our novel approach to modifying driver following behaviour with the headway evaluation system.

**Rear-End Collisions and their Antecedents**

Every day, over 1000 people under the age of 25 are killed in traffic accidents around the world (WHO, 2009). Road quality, driving conditions, and the actions of other road users often contribute to the likelihood of having an accident. However, the ultimate cause of most accidents
is said to be driver errors (Stanton & Salmon, 2009). Broadly defined, driver errors are instances where a driver fails to generate a suitable response to the circumstances preceding a collision. One such error is tailgating or maintaining a short headway (Stanton & Salmon, 2009).

Headway can be defined as the time between a lead vehicle passing a point on the roadway and a following vehicle arriving at the same point (Michael, Leeming, & Dwyer, 2000; Vogel, 2003). This measure is closely related to time-to-collision (TTC), which is the time before two vehicles collide if neither driver takes evasive action (Vogel, 2003). A short headway is not inherently dangerous but if a lead vehicle suddenly brakes, headway effectively becomes TTC for the following driver (Vogel, 2003). A small headway at the onset of a critical event equates to a short TTC and a reduced likelihood of avoiding an accident. Therefore, drivers who erroneously maintain smaller headways run an elevated risk for rear-end collision involvement (Broughton, Switzer, & Scott, 2007; Dingus et al., 1997). This is a major road safety concern given that rear-end collisions account for 30% of all car accidents (Lee, McGehee, Brown, & Michelle, 2002).

Following the tenet that collisions are seated in driver errors, automotive manufacturers have been poised to revise the role of the driver. The belief is that as the driver relinquishes more aspects of vehicle control, they will have fewer opportunities to commit errors. In turn, this promises to reduce the number and severity of error related collisions, if not eliminate them (Stanton & Marsdon, 1996; Stanton & Salmon, 2009). To achieve this, an increasing number of manufacturers are turning to vehicle automation technology (Stanton & Marsdon, 1996, Summala, 2000).
Technology as a Collision Intervention

The technology that manufacturers are implementing in order to automate the task of following other vehicles is known as Adaptive Cruise Control or ACC. ACC most commonly employs radar to measure the relative speed and distance of a lead vehicle. It then uses that information to maintain a constant headway by adjusting the throttle and brakes accordingly (Connolly, 2009). Traditionally, the rate of acceleration and deceleration has been limited to ensure driver comfort (Pauwelussen & Feenstra, 2010). Manufacturers have also been reluctant to implement high levels of automation given the liability issues that would arise if a system failure gave way to an accident. For those reasons, the driver has remained responsible for steering and collision avoidance (Vahidi & Eskandarian, 2003; Pauwelussen & Feenstra, 2010).

More recently, advances in this technology including the use of object recognition cameras in concert with Radar or LIDAR (Light Detection and Ranging) have been used to enable automatic emergency braking in response to forward hazards such as vehicles and pedestrians (Coelingh, Eidehall, & Bengtsson, 2010). One such example is the Google self-driving car which has traversed over 300,000 miles with minimal human intervention (Urmson, 2012). This trend suggests that technology is being designed to replace rather than to support driver control (Stanton, Dunoyer, & Leatherland, 2011). In the past, the proliferation of these technologies has been limited by the costs associated with the exotic materials required to build them (Kochan, 2003). This has restricted their application to high-end vehicles (Vahidi & Eskandarian, 2003). Today, the prevalence of radar and LIDAR technologies has made them more cost effective to implement and manufacturers have set their sights on a "zero accident future" (Coelingh et al., 2010; Richards, 2010). In the coming years, manufacturers endeavor to provide very high levels of automation across a wide range of vehicles, placing it in the hands of
the masses. Automation has some appreciable benefits including the potential to enhance driver comfort and convenience (Young & Stanton, 2007a). However, there is evidence to suggest that in a bid to reduce human errors, automation can lead to new errors and behaviours that are often unintended or unanticipated by the technology’s designers (Skitka, Mosier, & Burdick, 2000; Parasuraman & Manzey, 2010).

Problems with Vehicle Automation

**Behavioural Adaptation and Decreased Mental Workload.** In the presence of vehicle automation technology, drivers have demonstrated a propensity to change their behavior in undesired ways (Parasuraman & Manzey, 2010). This tendency is commonly referred to as negative behavioural adaptation (Rudin-Brown & Parker, 2004). While behavioural adaptation does not completely eliminate the virtues of safety technology, it has a tendency to reduce the anticipated benefits (Parasuraman & Manzey, 2010; Hjalmdahl & Varhelyi, 2004). An early and frequently cited example of behavioural adaptation was provided by Sagberg, Fosser, and Saetermo (1996) who demonstrated that taxi drivers using vehicles equipped with anti-lock brakes (ABS) stopped later and followed other drivers more closely. In the presence of ABS technology, their behaviour changed in a manner that undermined the potential safety benefits of the system (Sagberg, Fosser, & Saetermo, 1996). In the case of ACC, a similar problem with behavioral adaptation emerges due to its influence on the driver's mental workload (Farida, 2006; Rudin-Brown & Parker, 2004).

ACC limits the need for the driver to physically manage the accelerator or the brakes. This is perceived to be advantageous as it can reduce the potential for human error such as pressing the wrong pedal (Stanton & Salmon, 2008). Additionally, it relieves the driver of the
need to make decisions concerning when and how to accelerate or brake (Stanton, Young & McCaulder, 1997). Theoretically, this freedom from managing longitudinal vehicle control is beneficial as the driver should be able to apply more cognitive resources to critical tasks such as hazard recognition (Stanton & Marsden, 1997). However, drivers are typically only overloaded under exceptional circumstances (Stanton & Marsden, 1997; Young & Stanton, 1997). This gives way to behavioural adaptation as ACC grants drivers the liberty to apply cognitive resources to tasks that are unrelated to driving (Rudin-Brown & Parker, 2004).

Rudin-Brown and Parker (2004) revealed that when using ACC to follow a lead vehicle around a closed circuit, drivers directed more attention to a secondary task than they did when ACC was turned off. In the interviews following the driving simulation, drivers reported that the ACC system contributed to a sense of safety whereby they did not feel the need to check the road as frequently. Some drivers also reported resting their feet further away from the pedals than they normally would (Rudin-Brown & Parker, 2004). In addition to the secondary task, the researchers would periodically activate the brake lights of the lead vehicle by remote to assess the driver’s braking response time. This test revealed that ACC lead to a significant reduction in braking performance. With the ACC system set to maintain a 2.6 second headway autonomously, drivers only responded to 39.6% of the brake light events promptly enough to avoid a collision, compared to 63.5% when maintaining a 2 second headway manually (Rudin-Brown & Parker, 2004). Young and Stanton (2007a) showed similar results as increasing levels of automation contributed to higher performance on a secondary task. In particular, they found that ACC led to an increase in auxiliary task performance for novice drivers or those with no prior experience (Young & Stanton, 2007a). These findings have strong implications for young drivers. This group of motorists readily adopts mobile phones and mp3 devices (Lee, 2007) and may be prone
to engaging in secondary tasks while driving. For them, the motivation to delegate longitudinal control to the vehicle may be difficult to resist. The result could be more time spent looking away from the roadway at in-vehicle devices and an increased likelihood of collision involvement (Ma & Kaber, 2005).

**Diminished Situation Awareness and Automation Complacency.** Another factor that can endanger the driver in the presence of automation technology is a lack of Situation Awareness (SA). Stanton, Dunoyer, and Leatherland (2011) define SA as an understanding of the relationship between the driver's goals, the vehicle’s state, the road environment, and the behaviour of other road users at any moment in time (Stanton et al., 2011). In the presence of automation, the driver delegates functions to the vehicle that they would have ordinarily performed manually (Hoc et al., 2008). This effectively changes their role wherein they are required to monitor the automation system (vehicle state) to ensure that it is functioning properly (Hoc et al., 2008; Pararsuraman & Manzey, 2010). ACC is problematic because it replaces the tasks associated with longitudinal control while providing the driver with little to no information or feedback, unless a critical event occurs. This creates the opportunity for discrepancies to emerge between the driver's understanding of how the system is functioning and its actual status (Stanton et al., 2011). Such an effect is inconsequential so long as the automated system works properly. However, in the event of a system malfunction or failure, it could cause the driver to accept inappropriate or incorrect directives (Skitka et al., 2000; Pararsuraman & Manzey, 2010). This particular outcome is known as automation complacency. Automation complacency refers to events where the vehicle operator fails to notice a system failure, malfunction, or error. It is said to occur because the operator of an automated system tends to neglect the information required to perform automated functions manually (Hoc et al., 2008). In the case of ACC, this
could mean a poor understanding of actual following distance which limits the opportunity to confirm or deny the proper functioning of the system. Automation complacency can lead the vehicle operator to assume that all is well while failing to override the system, even if it malfunctions (Parasuraman & Manzey, 2010; Rudin-Brown & Parker, 2004). While new technologies including the Google self-driving car exhibit high levels of reliability they still require occasional human intervention. Google also indicates that there are situations that have yet to be mastered including construction signals and snowy environments (Google, 2012). That beings said, while technology may be improving and instances in which the driver has to resume manual control may be infrequent, the driver may still be ill-prepared to cope with them if they do emerge.

Hjalmdahl and Varhelyi (2004) demonstrated a similar effect among drivers using an active accelerator pedal that applied counterforce as drivers approached the posted speed limit. When the drivers left the area in which the pedal was active, they failed to adjust to new speed limit zones. This was attributed to the drivers monitoring their speedometers less frequently while incorrectly assuming that the pedal was working properly (Hjalmdahl & Varhelyi, 2004). This tendency to disregard information that would normally facilitate vehicle control can be dangerous to all drivers in the event that the technology is unable to intervene. For inexperienced drivers, the same level of complacency may be particularly deleterious because it could undermine the driver's ability to acquire and maintain the skills needed to respond to hazards (Stanton & Marsden, 1997; Young & Stanton, 2007a).

**Factors Limiting Skill Acquisition.** Over the first several thousand kilometers of driving, major changes in cognitive skills start to emerge. In particular, drivers develop the capacity to search for relevant information in the appropriate locations (Summala, 2000). This
ability is facilitated in part by the unique but overlapping roles of the focal and ambient visual systems. The primary function of the focal visual system is object recognition, reading, and other tasks that require a high degree of visual acuity. The role of the ambient visual system is to aid the process of spatial orientation, particularly during locomotion (Horrey, Wickens, and Consalus, 2006). While limited focal visual abilities exist beyond the fovea, they are strongest at the fovea. Conversely, ambient visual abilities are strong in the fovea but do not degrade as rapidly over the periphery (McKee & Nakayama, 1984 as cited in Horrey et al., 2006).

Experienced drivers have the capacity to use ambient vision to retain lateral control over their vehicle (Summala, Nieman, & Punto, 1996). This ability allows versed motorists to utilize visual scanning strategies in which focal vision and thus attention are applied further away from the vehicle in order to better anticipate and manage critical situations (Summala, 2000). To illustrate, Borowsky, Shinar, & Oron-Gilad (2010) demonstrated that experienced drivers spent more time fixating on areas associated with potential hazards, allowing them to identify hazards more readily. This pattern of abilities suggests that an experienced driver may be able to recover from an automation system failure having the capacity to anticipate, identify, and cope with critical situations independently. To corroborate this, Parker and Rudin-Brown (2004) simulated an ACC system failure while drivers were following a lead vehicle around a closed circuit. This event caused the vehicle to begin accelerating toward the lead vehicle. Each member of their sample, which contained only experienced drivers with at least five years of licensure, was able to identify the error and avoid a collision.

Conversely, inexperienced drivers lack the capacity to use ambient visual attention to maintain vehicle control. Instead, they rely very heavily on their focal vision for basic vehicle control including lane keeping (Summala, Nieminen, & Punto, 1996). As a consequence,
inexperienced drivers tend to show very narrow and stereotyped scanning patterns, often limited to the road directly in front of the vehicle (Huestegge, Eva-Skottke, Anders, Musseler, & Debus, 2010). In the same investigation, Borowsky et al. (2010) demonstrated that hazards must be apparent before inexperienced drivers notice and respond to them. They theorize that this is because new drivers have yet to accumulate enough feedback or experience from situations where potential hazards have materialized (Borowsky et al., 2010).

Today, ACC and automatic braking technologies are being designed to replace the task of driver longitudinal control with the added function of bringing the vehicle to a complete stop in response to forward hazards (Stanton et al., 2011; Coelingh et al., 2010). If collision avoidance is learned through an exposure to the materialization of potential hazards or feedback from hazardous situations (Borowsky et al., 2010), automatic intervention could undermine this process. Furthermore, as Parker and Rudin-Brown (2004) demonstrated, drivers are more likely to engage in secondary tasks in the presence of ACC, ignoring cues that signal the need to apply the brakes. New drivers using ACC with automatic braking may thereby lose the opportunity to learn how to respond to emergency situations independently (Stanton & Young, 2007; Young & Stanton, 2007a). The confluence of diminished situation awareness, automation complacency, and limited skill acquisition could make regaining manual control in the event of an automation system failure insurmountable for an inexperienced driver. Lee (2007) describes this scenario as a perfect storm in which complex distractions and complex vehicles lead to increasingly confident yet unprepared drivers (Lee, 2007).
Problems with Headway Training and Perception

In light of the shortcomings associated with automation, it is important to consider alternate methods to help drivers to remain safe when following other vehicles. While automation related research has characterized inadequate headway as a human error, less consideration has been given to how or why this particular error may occur. However, some have posited that tailgating may be a function of poor headway training and perception (Taieb-Maimon & Shinar, 2001; Ben-Yaacov, Maltz, & Shinar, 2002).

Different countries have varying guidelines pertaining to safe headway maintenance. In Germany, drivers are told that they should maintain a minimum headway that is equal to half the speedometer. This means that a driver travelling at 80Km/h should remain at least 40m from a lead vehicle (Vogel, 2003). In Canada and in the United States, drivers are instructed to maintain a minimum headway of two seconds. This is commonly referred to as the two second rule. Wang and Song (2009) indicate that perception times can vary between 0.5 and 4 seconds however the average driver’s perception-reaction time said to be approximately 2.5 seconds. In a review on brake reaction time literature, Young and Stanton (2007b) consider total braking time (TBT). TBT accounts for the time between the onset of the lead vehicle’s brake lights and accelerator release, as well as movement from the accelerator to the brake pedal. In studies where the driver was unaware that a critical event would occur, TBT ranged from .65 to 2.45 seconds (Young & Stanton, 2007b). Thus the two second rule was created to accommodate the time that drivers require to recognize and to respond to forward hazards. To communicate the two second rule to motorists, the Ontario Ministry of Transportation (MTO) uses the following instructions:
Pick a marker on the road ahead. When the rear of the vehicle ahead passes the marker, count "one thousand and one, one thousand and two". If you reach the marker before you finish counting, you're following too closely (MTO, 2010, p.1).

The New York Department of Motor Vehicles also uses a slight variation of the same instructions (NYS DMV, 2010). In spite of these recommendations, tailgating and rear-end collisions persist and there is evidence to suggest that this may relate to the driver’s capacity to correctly apply the two second rule.

Even when a driver is motivated to maintain a two second headway, they may unwittingly select a shorter following distance. This is said to occur because drivers have trouble accurately estimating headway in seconds (Taieb-Maimon & Shinar, 2001). To illustrate, Taieb-Maimon and Shinar (2001) asked drivers to follow a lead vehicle at what they felt was the minimum safe headway they could maintain. They were then asked to report what they believed their actual headway was in seconds. At 50 Km/h, the drivers reported that they were maintaining a headway of 1.93 s. In reality, the drivers were maintaining a precarious 0.66 s distance from the lead vehicle. Furthermore, this estimate increased to 2.61 s at 100 Km/h, even though their time headway had not changed significantly. This demonstrated that drivers have a tendency to overestimate time headway and inadvertently select shorter following distances (Taieb-Maimon & Shinar, 2001). In spite of these findings, we remain steadfast in the way that we teach headway maintenance across North America.

**Headway Feedback through Warning Systems**

From the perspective that poor headway perception underlies tailgating, a number of studies have investigated the implementation of warning systems. These technologies are
designed to notify the driver when headway becomes shorter than a predetermined threshold by presenting them with an auditory cue (Ben-Yaacov, Maltz, & Shinar, 2002; Shinar & Schechtman, 2002). Previous research has demonstrated that these devices can be effective in improving headway. For example, Ben-Yaacov et al. (2002) outfitted a vehicle with a laser-based headway warning system that would emit an audible tone when drivers fell below a specific headway. In their investigation, Ben-Yaacov et al. (2002) had participants complete a total of four trials that took place on a course laid out on public highways. For the initial trial, drivers were instructed to select any lead vehicle and to stay close behind it to the best of their ability. During this time, the warning system remained muted. For the second trial, the warning system was activated and set to emit a tone when drivers were at headways of less than 1 second. The third trial took place immediately after exposure to the device with the system muted again. The system was also muted for the fourth and final trial, which took place 6 months after the initial drives. The researchers found that in the first trial, drivers spent 42.2% of their time at headways below 0.8 seconds. This dropped to 3.5% with the warning system active and remained at 6.5% when the system was muted again. Furthermore, when the drivers were tested six months later, they only fell below 0.8 seconds for 10.4% of the drive (Ben-Yaacov et al., 2002). This suggests that warning systems have the capacity to increase driver headway. However, the authors concede that the results do not imply that drivers will adjust their headway under their own free will (Ben-Yaacov et al., 2002). In spite of their apparent efficacy, some studies have provided evidence to suggest that motorists are not likely to abide by in-vehicle warning systems.

Young, Regan, Mitsopoulos, and Hawworth (2004) led a series of focus groups designed to tap into how motorists perceived various forms of driver aids, including following distance
warning systems. The researchers revealed that drivers believed that warning systems may become annoying or intrusive, particularly in heavy traffic. Drivers also expressed concern over whether or not the system could be voluntarily disabled. When asked if they would be tempted to circumvent a warning system, drivers indicated that they would be compelled to tamper with it. Some focus groups members discussed the prospect of disconnecting the warning system itself or tampering with the radar equipment that enables it (Young et al., 2004). These findings suggest that adherence to headway warning systems may be problematic. Furthermore, Lee (2007) cautions that a collision warning system aimed at promoting conservative driving may encourage young drivers to maximize rather than minimize the number of warnings that they receive (Lee, 2007). Further evidence of this potentiality can be found in the same series of focus groups led by Young et al. (2004). Concerns were raised that some drivers may willfully attempt to evoke a response from the system. One focus group member suggested that young drivers may compete to see who can elicit the strongest response from a headway warning system by getting as close to a lead vehicle as possible (Young et al., 2004). This suggests that if poorly implemented, a warning system may actually exacerbate risky driving behaviour among young motorists.

The headway evaluation system as an Alternate Approach

The need to curtail the rate at which drivers are killed in traffic accidents persists. While technology has been employed to mitigate tailgating and rear-end collisions, the present range of interventions has not been sensitive to the needs of young drivers. In the bid to relieve the driver of their control, automation can undermine collision avoidance skills. On the other hand, attempting to alert the driver through warning systems has the potential to exacerbate risk-taking among young drivers. This indicates that there is a need for an alternative that is sensitive to the
manner in which drivers hone their skills and that addresses the factors that enable dangerous driving habits.

When a driver is in the graduated licensing system, they are required to drive in the company of an adult passenger. Unlike teen passengers, adults can have a protective effect as they augment the driver’s abilities by helping them to identify and cope with hazards (Lee, 2007). Furthermore, experienced drivers provide two very important kinds of feedback: immediate feedback that conveys performance on a moment to moment basis and aggregate feedback which gives the motorist a more general understanding of their performance (Lee, 2007). However, when a driver earns a full license and exits the graduated licensing system this feedback diminishes and drivers are left to drive as they please (Duncan et al., 1991). Some elements of vehicle control continue to provide feedback in the absence of tuition. For example, poor clutch and gear-lever operation can lead to the grinding of gears. Similarly, near accident events can help to shape driving behaviour (Duncan et al., 1991). On the other hand, tailgating presents a unique risk because maintaining a short headway is seldom accompanied by feedback. Drivers recognize that the sudden deceleration of a lead vehicle is a relatively rare occurrence (Evans, 1991 as cited by Ben-Yaacov, Maltz, & Shinar, 2002). Furthermore, the average driver is said to encounter a front to rear-end collision only once every 25 years (Horowitz & Dingus, 1992). This lack of feedback leads to what Hutton et al. (2002) refer to as a conditioning trap. A conditioning trap occurs when a safe behaviour has extinguished because of the low probability of a negative outcome resulting from behaving otherwise. As an additional consequence, the competing unsafe behaviour that is applied successfully in one context is often overgeneralized to a situation in which it is highly dangerous (Hutton et al., 2002). For example, a driver may tailgate without incident under good driving conditions and attempt to do the same in the face of
poor visibility or slick roads. Conditioning traps make it easy for motorists to develop and to maintain unsafe car following behaviour with growing experience. To illustrate this effect, Duncan et al. (1991) discovered that novice drivers maintained significantly longer headways while preparing to overtake a lead vehicle than experienced drivers, as well as expert drivers with advanced driver training (Duncan et al., 1991).

While typical driving conditions can foster unsafe habits, reinstating the form of driver feedback that one receives from an instructor has the capacity to reshape unsafe behaviours. Hutton et al. (2002) used a case study to demonstrate that one-on-one feedback in which a passenger informed the driver of their time headway increased the following distances that they maintained (Hutton et al., 2002). In their investigation, Hutton et al. (2002) asked the driver to traverse a 9 Km long course along real roads. During the drive, a research confederate riding in the passenger seat would comment on their time headway when they were less than 2 seconds away from the lead vehicle. Prior to the intervention, the driver remained at their target headway of 2 seconds for 57.2% of their drive. In the presence of feedback, they maintained a 2 second headway for 83.2% of their drive. Furthermore, during a follow-up condition in which no feedback was present, the driver maintained safe headways for over twice the duration that they had prior to the intervention (Hutton et al., 2002).

While effective, it is not always possible to enjoy the benefits of a passenger capable of delivering this type of feedback. However, as the modern vehicle is equipped with a growing volume of technology designed to collect vehicle data, the opportunity to better inform the motorist also expands. This data could be used to generate continuous appraisal of driving performance similar to that which is presented by an experienced passenger during the early stages of the graduated licensing system. Just as an instructor or mentor would do, headway
information could be presented in a manner that is actionable or one that communicates how the
driver can improve (Huang, Roetting, McDevitt, Melton, & Courtney, 2005). Lee (2007)
indicates that technology alone is unlikely to make young drivers safer. However, tuning it to
complement or to extend the graduated licensing system may do so. The solution to safer driving
may thereby be to tailor technology so that drivers perceive it to be a form of mentor (Lee,
2007). A headway evaluation system may afford drivers this much needed form of mentorship.

The goal of the present investigation was to test the efficacy of a headway evaluation
system. This in-vehicle display was designed to present real-time headway information to the
driver in the effort to enhance their capacity to recognize and to establish a safe headway. At the
same time, the device was designed to acknowledged safe headway maintenance with a long-
term representation of performance. This component was designed to reflect the aggregate
feedback that an instructor or mentor may provide. Similar feedback devices have been
implemented in order for drivers to maximize their fuel economy. These technologies have been
welcome by drivers as there is anecdotal evidence to suggest that some users enjoy playing
games with them in an attempt to conserve fuel (Barkenbus, 2010). Motivating or rewarding safe
driving presents a greater challenge. While there are opportunities to feel good about unsafe
behaviour (e.g. thrill-seeking and saving time) and some opportunities to feel bad about unsafe
behaviour (e.g. accidents, penalties, and injuries), there are few opportunities to feel positive
about safe behaviour. Some insurance providers offer incentives for safe driving but the delay is
often too great to reward specific acts (Hurst, 1980). The proposed system was intended to
overcome this limitation by offering more immediate feedback. Furthermore, there is evidence to
suggest that drivers welcome this type of system into their vehicles. Huang et al. (2005)
conducted an investigation on the attitudes of truck drivers toward feedback through technology.
59% of those surveyed agreed with the statement “positive feedback was more helpful to them than negative feedback”. In a similar investigation, truck drivers also indicated that that they wanted feedback that was specific, constructive, and individualized. They also desired signs of recognition such as a bonus or an award for good performance (Roetting, Huang, McDevitt, & Melton, 2003). The truck drivers suggested that while an audible or visible alarm worked best for a warning system, a computer screen would be more suitable for a feedback system (Roetting et al., 2003). Similarly, Huang et al. (2005) found that the majority of the truck drivers who were surveyed would like to receive feedback using a dashboard located display (Huang et al., 2005).

This provides evidence to suggest that drivers may find interacting with a dashboard mounted display that is designed to present positive feedback to be appealing. In particular, they may discover that a long-term representation of headway performance enables the form of individualized feedback and sense of reward that they seek. Consequently, drivers may welcome a headway evaluation system as the mentor that Lee (2007) describes, allowing it to enhance their capacity to accurately appraise their headway and to curtail their unsafe car following behaviour. Such an intervention would have the potential to reduce the likelihood of rear-end collision involvement while avoiding the drawbacks associated with automation and warning systems.

**Research Goals**

The current body of literature gave rise to five major research goals that were explored across two experiments. The first experiment was concerned with headway behaviour in the absence of the headway evaluation system and therein we had two goals:
1. First, we wanted to evaluate the efficacy of verbal headway instruction. Because drivers currently learn to maintain safe headways using the two second rule, we wanted to determine whether this method encouraged drivers to maintain safer headways than permitting them to select what they perceived to be a safe headway.

2. We were also interested in whether there were any appreciable differences between fully licensed drivers and learning drivers in the way that they applied these instructions. All of our experiments, including the development of the proposed headway evaluation system, were to be tested in the University of Guelph’s DS600c fixed based driving simulator. For that reason, our second goal was to compare the headways that drivers maintained in the current study to those maintained by drivers in previous, real-world car following studies. This would allow us to determine whether the simulator was a suitable platform for testing the proposed headway evaluation system.

The second experiment was concerned with the implementation of the headway evaluation system and therein we had three goals:

3. Our third major research goal was to compare real-time and long-term headway feedback. In particular, we wanted to determine whether including long-term feedback improved the headway that drivers maintained over real-time feedback alone.

4. Our fourth goal was to compare verbal instruction to the headway evaluation system. To achieve this, we aimed to draw a comparison between Experiment 1 and Experiment 2 to assess whether the headway evaluation system improved headway compared to the two second rule or drivers selecting their own safe headway.

5. Finally, our fifth goal was to evaluate driver receptiveness to the headway evaluation system. Because drivers are reticent to accept warning systems (Young et al., 2004), we
endeavored to evaluate the extent to which drivers were willing to engage with the headway evaluation system.

Experiment 1

Evaluating the Efficacy of Verbal Headway Instruction

Today, drivers in Ontario and other parts of North America continue to learn the two second rule as a means of maintaining a safe headway. For that reason, we wanted to establish whether there was an appreciable safety benefit to drivers adhering to the two second rule over drivers selecting what they believed to be the minimum safe headway they could maintain. Few previous investigations have tested the efficacy of the two second rule instructions as laid out by the MTO. We also wanted to examine whether a driver’s level of licensure influenced time headway selection. Therein we sought to compare drivers with a learner’s permit against fully licensed drivers. In addition to headway, we also sought to examine lateral vehicle control and mental workload. These data were to serve as a point of comparison for Experiment 2, allowing us to assess the impact of the proposed headway evaluation system on vehicle control and mental effort.

Hypotheses

Based on the findings of Taieb-Maimon and Shinar (2001), we hypothesized that fully licensed drivers would demonstrate a tendency to overestimate their headway while adhering to either a minimum safe headway or the two second rule. Based on the findings of Duncan et al. (1991) in which inexperienced drivers maintained longer headways than experienced drivers, we hypothesized that learning drivers would prefer greater headways than fully licensed drivers.
Summala et al. (1996) demonstrated that the perceptual abilities of experienced drivers led to enhanced lateral vehicle control therefore we hypothesized that fully licensed drivers would exhibit better lateral vehicle control than learning drivers. Furthermore, because lateral vehicle control is more challenging for inexperienced drivers, we predicted that learning drivers would report higher mental workloads than fully licensed drivers.

**Comparing Headway in the DS600c Simulator to Real World Headway**

In order to develop and test the headway evaluation system, we wanted to ensure that the University of Guelph’s Drive Safety DS600c fixed-base driving simulator would faithfully reproduce the task of following a lead vehicle. If the headway evaluation system itself or the knowledge that drivers were to gain from the system were to be applied to real driving, the simulator would need to allow drivers to perceive the distance of a simulated lead vehicle in the same way that they perceive the distance of a real car. However, some studies have suggested that the perception of relative distance in a driving simulator can be problematic. For example, Panerai et al. (2001) conducted an investigation on maintaining safe distances in truck driving. In their series of experiments, drivers with varying levels of experience were asked to traverse a road course in a real truck. They were then asked to drive a similar course laid out in a Renault V.I. truck simulator. This particular simulator was comprised of a truck cab situated between a frontal screen and two rear screens, one for each wing mirror. In comparing their truck simulator to real world driving, they discovered that drivers underestimated distances by up to 49% in the simulator (Panerai, Droulez, Kelada, Kemeny, Balligand, & Favre, 1991). The researchers caution that when using a simulator, careful consideration must be given to the factors that influence the driver’s ability to estimate distance. They indicate that this is particularly important
when studies are examining time headway or the application of technologies designed to address inter-vehicle distance (Kemeny & Panerai, 2003).

One particular factor in simulator design that influences accurate distance perception is the simulated eye height that the driver experiences. If the eye height is too great relative to the images of the simulated driving environment, the result can be an over estimation of inter-vehicular distance (Kemeny & Panerai, 2003). Kemeny and Panerai (2003) suggest that this may explain why drivers overestimated their headway in the Renault V.I. truck simulator. The excessive height of the truck cab relative to the forward screen created an unrealistic eye height which contributed to an inaccurate perception of headway (Kemeny & Panerai, 2003). The authors also advise that driving simulators should use a large field of view in order to enable accurate speed and distance perception (Kemeny & Panerai, 2003). The Renault V.I. simulator had a relatively small field of view with only 90 degrees in front and 90 degrees behind (Panerai et al., 1991). The DS600c driving simulator is substantially different from the Renault V.I. simulator in both of those aspects. Where the Renault simulator used a tall truck cabin, the DS600c is based on the body and cabin of a family sedan and the height of the simulated environment or scenery was designed to match the height of the body. Furthermore, where the Renault V.I. simulator used frontal and rear screens, the DS600c uses a 300 degree wraparound environment. Consequently, we wanted to compare the DS600c driving simulator against previous investigations on headway in real vehicles. More specifically, we wanted to use the headways that fully licensed drivers achieved while using verbal headway instruction as a baseline by which to compare the DS600c to real-world driving. We hypothesized that because of the design of the DS600c simulator, particularly the realistic eye height and the large field of
view, driver headway would be very similar to that which has been observed in prior real-world car following experiments.

**Method**

**Participants.** A total of 53 drivers took part in this experiment. All participants were undergraduate students at the University of Guelph who were recruited from the introductory psychology participant pool. As compensation, participants received 1 research credit toward their introductory psychology class for taking part in the experiment. In total, 26 fully licensed drivers were recruited but two were unable to complete the experiment due to simulator adaptation syndrome. Similarly, a total of 27 drivers with an Ontario learner’s permit were recruited but three drivers were unable to finish due to symptoms of simulator adaptation syndrome. This resulted in a total of 24 fully licensed drivers and 24 learning drivers who completed Experiment 1. Thus, the actual sample size was 48. Simulator adaptation syndrome (SAS) will be discussed in greater detail later (see Procedure). Drivers were between the ages of 18 and 24 ($M = 20.01, SD = 2.04$). The Full G group was comprised of 20 male drivers and 4 female drivers with a mean length of licensure of 59 months (from the time their learner’s permit was issued). The learning drivers group was comprised of 9 male drivers and 15 female drivers with a mean length of licensure of 13 months. Drivers were randomly assigned to one of two groups: one group was to maintain the two second rule while the other was to adhere to the minimum safe headway that they believed they could maintain. This resulted in a total of four groups. For a complete summary of participant characteristics, see Table 1.

**Design.** The experiment employed a 2x2 between subjects design. There were two independent variables: the headway instructions the drivers received (two second rule or
Table 1

Participant characteristics: Age, length of licensure, daily driving, accident involvement, and gender by group.

<table>
<thead>
<tr>
<th>Driver Group</th>
<th>n</th>
<th>Mean Age (SD)</th>
<th>Mean Months Licensed (SD)</th>
<th>Mean Estimated Km driven per day (SD)*</th>
<th>Accident-Involved Drivers**</th>
<th>Frequency of Men/Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full License</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two Second Rule</td>
<td>12</td>
<td>20.83 (1.69)</td>
<td>55.33 (16.84)</td>
<td>53.16 (32.63)</td>
<td>2</td>
<td>10/2</td>
</tr>
<tr>
<td>Minimum Safe</td>
<td>12</td>
<td>22.25 (2.13)</td>
<td>61.50 (22.61)</td>
<td>71.82 (69.15)</td>
<td>5</td>
<td>10/2</td>
</tr>
<tr>
<td>Learning Drivers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two Second Rule</td>
<td>12</td>
<td>19.25 (1.35)</td>
<td>12.08 (7.13)</td>
<td>17.92 (24.69)</td>
<td>6</td>
<td>7/5</td>
</tr>
<tr>
<td>Minimum Safe</td>
<td>12</td>
<td>18.5 (0.67)</td>
<td>14.67 (6.93)</td>
<td>12 (14.07)</td>
<td>3</td>
<td>2/10</td>
</tr>
</tbody>
</table>

*Some drivers indicated that they do not have access to a car every day. Drivers were asked to report how far they drove on a typical day that they do go driving.

**These figures do not reflect drivers with more than one accident, however, they include accidents experienced as a passenger or as a driver.
minimum safe headway) and level of licensure (learning driver or fully licensed). The result was four cells with an even number of drivers in each cell (see Table 1).

**Material and Apparatus.** The testing took place in a fixed-base, Drive Safety DS600c simulator. The body and cabin of the simulator consisted of a Saturn sedan equipped with standard vehicle controls that were supplemented by force-feedback steering, three-dimensional sound, and vibration transducers. Driving scenes were projected onto six 7ft screens that provided a 300 degree wrap-around environment: 250 degrees in the front, 50 degrees in the rear (see Figure 1).

Two driving scenarios were created, each 20 Km in length. Each scenario was designed to replicate driving through a rural region on a clear day (see Figure 1). The straight roadway consisted of one lane in each direction and hosted a low level of oncoming traffic to enhance the perceived realism of the scenarios. The posted speed limit for the duration of the drives was 80 Km/h. In both scenarios, a lead vehicle was programmed to traverse the road course. At the start of each drive, the lead vehicle was positioned at a four-way stop. When the driver came within 20 meters of the lead vehicle, the lead vehicle proceeded toward the intersection and performed a stop. This allowed drivers to pull up behind the lead vehicle while it was stopped at the intersection as they would in normal driving. The lead vehicle would then proceed through the intersection and steadily accelerate to 80Km/h.

The speed of the lead vehicle varied gradually, ranging from 75 Km/h to 80 Km/h. This range was selected in order to make it more challenging for the driver to maintain a constant headway but without demanding heavy braking, given that rapid braking events are an infrequent occurrence in normal driving (Michael et al., 2000). In order to accomplish this, we divided the road course into segments of 200 meters. At the edge of each 200 meter segment was a software
Figure 1. DS600c Fixed based driving simulator. The image on the left illustrates the full body/cab and the wraparound screens. The image on the right shows the rural environment used for the current experiment, along with the lead vehicle.
trigger that would set the lead vehicle to a predefined speed as the driver passed over it. In this case, we used a random number generator (Haahr, 2012) to return a list of random integers within the range of 75Km/h and 80 Km/h. One integer was assigned to each of the 200 m segments. This was done to ensure that the sequence in which the lead vehicle accelerated or decelerated was difficult for the drivers to predict but constant across all participants. The rate of both acceleration and deceleration was 0.5 m/s\(^2\). This rate was selected to ensure that changes in speed from segment to segment were gradual. The simulator collected the time headway (s) at a rate of 60 Hz. In addition to time headway, the simulator also collected Standard Deviation from Lateral Position (SDLP), which represents the extent to which a driver varies from the center of their lane. SDLP is measured in meters and is a common assay for lateral vehicle control or steering performance.

**NASA-TLX.** In order to assess the drivers’ subjective mental workload, we administered the NASA Task Load Index (TLX). This popular paper and pencil assessment technique is designed to examine the specific sources of mental workload experienced during a given task (see Appendix A). The index employs a series of subscales which ask the user to rate imposed workload or that which is induced by the situation itself (mental, physical, and temporal) along with the psychological impact of the task at hand (performance, effort, and frustration level) (Hart & Staveland, 1988; Cao, Chintamani, Pandya, & Ellis, 2009). The NASA-TLX is well known for its sensitivity, low intrusiveness, reliability, and ease of implementation. Studies have also shown that while there is a high correlation between the NASA-TLX and other measures of mental workload, experimental subjects favour the NASA-TLX (Cao et al., 2009). For the present investigation, the unweighted or raw TLX (RTLX) scores were used. This is the most common approach and studies have demonstrated that there is a high correlation between
weighted (TLX) and unweighted (RTLX) scores. The result is a workload score ranging from 0 to 100, with 0 being the least taxing and 100 being the most taxing (Cao et al., 2009).

Procedure

Upon arriving at the DRIVE lab, the participant was asked to read and sign a consent form. At that time, the researcher reminded drivers of their right to withdraw from the study at any time. If the participant expressed the desire to take part, they were then screened for the predictors of simulator adaptation syndrome (SAS), see Appendix B. SAS occurs when the individual using the simulator experiences feelings of illness or discomfort. Symptoms of SAS can include fatigue, headache, eyestrain, difficulty focusing, disorientation, and nausea (Mullen, Weaver, Riendeau, Morrison, & Bedard, 2010). This phenomenon is said to occur because of an inability to simulate the motion environment accurately enough. It has been theorized that the central nervous system has a model of neural activity associated with bodily movement that is derived through daily experience. When introduced to an atypical motion environment such as a simulator, where vestibular input is absent, a mismatch is created between the expected sensory inputs and the actual inputs (Johnson, 2005). For their own safety, only participants in good health and those who reported few or none of the SAS predictors were allowed to proceed.

Drivers who passed the SAS prescreening were presented with a series of questions pertaining to driving experience including length of licensure, normal driving habits, and accident involvement (see Appendix C). Once they had completed the questionnaires, the researcher explained to the participant that they would be embarking on a series of three drives and that they would be following a lead vehicle for the duration of each drive. They were told that the premise was that they were following a friend to a destination. For that reason, they
were not to pass the lead vehicle but they were to follow at a safe distance using their respective headway instructions (the two second rule or minimum safe headway). At that time, those who were assigned to use the two second rule were presented with the instructions as outlined by the Ontario Ministry of Transportation (2010, p.1) for maintaining a two second following distance:

1. Pick a marker on the road ahead, such as a road sign or telephone pole.
2. When the rear of the vehicle ahead passes the marker, count "one thousand and one, one thousand and two".
3. When the front of your vehicle reaches the marker, stop counting. If you reach the marker before you count "one thousand and two," you are following too closely.

Drivers who were assigned to maintain a minimum safe headway were given the same instructions used by Taieb-Maimon and Shinar (2001) to encourage drivers to attain a minimum safe headway:

Follow at closest headway that you are able to maintain from the lead vehicle that will still enable you to stop in time if the lead driver suddenly decides to brake. (Taieb-Maimon & Shinar, 2001, p.162)

Each driver began with a six minute practice drive designed to give them the opportunity to acclimatize to the simulator's controls. Once the practice drive was complete, they were then asked to embark on two 16 minute experimental drives that were nearly identical with the exception of small differences in scenery. This was done in order to minimize the potential for simulator adaptation syndrome by allowing drivers to take a break in the middle, if they so desired. The order in which the drives were presented was counterbalanced. In total, the
simulation session lasted roughly 40 minutes. When the drivers were finished, the NASA-TLX was administered and drivers were given a debriefing in which the goal of the investigation was explained.

Data Analyses

There were four dependent variables: time headway (s), standard deviation of the drivers' time headway (s), SDLP (m), and the NASA-RTLX score. Each dependent variable was analyzed separately using a 2 x 2 (headway instruction x level of licensure) factorial analysis of variance. As the drivers received the same instructions for both experimental drives and performed them consecutively, without feedback on their performance, the data from the two experimental drives were aggregated.

Results

Three cases from the group of learning drivers who were asked to maintain a minimum safe headway were excluded from the analyses because they failed to adhere to the instructions to follow the lead vehicle. In those instances, the drivers were at mean headways of beyond 6 seconds. Vogel (2002) indicates that at headways of beyond 6 seconds, motorists select a speed that is independent of a lead vehicle. Furthermore, it is unlikely that a driver would need to perform evasive maneuvers if presented with a stopped vehicle at a 6 second time-to-collision. From this we can infer that a motorist is no longer following a lead vehicle at a headway of 6 seconds or greater (Vogel, 2002).

Time Headway. There was no main effect of headway instruction, $F(1, 41) = .18, p = .673$. The drivers using the two second rule did not differ from those who received the minimum safe headway instructions. In line with our hypothesis, there was a main effect of
driving experience, \( F(1, 41) = 7.53, p = .009, \) Partial \( \eta^2 = .16 \). Full G drivers exhibited shorter headways compared to learning drivers (see Figure 2). Finally, there was no interaction between license type and headway instruction, \( F(1,41) = .949, p = .336 \). This pattern indicates that overall, learning drivers maintained longer and safer headways than fully licensed drivers.

**Standard Deviation in Headway.** There was no main effect of headway instruction, \( F(1, 41) = 1.41, p = .242 \). Drivers using the two second rule and those maintaining a minimum safe headway did not differ in terms of their headway standard deviation. There was a main effect of level of licensure, \( F(1, 41) = 13.56, p = .001 \), Partial \( \eta^2 = .25 \). The standard deviation of driver headway was greater among learning drivers than it was among fully licensed drivers (see Figure 3). However, there was no interaction between level of licensure and headway instruction, \( F(1,41) = .949, p = .738 \). These findings suggest that fully licensed drivers outperformed learning drivers, having exhibited less variability in the headways they maintained.

**Standard Deviation from Lateral Position.** The homogeneity of variance assumption was violated as Levene’s test was significant. A Log10 transformation was applied to the SDLP data in order to establish homogeneity of variance. Because mean standard deviation from lateral position was less than 1 meter across all cells, the SDLP data was converted from meters to centimeters prior to transformation and will hereto forward be reported in centimeters. The ANOVA revealed that there was no main effect of headway instruction, \( F(1,41)=.26, p= .615 \). Drivers using the two second rule and those maintaining a minimum safe headway did not differ in terms of their lateral vehicle control. As predicted, there was a main effect of level of licensure, \( F(1,41)=15.61, p= .000 \), Partial \( \eta^2 = .27 \) (see Figure 4). Learning drivers had a larger SDLP than fully licensed drivers. Once again, there was no interaction between level of licensure
and headway instruction, $F(1,41)=.491, p = .487$. This pattern reveals that Full G drivers exhibited better lateral vehicle control than learning drivers, as indicated by their smaller SDLP.

**NASA-TLX.** The ANOVA revealed that there were no significant experimental effects on NASA-RTLX scores. There was no main effect of headway instruction, $F(1,41)=1.37, p = .249$, indicating that there was no appreciable difference in mental workload between using the two second rule and maintaining a minimum safe headway. Contrary to our hypothesis, there was no main effect of level of licensure, $F(1,41)=.131, p = .719$. Fully licensed drivers and learning drivers did not experience different levels of mental effort, as measured by the NASA-TLX. Furthermore, there was no interaction between headway and level of licensure, $F(1,41)=.024, p = .877$ (see Figure 5).

**Discussion**

The two second rule as outlined by the MTO did not encourage significantly greater headways than those achieved by drivers selecting their own minimum safe headway. While the two second rule is meant to be a means of ensuring that drivers observe ample safety margins, these findings suggest that it may not have an adequate influence on driver behaviour. For example, the fully licensed drivers in the current investigation maintained a mean headway of 1.91 seconds while using the two second rule (see Figure 2). Just as Taieb-Maimon (2007) demonstrated, even when a driver is making a concerted effort to count to a headway of 2 seconds, they fall short (Taieb-Maimon, 2007). This is problematic because 2 seconds is intended to be the very minimum headway that a driver should maintain in order to remain safe. Drivers in the current investigation were motivated to apply the two second rule to the best of their ability but still failed to obtain a 2 second headway. This means that even if a driver was
Figure 2. Headway (s) as a function of verbal instruction and level of licensure. Error bars are ± 1SE.
Figure 3. Standard deviation in headway (s) as a function of verbal instruction and level of licensure. Error bars are ±1SE.
Figure 4. Standard deviation from lateral position (SDLP, cm) as a function of verbal instruction and level of licensure. Error bars are ± 1SE.
Figure 5. NASA-RTLX Scores as a function of verbal instruction and level of licensure. Error bars are ± 1SE.
committed to using the two second rule in their own vehicle, they may inadvertently select a headway that is shorter than their target. However, errors in headway estimation are not the only factor contributing to tailgating. Because the driver learns that they can often follow closely without crashing (Dingus et al., 1997; Michael, Leeming, & Dwyer, 2000), they may not make a conscious effort to maintain safe headways under normal driving conditions. Observational studies have indicated that headways of less than 1 second are commonplace on highways across the U.S. and United Kingdom (Shinar, 2000). This highlights the need for an intervention that gives drivers an understanding of their headway and continually motivates them to adhere to a safe headway as well.

A distinct pattern emerged with respect to the headways that either license group achieved when selecting their perceived minimum safe headway. Learning drivers maintained a mean headway of 2.53 seconds ($SD = 1.18$) while fully licensed drivers maintained a mean headway of 1.53 seconds ($SD = .65$), as shown in Figure 2. This reflects the findings of Duncan et al. (1991) wherein novice drivers preferred to maintain significantly greater headways than both experienced and expert drivers (Duncan et al., 1991). Some have theorized that drivers tend to use headway as a form of safety margin. This theory posits that inexperienced drivers are, at least to some extent, aware of their inability to rapidly respond to hazards and thereby select greater safety margins (van Winsum, 1999). The learning drivers may have felt more comfortable at greater headways than the recommended 2 seconds because they were compensating for their lack of collision avoidance skills (Duncan, 1991). On the other hand, the fully licensed drivers may have been comfortable with short headways having recognized that rapid lead vehicle deceleration is a relatively rare occurrence (Michael et al., 2000). The results of the current experiment also revealed that fully licensed drivers were less variable in their
lateral vehicle control, as well as their headway, compared to learning drivers. As the capacity for steadier vehicle control increases with experience, so too may the driver’s comfort with maintaining shorter headways.

As our driver demographic information reveals, the group of learning drivers was predominantly female while the fully licensed drivers were predominantly male (see Table 1). It is possible that this may have influenced the headways observed in the present experiment. However, it is unlikely that the observed differences in headway between the learning drivers and the fully licensed drivers could be attributed to gender alone. In fact, Taieb-Maimon & Shinar (2001) demonstrated that female drivers maintained shorter headways than men (Taieb-Maimon & Shinar, 2001). This suggests that the overrepresentation of women among the learning drivers in the current experiment may be causing us to underestimate the difference in headway maintenance between fully licensed and learning drivers.

Ultimately, the mean headway that learning drivers achieved while selecting a minimum safe headway was close to the ideal minimum headway. It has been estimated that 90 – 95% of the general population can achieve a 2.5 second brake reaction time under good road surface and visibility conditions (Green, 2000). This suggests that the 2.53 second headway observed by the learning drivers would be conducive to collision avoidance in the event of rapid lead car braking. However, it is important to consider that novice drivers are not as quick, nor as efficient, as experienced drivers in recognizing hazards (Borowsky et al., 2010). In other words, while the learning drivers were not tailgating, that is not to say that they are invulnerable to collisions at a 2.53 second headway. The fully licensed drivers who were selecting their own headway would be pushing the limits of their abilities at 1.53 seconds. Some fully licensed drivers maintained headways as low as .60 seconds. These findings suggest that the headway evaluation system may
be most beneficial to drivers who have emerged from the graduated licensing system. The drivers in the present sample were not highly experienced. The mean length of licensure was 58 months or 4.8 years, including the time they spent in the supervised period of the graduated licensing system. However, this was enough time for driver headway to effectively decrease by an entire second (from 2.53 seconds as a learning driver to 1.53 seconds as a fully licensed driver). This may be further evidence to suggest that headway tends to diminish in absence of feedback. While learning drivers remain safe in the presence of their experienced passenger, fully licensed drivers do not typically receive headway feedback and are vulnerable to the conditioning trap as described by Hutton et al. (2002). Fully licensed drivers may quickly recognize that they can maintain short headways without consequence (Hutton et al., 2002). Furthermore, even the drivers who do crash may fail to attribute their accident to tailgating because they have followed closely without crashing far more frequently (Dingus, 1997; Michael et al., 2000). Providing fully licensed drivers with the headway evaluation system may help to reinstate feedback. This could prevent headway from diminishing after the driver leaves the graduated licensing system and starts to accumulate experience driving independently.

Our second goal was to compare the headways that drivers maintained in the current investigation to those maintained by drivers in studies that involved real-world car following. In line with our hypothesis, our findings were a close reflection of previous investigations on real-world car following. Fully licensed drivers employing the two second rule maintained an average headway of 1.91s (SD = .66). This finding aligned with those of Taieb-Maimon (2007) in which drivers maintained a mean headway of 1.86 seconds (see Figure 6). However, there were slight methodological differences between this study and the present one. In their investigation on headway estimation, Taieb-Maimon trained drivers to use a counting technique that was a close
Figure 6. Mean headway (s): Present study vs. Taieb-Maimon (2007) and Otha (1994). Error bars are ± 1SD. No SD available for Otha (1994).
analogue to the two second rule. Drivers were asked to count aloud from 21 to 30, from 301 to 310, and from 3001 to 3010. While the drivers were counting, they were timed in order to determine how long it took for them to recite specific number sequences (e.g. “21, 22”). Once the investigator had found a sequence of digits that took the driver precisely 2 seconds to recite, the motorist was asked to recite that same sequence between the lead vehicle passing a stationary object and their vehicle arriving at the same object. After training was complete, drivers using this technique maintained a mean headway of 1.86 seconds (Taieb-Maimon, 2007). In the current investigation, Full G drivers asked to maintain a minimum safe headway achieved an average headway of 1.53s (SD = .65). This headway is far greater than those demonstrated by Taieb-Maimon and Shinar (2001) where perceived minimum safe headways ranged between 0.64 and 0.69 seconds when drivers were traveling between 50 and 100 km/h. Methodological differences between Taieb-Maimon and Shinar (2001) and the present investigation may account for this discrepancy.

In the present study, drivers estimated and maintained headway over long stretches of road. Taieb-Maimon and Shinar (2001) asked drivers to hold a minimum safe headway for periods of only 15 seconds, during which time LIDAR was used to sample headway 3 times. As a consequence, the headway recorded in Taieb-Maimon and Shinar (2001) may have been a reflection of the headway that drivers were willing to maintain for short periods of time, not the headway that drivers would maintain for the entire duration of a drive. Van Winsum (1999) indicates that maintaining smaller headways can be mentally demanding but that under certain circumstances, the driver is willing to invest more effort into the task of car following. This includes instances where the driver is attempting to overtake or is under immense time pressure (Van Winsum, 1999). The drivers may have been able to apply the effort necessary to maintain
very short headways for the 15 second measurement period. Had the researchers measured headway over a longer period of time, drivers may have maintained greater and thereby less demanding headways. That being said, the 1.53 second headway that drivers maintained under the minimum safe headway instructions in the current investigation aligned with a previous investigation on comfortable headway. Otha (1994, as cited by Taieb-Maimon & Shinar, 2001) found that drivers who were asked to achieve a comfortable headway maintained a mean headway of 1.4 seconds (see Figure 6). This indicates that drivers in the current study may have selected headways that they believed they could maintain with a reasonable amount of effort for the entire duration of each of the drives. Drivers may have also interpreted the minimum safe headway instructions to mean that they were to maintain the closest headway that felt comfortable to them. Anecdotally, after reciting the instructions for the minimum safe following distance to some drivers, they responded "so I should maintain a comfortable distance?".

Together these findings suggest that the headways that drivers maintained in the Drive Safety DS600c simulator were very close to those maintained by drivers in real world car following experiments. There was little evidence to suggest that drivers were grossly underestimating their headway as they did in Panerai et al.’s (2001) investigation comparing truck following distance in the real world to a truck simulator. One possible explanation for this outcome is the difference in viewpoint or eye height created by the simulator in the current investigation and the one used by Panerai et al. (2001). For their study on speed and safety distance in truck driving, Panerai et al. used a truck cabin on a motion base that put the driver at a high viewpoint relative to the rendered images of the driving environment. Because the visual system uses the height of an object relative to the horizon to infer distance, increasing the height of the viewpoint changes the perception of absolute distance (Panerai et al., 2001). As the height
of the driver’s viewpoint in the simulator increases, the image of the lead vehicle lowers relative to the horizon. This makes the vehicle appear closer in the eyes of the observer, compelling them to adopt a greater following distance (Panerai et al., 2001). The Drive Safety DS600c simulator used for the current investigation employs the body of a family sedan which has a fixed base and thus a fixed height. At the time of setup, the projected images of the driving environment were calibrated to match the ride height of the vehicle. As a result, the driver is able to experience a viewpoint and subsequently a perception of lead car distance that is similar to that which they experience in a real vehicle. Because headway was similar to those exhibited by drivers in real vehicles, there is evidence to suggest that the DS600c would offer a suitable medium for developing and testing a system designed to influence driver headway.

Thus, to summarize, fully licensed drivers applying the two second rule in our simulator achieved an average headway that was similar to those demonstrated in real world car following, as did drivers asked to select their own minimum safe headway. This provides evidence to suggest that the headway evaluation system could be developed and tested in the DS600c driving simulator. These findings also provide further evidence to suggest that when fully licensed motorists are free to select their own headway, they will maintain headways of well below 2 seconds. On the other hand, novice drivers selecting their own headway maintain longer and safer headways that would not be construed as tailgating. While applying the two second rule, fully licensed motorists were able to achieve headways that were close to but slightly short of their 2 second target. This suggests that the counting technique prescribed by the Ontario Ministry of Transportation, among other agencies across North America, can assist motorists in achieving greater headways. However, the two second rule stipulates that 2 seconds is the very minimum headway that a motorist should maintain. Even while making a concerted effort to
achieve a 2 second headway, drivers fell short. Overall, these findings indicate that drivers who have exited the supervised stages of the graduated licensing system stand to gain the most benefit from the proposed headway evaluation system. If the system could encourage fully licensed drivers to exhibit headways that are closer to 2.5 seconds, they would better position themselves to reliably avoid rear-end collisions in the way that learning drivers appear to do.

Experiment 2

Designing and Implementing the headway evaluation system

In our second experiment, the goal was to implement the headway evaluation system in order to present the driver with headway feedback. Previous studies that have incorporated headway into an in-vehicle display have depicted a fixed, recommended headway (e.g. Vashitz, Shinar, & Blum, 2008), or headway warnings such as too close, safe, or too far (e.g. Ho, Reed, & Spence, 2006). This approach can be problematic. Under circumstances where the driver is well aware of the situation and capable of responding, warnings or notifications are no longer useful. When unwarranted, attempts to alert the driver can lead to frustration and distraction that undermine system acceptance (Donmez, Boyle, & Lee, 2007). For example, Young et al. (2004) revealed that drivers were concerned that warning systems would become a distraction in heavy traffic where short headways may be unavoidable. This prospect made some motorists interested in deactivating the system. Furthermore, if the driver only receives warnings at critical moments, they run the risk of misinterpreting the warning, initiating the wrong response, or failing to respond in time (Mendoza, Angelelli, & Lindgren, 2011).

Alternatively, continuous feedback gives the driver the information they need to determine whether their circumstances are dangerous on a moment-to-moment basis. Rather than
allowing the system to make assumptions about the driver or the situation, the driver is free to use their judgment concerning when to access the feedback and how to apply it (Lee, Hoffman, Stoner, Seppelt, & Brown, 2006). Because the feedback is ever-present, the driver has the opportunity to understand how the situation and level of danger are evolving over time (Lee et al., 2006; Mendoza, et al., 2011). This means that they can take appropriate action before critical events arise and avoid incidents altogether (Mendoza et al., 2011). With the headway evaluation system, the aim was to ensure that headway feedback was continuous without being intrusive. This ensures that the driver has the information they need to remain safe but reduces the potential for frustration and system rejection.

Dingus et al. (1997) were the first to provide the driver with continuous headway feedback on an in-vehicle display. In their experiments, participants were asked to follow a lead vehicle driven by a research confederate as they traversed a 40.3 km course laid out on public roads. In the experimental condition, the researchers mounted a display beside the speedometer in the participant’s vehicle to show them their headway in feet. During the baseline condition, the same display served as a redundant speedometer. Compared to baseline performance, this approach did not yield any appreciable changes in headway maintenance. While the drivers were presented with a measure of their exact headway, the headway feedback was meaningless without any indication of which values were safe and which fell within a critical range (Dingus et al., 1997; Peterson, Uhlarik, Raddatz, & Ward, 2003).

In the same series of experiments, Dingus et al. (1997) also presented drivers with symbolic feedback on an in-vehicle display. The researchers tested two different designs. The first used an icon of a car that slid along an illustration of a roadway to represent the proximity of the lead vehicle. The roadway was divided into three coloured headway zones: green (>1.6 s),
amber (1.1-1.6 s), and red (0.9 s). The second used a series of 9 bars divided into the same coloured zones (green, amber, and red). The bars would appear one beneath the other as headway decreased. Both displays were designed to encourage drivers to maintain headways of beyond 2 seconds. During moments in which the driver was following the lead vehicle at a constant rate, only the display that used a moving car icon led to headways that differed significantly from baseline. With the car icon display active, mean headway neared 2 seconds, which was an improvement over the baseline headway of 1.8 seconds (Dingus, McGeHee, Manakkal, Jahns, Carney, & Hankey, 1997). This design may have been the more successful of the two because it featured a high degree of pictorial realism. This means that it presented a close reflection of the spatial relationship between the driver and the lead vehicle as it actually existed (Petersen, 2003). This would have made the display more meaningful to the user. Studies have also shown that providing the user with a spatial analog of the real world is advantageous because it reduces the amount of information that needs to be processed before they can initiate a response (Roscoe, Corl, & Jensen, 1981). In that respect, this layout provides a suitable format in which to present headway feedback. However, the driver only knew which of the three coloured zones they were in and would have had a limited understanding of how close they were to their target of 2 seconds and beyond. Because the driver is trained to consider headway in seconds, and recommended headway is prescribed in seconds, the failure to provide feedback in seconds would have limited the utility of the car icon display. While quantitative feedback alone offered little benefit, it could be paired with symbolic feedback to give drivers a grasp of their true headway and the full extent to which it differs from a safe headway. The result would be headway feedback in a format that is both easily understood and readily applied.
The present design sought to capitalize on the strengths of the symbolic approach as well as continuous feedback by using a symbology that combined qualitative and quantitative feedback along a continuum. To achieve this, we created what we call the Real-Time Headway Gauge. Represented by the vertical bar in Figure 7, this visual component is not unlike a speedometer but for the purpose of monitoring following distance. The gray colored scale with numbers (seconds) along the side remained stationary while the needle slid up and down the scale. At the head of the needle was a box displaying following distance in meters (see Figure 7). Therefore, the gauge always reported (1) following distance in seconds based on the position of the needle along the scale and (2) following distance in meters based on the text displayed in the head of the needle. As the driver's goal was to remain 2 seconds or further from the lead vehicle, the needle was colored green when they were \( \geq 2 \) seconds behind it. If the driver reached a headway of less than 2 seconds, the needle would turn red to signify an unsafe headway (see Figure 7). This symbology was modeled after a gauge that already features the successful mating of qualitative and quantitative information. The real-time gauge is an adaptation of the altimeter that can be found on the Primary Flight Display (PFD) of many modern aircraft (Spence, 2007). This altimeter design allows pilots to quickly assess whether their altitude is safe. It also relays an exact measurement of altitude so that the pilot can remain informed at moments where greater detail is required, such as takeoff and landing (Spence, 2007). The real-time headway gauge was designed to achieve the equivalent result for headway maintenance. It would allow the motorist to quickly assess whether their headway was dangerous by marking the exact position of the vehicle along the scale and by showing the driver the point at which their headway crosses the threshold from safe to unsafe. When this layout is applied to an aircraft altimeter, it allows the operator to assess safety with very short glances of less than 200 ms (Spence, 2007).
Figure 7. A depiction of the Real-Time Headway Gauge on the headway evaluation system. The needle is colored green when headway $\geq 2$ seconds (left) and red when headway $< 2$ seconds (right).
should therefore limit the duration of the off-road glances required to monitor the headway evaluation system. The range of the scale was from 0 seconds to 2.5 seconds. The 2.5 second mark is located near the top of the gauge and the needle could only climb to 3 seconds. This was to convey to the user that while a 2 second headway is recommended by the MTO, 2.5 seconds and beyond is the ideal minimum headway (Wang & Song, 2009). While the scale itself did not display headway above 2.5 seconds, the distance in meters displayed in the head of the needle would continue to rise. This was to ensure that the user could understand how their headway was changing while they were beyond 2.5 seconds. In the event that the driver went beyond 4 seconds, the display read “out of range”, indicating that the driver was not following a lead vehicle and that there was no information to display. The needle position refreshed at a rate of 1Hz.

In addition to real-time feedback, our goal was to present the driver with long-term feedback in order to present them with a form of mentorship. Where real-time feedback was designed to help drivers to understand their headway, long-term feedback was designed to encourage the driver in the way that an experienced passenger does. In Ontario and across much of North America, policy makers have implemented Graduated Licensing Systems (GDLS). Graduated licensing imposes restrictions on new drivers in a bid to minimize their exposure to risk. Some of these restrictions include nighttime driving, blood alcohol level, passengers, and the types of roadway they are allowed to traverse. Most importantly, many systems also require new motorists to be accompanied by an experienced driver during the early stages of licensure. These restrictions are then systematically removed as the driver gains experience (Doherty & Andrey, 1997). Studies have revealed that accident rates remain very low when new drivers are accompanied by an experienced driver. However, there is a substantial increase in accident
involvement when the restrictions are lifted and new motorists are free to drive unsupervised (Mayhew, Simpson, & Pak, 2003). While the exact mechanisms underlying this drastic increase in collision risk are not well understood, a big part of this effect may be that drivers avoid risky behaviours under supervision and that adult passengers help to support the driver by identifying hazards (Lee, 2007).

As experience increases, collision risk gradually diminishes. Compared to the first month of licensure, accident rates drop by up to 60% by the second year of driving (Mayhew et al., 2003). However, in the absence of adequate feedback, drivers tend to exhibit certain risky behaviours more frequently. This includes drivers maintaining smaller headways than they did as novices after gaining independent driving experience (Duncan et al., 1991). More recently, technology has been regarded as a means of keeping all motorists safer. The problem is that automation technology can be insidious as it induces behavioural adaptation and diminished situation awareness (Lee, 2007). In some ways, automation can actually distance people from driving (Lee, 2007) and reduce feedback. While warning system technology theoretically has to potential to reinstate feedback, young motorists are reluctant to accept warning systems and other devices that are perceived to be intrusive. Meschtscherjakov et al. (2009) warn that driving assistance technology is easily mistaken as a critique of driving behaviour (Meschtscherjakov, Wilfinger, Schendl, & Tscheligi, 2009). For those reasons, Lee (2007) asserts that young drivers may be more likely to accept technology if they were to view it as a mentor, rather than as a monitor. He suggests that if implemented carefully, technology can be used to effectively extend the benefits of an adult passenger or to complement the graduated licensing system (Lee, 2007).

The concept of using technology as a mentor for safe driving has not been well explored. However, for a number of years manufacturers have been exploring the use of technology as a
mentor for fuel economization. With fuel prices on the rise, and consumers keen to reduce consumption, manufacturers are outfitting vehicles with integrated displays that allow the driver to monitor their efficiency. In many applications, the driver receives aggregate, positive feedback designed to represent their performance over a greater period of time, such as the duration of a trip. This is designed to reward the driver for their consistency and to reinforce fuel-conscious driving habits. For example, Ford Motor Company created a system called Smart Gauge that presents the driver with bright, green leaves and vines on either side of the speedometer. As efficiency increases, the driver is presented with longer vines and denser leaves (Inbar, Tractinsky, Tsimhoni, & Seder, 2011). This approach is sometimes referred to as gamification.

Gamification is a term that has more recently been used to describe instances where game elements such as are used in a non-gaming context in order to improve the user’s experience and to enhance engagement (Deterding, Sicart, Nacke, O’Hara, & Dixon, 2011). Pavlus (2010) argues that well designed games are a means of encouraging people to address problems that they cannot or simply do not want to engage with, including carbon emissions (Pavlus, 2010). The gamification approach appears to be promising in the realm of fuel economization. There is evidence to suggest that drivers enjoy using feedback devices in hybrid-electric vehicles to play energy conservation games. Drivers are said to compete in order to see who can achieve the best mileage over time (Barkenbus, 2010). Furthermore, Hallihan et al. (2011) found that fuel efficiency feedback leads to real and potentially lasting changes in driving habits. In their investigation, Hallihan and colleagues implemented a mockup of Toyota Motor Corporation’s Hybrid System Indicator (HSI). This is a meter that shows the driver how efficient their driving is on a moment to moment basis. In the presence of this feedback, there were significant changes in the rate at which drivers accelerated (Hallihan, Mayer, Caird, & Milloy, 2011). Because this
approach has the potential to change driving behavior and to promote engagement, our goal was to adapt it so that positive feedback could be used to promote safe driving as opposed to fuel efficient driving.

To create the positive feedback component of the headway evaluation system, we created what we call the Long-Term Headway Gauge. The long-term headway gauge is represented by the horizontal bar in Figure 8. The gauge was broken into six blocks or tokens that the driver could earn. Inspired by fuel economy gauges that allow drivers to accumulate leaves for maintaining efficiency (Meschtscherjakov et al., 2009), this gauge allowed drivers to accumulate green tokens for adhering to a safe headway. The more time a driver spent at a safe headway, the more green tokens they would keep on the display. The more a driver were to tailgate, the greater the number of missing tokens or opaque blocks they would receive. To ensure that changes in the gauge would be visually salient, the elements were overlaid on a black background to enable a high degree of contrast.

While fuel economy feedback devices typically give long-term feedback that represents performance over the course of an entire drive or a number of drives (Meschtscherjakov et al., 2009), drivers in our experiment would only be using the interface for a single session in the simulator. For that reason, drivers needed to receive aggregate feedback that changed more rapidly. This would give them time to learn how the gauge responded to their driving and how to adjust their behaviour in order to consistently earn tokens. To achieve this, we programmed the gauge to give the driver an indication of how they performed during each previous minute of driving. Each of the six tokens represented ten seconds of the previous minute. The tokens scrolled across the screen from right to left with the rightmost token representing the most recent 10 second period. Therefore, this portion of the display refreshed or updated every 10 seconds. If
Figure 8. A depiction of the Long-Term Headway Gauge (top) in addition to the Real-Time Headway Gauge (center).
Figure 9. The states of the Long-Term Headway Gauge. (a) Represents a headway of ≥ 2 seconds for 60 seconds of the previous minute, (b) represents a driver who has just fallen below 2 seconds, (c) < 2 seconds for 10 seconds, (d) < 2 seconds for 20 seconds, (e) < 2 seconds for 30 seconds, (f) < 2 seconds for 40 seconds, (g) < 2 seconds for 50 seconds, (h) < 2 seconds for 60 seconds of the previous minute.
a driver maintained a headway of $\geq 2$ seconds, they would receive a green block for each 10 second period for which they remained beyond 2 seconds. If a driver maintained a headway of $< 2$ seconds, the driver would receive an opaque block for every 10 second period for which they maintained a headway of less than 2 seconds (see Figure 9).

**Hypotheses**

The first goal of the second experiment was to implement the headway evaluation system and to assess the various components of the display. In particular, we were interested in examining whether presenting drivers with a long-term or aggregate representation of their headway, in addition to real-time feedback, would lead to greater headways than providing the driver with real-time feedback alone. Because the learning drivers exhibited safe headways in Experiment 1, and because novice drivers are inclined to maintain longer, safer headways (Duncan et al., 1991), the focus of Experiment 2 was fully licensed drivers. We predicted that headway would be greatest in the presence of the long-term component because it would emulate the feedback that a driver receives from an experienced passenger during the early stages of the graduated licensing system. Based on the findings of Huang et al. (2005) in which truck drivers expressed a desire to receive positive feedback on an in-vehicle display, we also predicted that drivers would report that the headway evaluation system was appealing to use.

We also sought to compare results across Experiment 1 and Experiment 2. This would allow us to compare headway in the presence of the headway evaluation system to the headways that the fully licensed drivers maintained while using verbal instruction. This comparison would also allow us to determine whether using the headway evaluation system had an impact on lateral vehicle control or driver mental workload. We predicted that headway would be greater while
using the headway evaluation system than it was when drivers were using either the two second rule or maintaining a minimum safe headway. We also predicted that the positioning and design of the headway evaluation system would minimize its impact on lateral vehicle control as well as driver mental workload.

Our final goal was to use a questionnaire and a brief, informal interview to assess the extent to which drivers were receptive to using the headway evaluation system (see Appendices C and D). We wanted to tap into whether drivers understood it, whether they though it was useful, and whether they would be likely to continue using it. During the interview, we asked drivers to report on what they liked and/or disliked about the system, with a focus on the long-term gauge in particular. We predicted that unlike warning systems, drivers would report that the headway evaluation system and the long-term gauge in particular were motivating and appealing to use. We also predicted that they would express a willingness to continue using the system.

**Method**

**Participants.** Twenty fully licensed drivers (Ontario Full G or equivalent) were recruited for Experiment 2. All participants were undergraduate students at the University of Guelph who were recruited from the introductory psychology participant pool. Participants received 1 research credit toward their introductory psychology class for taking part in the experiment. Drivers were between the ages of 18 and 23 ($M = 19.5, SD = 1.57$). The group was comprised of 10 female drivers and 10 male drivers with a mean length of licensure of 37.4 months (from the time their learner’s permit was issued). None of the participants developed Simulator Adaptation Syndrome (SAS) and consequently there were no data loss. For a detailed summary of participant characteristics, see Table 2.
Design. Experiment 2 employed a within-subjects design in which drivers experienced two different versions of the headway evaluation system. The first consisted of the real-time headway gauge alone and the second included both the real-time headway gauge and the long-term headway gauge. A within-subjects design was employed for the second experiment because we observed a substantial amount of variance in driver headway in Experiment 1. As Figure 5 reveals, fully licensed drivers using the two second rule in our investigation varied in the headways that they maintained to a far greater extent than drivers did in Taieb-Maimon & Shinar’s (2007) investigation. For that reason, we opted for a within-subjects design in order to limit variance stemming from individual differences in headway maintenance. We wanted to have capacity to isolate any increase in headway, or other changes in driving performance, associated with presenting long-term feedback as an addition to real-time feedback. A within-subjects design would allow us to maximize our power and would vastly improve the chance of observing any differences between each version of the headway evaluation system. The capacity to do so was paramount to this investigation, given that the long-term gauge was the most significant, novel contribution that the headway evaluation system was to offer to the realm of driver safety technology.

We also wanted to compare headway in the presence of the headway evaluation system to verbal headway instruction. From an experimental design perspective, a fully counterbalanced, within-subjects design that included both versions of the headway evaluation system and both types of verbal headway instruction would seem ideal for Experiment 2. However, this approach would have been problematic for a number of reasons. Our concern was that once drivers were exposed to either version of the headway evaluation system, it would introduce a form of demand characteristic that would change the headways they maintained under verbal instruction.
Table 2

*Participant characteristics: Age, length of licensure, daily driving, accident involvement, and gender.*

<table>
<thead>
<tr>
<th>Experience Level</th>
<th>n</th>
<th>Mean Age (SD)</th>
<th>Frequency Men/Women</th>
<th>Mean Months Licensed (SD)</th>
<th>Mean Estimated Km driven per day* (SD)</th>
<th>Accident-Involved Drivers**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully Licensed</td>
<td>20</td>
<td>19.5 (1.57)</td>
<td>10/10</td>
<td>37.45 (17.90)</td>
<td>54.05 (77.11)</td>
<td>7</td>
</tr>
</tbody>
</table>

*Some drivers indicated that they don’t have access to a car every day. Drivers were asked to report how far they drove on a typical day that they do go driving.*

**This figure does not reflect drivers with more than one accident. This figure includes accidents experienced as passenger or driver.*
For example, the headway evaluation system may have caused drivers to reevaluate what they perceived to be a minimum safe headway, having been alerted to the fact that longer headways were considered to be safer. Furthermore, including additional levels for verbal instruction would increase the total driving time considerably. This increase in driving time would heighten the risk of driver boredom, fatigue, and/or simulator adaptation syndrome. For those reasons, we limited Experiment 2 to two levels: (1) real-time feedback paired with long-term feedback and (2) real-time feedback alone. To achieve this, each driver embarked on two drives. For one drive, only the real-time headway gauge was active and for the other drive, the long-term headway gauge appeared in concert with the real-time headway gauge. The sequence in which the drivers experienced the different versions of the headway evaluation system was counterbalanced to control for order effects. Thus, In order to compare the system against verbal instruction, we aimed to compare data across Experiments 1 and 2. This solution would allow us to contrast driving performance with the headway evaluation system against the two second rule and the minimum safe headway, but with one important limitation. Because Experiment 1 employed a between-subjects design, it would not be possible to include Experiment 1 and both levels of Experiment 2 in a single analysis of variance. Only one level of Experiment 2 (one version of the headway evaluation system) would be compared against the verbal instruction in Experiment 1.

Materials and Apparatus. The testing employed the same driving scenarios that were created for the first experiment. Each 20 km scenario was designed to replicate driving through a rural region on a clear day. The straight roadway consisted of one lane in each direction and hosted a low level of oncoming traffic to provide a level of realism. The posted speed limit for the duration of the drives was 80Km/h. In both scenarios, a lead vehicle was programmed to traverse the road course. As in Experiment 1, the lead vehicle set off from a four-way stop and
gradually accelerated to 80Km/h. The speed of the lead vehicle varied between 75 Km/h and 80 Km/h thereafter so that the driver would have to actively regulate their headway. The simulator collected the driver's Time Headway (s) at 60 Hz. The NASA-TLX was employed for this experiment as well. Once again, the raw TLX (RTLX) scores were collected as an index of driver mental workload.

Display Hardware. The headway evaluation system was presented to the driver over a 7” Lilliput LCD display with a native resolution of 640x480 pixels. For details on how the headway evaluation system’s GUI was generated, see Appendices G and H. The display was mounted on an adjustable arm and positioned high up on the center console, to the right of the steering wheel. This was done in order to ensure that it was close to the driver’s normal line of sight (the center of the horizon) without occluding any part of the driving environment (see Figure 10).

Lane-keeping and hazard response performance diminish as the eccentricity or the distance that a driver has to look away from their normal line of sight increases (Summala, 1996; Lamble et al., 1999). This effect occurs because it takes time to execute head and eye movements. It has also been demonstrated that as eccentricity increases, it takes a greater number of saccadic eye movements for the viewer to foveate their target (Frost & Poppel, 1976). Mounting an in-vehicle display in the selected location has been associated with preserved braking response time as well as lateral vehicle control because of its low eccentricity (Lamble, Laakso, & Summala, 1999; Wittmann et al., 2006). Keeping the eccentricity to a minimum limits the potential negative consequences of viewing the headway evaluation system by allowing the driver to make faster transitions between viewing the display and the roadway.
Figure 10. The headway evaluation system mounted in the cab of the DS600c during simulation. A is a depiction of the driver’s normal line of sight, centered on the horizon. B and C are the long-term and real-time gauges, respectively.
**Device Acceptance Questionnaire.** The device acceptance questionnaire included 12 items that were designed to address how the drivers received the headway evaluation system. The drivers were instructed to report the extent to which they agreed with each item or statement on a 7-point Likert scale (1 = Strongly Disagree to 7 = Strongly Agree). The questions were designed to tap into whether drivers found the headway evaluation system to be appealing, whether they understood it, and whether they saw any benefit to using it for training purposes or for continued use (see Appendix D). The script for the post-test interview is included in Appendix E.

**Procedure**

Once participants had arrived at the DRIVE lab, they were asked to read and sign a consent form. Participants were reminded that they were free to withdraw from the study at any time, without being penalized. Once they had expressed their willingness to take part in the study, the simulator adaptation syndrome (SAS) prescreening questionnaire was administered to assess their risk of encountering simulator sickness. Drivers were also presented with a series of questionnaires relating to their normal driving habits, driving experience, and accident involvement.

To allow the drivers to familiarize themselves with the simulator's controls, they were asked to complete a six minute practice drive. During this practice session, the drivers were introduced to the headway evaluation system and both the real-time and long-term components were explained. The drivers were then asked to complete the two 16 minute experimental drives. Both drives were nearly identical except that in one drive, the motorist used the display with both the long-term and the real-time gauges present while in the other drive they only received the real-time gauge. To control for practice effects, the drive order was counterbalanced. During the
experimental drives, the driver was instructed to catch up to then follow the lead vehicle while using the headway evaluation system to maintain a safe headway. The entire simulation session lasted roughly 45 minutes. Following the driving simulation, an informal interview was conducted with the participants to assess how they felt about the headway evaluation system and what they liked or disliked about it. The device acceptance questionnaire and NASA-TLX were administered at that time.

Results

Comparing Real-Time and Long-Term Headway Feedback. Paired samples t-tests were used to compare headway across the two conditions: real-time feedback alone and real-time feedback with accompanying long-term feedback. One case was excluded from the analyses due to missing simulator data output for one of their two drives.

Time Headway. The t-test was non-significant, \( t(18)=.495, p = .627 \). Contrary to our hypothesis, the headway that drivers maintained while using the long-term gauge (\( M = 2.58, SD = .41 \)) was not significantly greater than the headway that they achieved while relying on real-time feedback alone (\( M = 2.64, SD = .48 \)). Including the long-term headway gauge did not make headway longer or safer than it was when drivers were relying on the real-time gauge by itself (see Figure 11).

Standard Deviation in Headway. The t-test was non-significant, \( t(18)=.858, p = .402 \). Standard deviation in driver headway did not differ while using the long-term gauge (\( M = 0.34, SD = 0.17 \)) compared to using the real-time gauge alone (\( M = 0.40, SD = 0.22 \)). This indicates that headway was just as consistent while drivers were using the real-time gauge as it was when they were using the real-time and long-term gauges together.
Figure 11. Mean headway by headway evaluation system display type. Error bars are ± 1SE.
Figure 12. Mean standard deviation from lateral position by headway evaluation system display type. Error bars are ± 1SE.
SDLP. Once again, mean standard deviation from lateral position was less than 1 meter and will therefore be reported in centimeters. A paired samples t-test revealed that there was a marginally significant difference in lateral vehicle control with and without the long-term gauge present, \( t(18)=1.83, p = .084, d = .445 \). In the presence of the long-term headway gauge, SDLP was lower (\( M=18.05, SD= 4.51 \) cm) than it was when only the real-time gauge was present (\( M= 20.63, SD= 6.85 \) cm). In other words, lateral vehicle control was better when the long-term gauge was present (see Figure 12).

Verbal Instruction vs. the headway evaluation system. The following analyses sought to compare the performance of Full G drivers across Experiment 1 and Experiment 2. Experiment 1 employed a between-subjects design (two second rule vs. minimum safe headway) while Experiment 2 employed a within-subject design (real-time gauge vs. real-time gauge and long-term gauge). The reasoning behind comparing headway across experiments was that it would allow us to thwart the potential negative effects (e.g. demand characteristics and participant discomfort) of incorporating verbal instruction and the headway evaluation system into the same within-subjects experiment. However, this precluded the use a single analysis of variance to compare headway across all four levels. Driver headway was slightly lower while using both gauges than it was while using the real-time gauge alone. In other words, drivers performed slightly better while using just the real-time gauge (see Figure 11). Consequently, we chose to take a conservative approach to the analyses by comparing performance with both gauges present against the headways obtained while using verbal headway instruction. The result was a between-subjects design in which the independent variable, headway instruction type, had three levels: headway evaluation system (with both real-time and long-term gauges), two second
rule, and minimum safe headway. A one-way ANOVA was used to examine the effect of headway instruction type and Tukey’s HSD was used to make post-hoc comparisons.

**Time Headway.** The ANOVA revealed a significant effect of headway instruction type, $F(2,40) = 13.57, p = .000$, Partial $\eta^2 = .40$. Post hoc comparisons using Tukeys HSD revealed that headway was significantly greater when motorists were using the headway evaluation system ($M = 2.58, SD = .42$) than it was when they were maintaining a minimum safe headway ($M = 1.53, SD = .65$) or using the two second rule ($M = 1.91, SD = .66$). This indicates that headway was longer and safer while drivers were using the headway evaluation system than it was under verbal headway instruction (see Figure 13).

**Standard Deviation in Headway.** The analysis revealed that there was a marginally significant effect of headway instruction type, $F(2,40) = 2.73, p = .077$, Partial $\eta^2 = .12$. Post hoc comparisons indicated that standard deviation in driver headway was the lowest while using the headway evaluation system ($M = .34, SD = .17$), with the difference between the system and the two second rule ($M = .49, SD = .21$) approaching statistical significance. However, the difference in standard deviation in headway exhibited by those using the system and those maintaining a minimum safe headway ($M = .35, SD = .15$) was not close to significance (see Figure 14). This suggests that headway was most consistent in the presence of the headway evaluation system and least consistent while drivers were using the two second rule.

**SDLP.** The ANOVA revealed that there was no effect of headway instruction type, $F(2,40) = 1.461, p = .244$. There was no difference in lateral vehicle control between drivers using verbal instruction to obtain a safe headway and those using the headway evaluation system (see Figure 15).
Figure 13. Mean headway (s) by instruction type: verbal vs. headway evaluation system. Error bars are ± 1SE.
Figure 14. Standard deviation in headway (s) by instruction type: verbal vs. headway evaluation system. Error bars are ± 1SE.
Figure 15. Mean standard deviation from lateral position (SDLP, cm) by instruction type: verbal vs. headway evaluation system. Error bars are ± 1SE.
Figure 16. Mean mental workload by instruction type: verbal vs. headway evaluation system. Error bars are ± 1SE.
**Mental Workload.** The ANOVA revealed a significant effect of headway instruction type, $F(2,40) = 5.57$, $p = .007$, Partial $\eta^2 = .064$. Post hoc comparisons indicated that mental workload was significantly higher when motorists were using the headway evaluation system ($M = 35.74$, $SD = 15.07$) than it was when they were maintaining a minimum safe headway ($M = 20.71$, $SD = 10.03$) or using the two second rule ($M = 25.03$, $SD = 10.96$). While using the headway evaluation system, the mean workload that drivers reported was nearer to the maximum workload score of 100 than it was after either type of verbal headway instruction (see Figure 16). That being said, mental workload remained in the medium to low range across headway instruction type.

**Discussion**

Including the long-term gauge on the headway evaluation system produced no appreciable benefit over presenting the real-time gauge alone in terms of the time headway that drivers maintained. It is possible that carryover effects limited the opportunity to observe the potential effect of the long-term gauge. For example, drivers who used the real-time gauge first may have simply applied what they had learned about maintaining a safe headway to their subsequent use of the long-term gauge. This effect would have fostered very similar performance across the two display types. However, paring the long-term gauge with the real-time gauge did improve steering performance, as measured by the drivers’ SDLP or the average distance in centimeters that they varied from the center of their lane. In the interviews following the driving simulation, there was one participant who stated that they had learned how to maintain a safe headway based on feedback from the real-time gauge. Thereafter, they were able to rely solely on the long-term gauge in order to assess their performance. As a result, they no longer needed to turn their head as much in order to assess their performance. This suggests that it may have been
easier for the drivers to timeshare steering the vehicle with viewing the headway evaluation system when the long-term gauge was present. The position of the long-term gauge within the display may have contributed this phenomenon. Because the long-term gauge was presented at the top of the LCD display, the eccentricity for that visual element may have been slightly smaller than that of the real-time gauge, which was located in the center of the screen (see Figure 10). Wittmann et al. (2006) tested several in-vehicle display positions that varied in eccentricity. They found that lateral vehicle control was superior when the display was mounted high up the center console, close to the windscreen. This position was closest to the driver’s normal line of sight and the low eccentricity allowed them to use ambient vision to manage lane position while they were viewing the display (Wittmann et al., 2006). In the present experiment, the long-term gauge was located in a similar position and was closer to driver’s normal line of sight than the real-time gauge (see Figure 10). As a consequence, it may have taken less time for drivers to switch between viewing the long-term gauge and viewing the roadway. For those who chose to use the long-term gauge when it was present, having the ability to spend more time viewing the roadway may have facilitated better lateral vehicle control. For some of the more experienced participants, it may have also meant that they were able to use ambient vision to keep the car in the center of their lane during the moments in which they were viewing the headway evaluation system (Wickens, 2002; Wittmann et al., 2006). That being said, it would be beneficial to use an eye tracking device in future investigations. Tracking eye movements while drivers are using the headway evaluation system would allow us to better assess how the system is influencing where drivers are looking and for how long.

When the headway evaluation system presented drivers with both real-time and long-term feedback, drivers achieved a mean headway of 2.58 seconds. Previous investigations have
indicated that we can reasonably expect the general population to achieve a 2.5 second brake reaction time under good driving conditions (Green, 2000). This suggests that a 2.58 s headway would allow the vast majority of motorists enough time to reliably recognize and respond to the braking of a lead vehicle. Furthermore, this headway was larger and safer than those selected by drivers maintaining a minimum safe headway or those attempting to use the 2 second rule. The most substantial difference was the 1.04 second disparity between drivers using the system and drivers maintaining a minimum safe headway. To put this into perspective, a vehicle travelling at a rate of 100 Km/h (the posted speed limit on Ontario’s major highways) covers 27.77 meters every second. This equates to a 29.06 meter difference in headway between the drivers using the headway evaluation system and the drivers selecting their own minimum safe headway. The Toyota Camry, one of the most popular sedans in North America, requires 49.4 meters to arrive at a complete stop from 100 Km/h when fully loaded (NHTSA, 1998). This means that the headway evaluation system effectively added more than half (58.82 %) of the distance required to stop a sedan to the distance maintained by those observing a minimum safe headway. If faced with the rapid deceleration of a lead vehicle, it is reasonable to expect that this additional time and distance would contribute to earlier braking and an increased likelihood of averting a rear-end collision. That being said, the present investigation only examined the efficacy of the device on a rural road with an 80Km/h speed limit. In future investigations, the headway evaluation system should also be tested at different speeds and on different roadways to ensure that the potential benefits of the system generalize to different driving environments.

One potential counterargument is that the headway evaluation system may be increasing driver headway simply because it is a secondary task. In other words, drivers may be selecting longer headways because they are compensating for the potential distraction that the system
creates rather than interpreting and applying the feedback that it generates. Some studies have suggested that drivers try to accommodate for demanding situations such as having a cell phone conversation while driving. To do so, they engage in compensatory behaviours like decreasing their speed (Fuller, McHugh, & Pender, 2008) and increasing their headway (Strayer & Drews, 2004). However, findings vary between studies and further investigation is required to determine whether the demands imposed by the headway evaluation system are influencing driving behaviour. For instance, the headway evaluation system could be compared against a different secondary task (e.g., a cell phone or navigation system) to determine whether or not other secondary tasks increase driver headway to the same extent.

The headway evaluation system itself was designed to be highly interpretable and to require as little time and effort to read as possible. For that reason, we did not anticipate a major increase in mental workload accompanying the use of the system. Nevertheless, the headway evaluation system required drivers to timeshare viewing an in-vehicle display with normal vehicle control. As a consequence, drivers reported a significantly higher workload while using the headway evaluation system than they did while applying either form of verbal headway instruction. Previous investigations have shown that mental workload, as measured by the NASA-TLX, does tend to increase in the presence of an in-vehicle display task (Kim & Son, 2011; Ranney, Mazzae, Garrot, & Barickman, 2001). However, the workload imposed by the headway evaluation system was lower than the workload associated with other common display tasks. The mean workload score when drivers were using the headway evaluation system was 35.7 (SD = 15.07) out of a maximum possible score of 100. This score is lower than the workload ratings previously associated with drivers between 20 and 30 years of age tuning the radio frequency (M = 51, SD = 35) or adjusting climate control settings on an in-vehicle display.
\( M = 52, SD = 30 \), as reported in Kim and Son, 2011. Instead, the observed workload was close to the workload experienced by drivers adjusting the volume control of their radio \( M = 35, SD = 22.5 \), a task that did not require the driver to view a display (Kim & Son, 2011). Furthermore, the results of the current investigation indicated that there was no difference in lateral vehicle control between drivers using the headway evaluation system and those who received verbal headway instruction. While using the headway evaluation system to manage longitudinal vehicle control increased driver effort, this additional workload did not interfere with lateral vehicle control.

**Evaluating Driver Receptiveness to the Headway Evaluation System**

At the end of the experiment, drivers were asked to report on their impressions of the headway evaluation system. To do this, we administered the device acceptance questionnaire which employed a series of 7 point Likert scales (see Appendix D). Chronbach’s alpha was high, indicating strong internal consistency reliability (12 items; \( \alpha = .92 \)). For inter-item correlations, see Appendix F. The device acceptance questionnaire was only administered once after the drives had been completed. This was done in order to limit the possibility of introducing demand characteristics. If the device acceptance questionnaire had been administered between each version of the headway evaluation system, the contents of the questionnaire may have alerted the participants to our hypotheses. As a result, the device acceptance questionnaire represents system acceptance overall, not acceptance specific to the two versions of the headway evaluation system (with and without the long-term gauge).

For the most part, drivers responded favourably to the device. Drivers exhibited the highest level of agreement toward statements addressing the ease with which they were able to
use and interpret the system. Drivers also agreed with statements pertaining to the appeal of the system and the prospect of the device being used for training purposes. However, drivers were less inclined to agree with statements that alluded to the concept of using the device themselves. The statements “I think that this system is helpful to my driving”, “I think that using this system while driving is a good choice” and in particular, “I would continue to use this system while driving in the future” commanded the lowest likert scores (see Table 3).

Post-Experiment Interview. Once drivers had completed the device acceptance questionnaire, they were asked to report in their own words whether or not there was anything that they liked or disliked about the headway evaluation system and whether or not they liked the long-term gauge specifically (see Appendix E). The drivers’ receptiveness to the system was mixed but they generally responded in one of five ways: There were drivers who indicated that they enjoyed using the long-term gauge, drivers who did not use the long-term gauge, drivers who used the long-term gauge but preferred that it was absent, drivers who disliked the long-term gauge, and there was one driver who found the long-term gauge to be a source of confusion.

An appreciable number \(n = 7, 35\%\) of the drivers indicated that they liked the long-term gauge. Among them, there were three motorists who indicated that they preferred to use the long-term gauge over the real-time gauge because it made the display easier to see. They felt that it was less effortful to glance at the display and to view the number of green tokens that they had collected than it was to read the real-time headway gauge. Of particular interest were three motorists who reported that they found the long term gauge to be motivating. One driver reported that they found the green tokens to be compelling and that they had the desire to collect as many green tokens as possible. They also felt that in the presence of the green tokens it was easier to tell how they were performing. Another driver who found the long-term gauge to be motivating
Table 3

*Device Acceptance Questionnaire results: mean, standard deviation, and range of ratings.*

<table>
<thead>
<tr>
<th>Item</th>
<th>Likert Score</th>
<th>Likert Score (SD)</th>
<th>Minimum Score</th>
<th>Maximum Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>I think that this system is helpful to my driving</td>
<td>5</td>
<td>1.21</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>I think that this system can help me to better understand safe driving</td>
<td>5.65</td>
<td>1.18</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>I think that using this system while driving is a good choice</td>
<td>5</td>
<td>1.41</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>I think that the system that was provided is effective</td>
<td>5.6</td>
<td>1.39</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>I think that this system is easy to use</td>
<td>6.4</td>
<td>0.75</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>I think that this system is convenient to use</td>
<td>6.05</td>
<td>0.76</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>I think that this system is easy to understand</td>
<td>6.65</td>
<td>0.59</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>I think that this system is appealing to use</td>
<td>5.35</td>
<td>1.14</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>I think that this system can enhance my safe driving intentions</td>
<td>5.7</td>
<td>1.39</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>I would continue to use this system while driving in the future</td>
<td>4.4</td>
<td>1.34</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>I am willing to use this system to acquire driving skills</td>
<td>5.1</td>
<td>1.50</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>I think that this system provides a good approach to driver training</td>
<td>6.2</td>
<td>1.71</td>
<td>4</td>
<td>7</td>
</tr>
</tbody>
</table>
reported that when it was present, it led them focus on their performance and they tried very hard not to lose any tokens. These motorists responded in a manner that was most consistent with our hypotheses, providing some evidence to suggest that drivers found the long-term gauge to be a form of incentive or motivation for adhering to longer, safer headways.

While there were drivers who liked the long-term gauge, there was an equal portion \((n = 7, 35\%)\) of drivers who reported that they did not use the long-term gauge. One motorist explained that they decided to forgo using the long-term gauge because they found the colour change of the needle on the real-time gauge to be highly communicative. When the needle dropped below 2 seconds and turned from green to red, it immediately signified that they were maintaining an unsafe headway. In their opinion, this signal provided enough feedback to allow them to adhere to a headway that was greater than 2 seconds. There was also a portion \((n = 2, 10\%)\) of drivers who indicated that they used the long-term gauge but that they would prefer to use the headway evaluation system without it. These drivers may have shared a similar experience to the motorist who felt that the real-time gauge provided sufficient feedback on its own. While, the driver who did not understand the long-term gauge did not characterize the source of their confusion, they too may have focused on the real-time gauge from the outset of their drives. As a consequence, they may not have had ample opportunity to observe and comprehend the relationship between their headway and the state of the long-term gauge.

Another subset of the drivers \((n = 3, 15\%)\) reported that they disliked the long-term gauge. Two of the drivers gave similar explanations in which they indicated that it made them feel as though they had “messed up”. They viewed the long-term gauge as something that was capturing and displaying their mistakes rather than rewarding them for their success at maintaining a safe headway. This effect may have occurred because the long-term gauge updated
once every 10 seconds. If a driver’s headway dropped below 2 seconds, the rightmost token would turn opaque up to 10 seconds after the moment at which their headway first dropped below the 2 second mark. The delay between the real-time gauge indicating an unsafe headway and the appearance of the opaque block within the long-term gauge may have caused drivers to feel that they were being reminded of a mistake that had already passed. When planning the long-term gauge, an earlier design called for red blocks to represent periods during which drivers maintained headways of less than 2 seconds. The final design utilized opaque blocks because of the concern that drivers would feel that they were being penalized for poor performance instead of being rewarded for good performance. However, the comments made by the third of the three drivers who disliked the long-term gauge suggest that this approach may not have been sufficient to prevent drivers from feeling negatively about poor performance. The third driver explained that trying to keep as many tokens on the screen as possible turned maintaining a safe headway into a form of competition that added a sense of pressure to their driving experience.

The accounts provided by the motorists who disliked the long-term gauge suggest that there may be room for improvement in the design of the gauge. Instead of a design in which green tokens are withheld when headway is too short, drivers may benefit from an approach where earning is paused when headway becomes unsafe and resumes when it is safe again. For example, drivers could earn points for time spent at safe headways that continuously accumulate on a counter similar to an odometer. If headway became unsafe, the counter could pause so that the driver would stop collecting points but would not lose any points. This approach could help to prevent drivers from feeling that they are being penalized for maintaining short headways. This design could also accommodate situations in which the driver is not at fault for maintaining a short headway (e.g. being cut-off by another vehicle).
Discussion. While the headway evaluation system increased the headways that drivers maintained, not all drivers expressed a willingness to continue using the system in the future. Warning systems can result in longer headways but drivers dislike them and studies suggest that they may simply turn them off (Lee, 2007; Young et al., 2004). The headway evaluation system and the long-term gauge in particular were designed to overcome this problem by creating a system that drivers perceived to be appealing to use. While some drivers did find the headway evaluation system to be appealing, their reluctance to continue using it suggests that much like a warning system, they may deactivate it if it were equipped to their own vehicles.

This finding may be seated in the fact that it is often difficult to compel drivers in this age group to drive with caution. That is because young drivers are highly vulnerable to what is known as the optimism bias. The optimism bias is a phenomenon whereby young motorists uphold the false belief that they are at a lower risk for accident involvement than their peers (White, Cunningham, & Titchener, 2011). Studies have shown that 93% of men and 75% of women rate themselves as more skillful than their peers and that 75% of men and 62% of women rate their accident risk as being lower than that of their peers (DeJoy, 1992 as cited by White et al., 2011). While drivers often understand that their habits can be risky, they do not acknowledge that they themselves are at risk (White et al., 2011). Because of the optimism bias, drivers may have felt that the headway evaluation system was meant to benefit their less skilled and more accident prone peers but not themselves. This theory would account for drivers reporting that the headway evaluation system was a good approach to training but not something that they perceived to be helpful to their personal driving, or something that they would continue to use.

In that respect, the headway evaluation system could have been improved by offering drivers a means of social comparison or a way for them to contrast their performance against that
of their peers. This may help to make them aware of their dangerous behaviour and to offer a more compelling incentive to engage with the system. Michael and colleagues (2000) found that an effective way to reduce speeding on the highway was to communicate to drivers the total portion of drivers who were not speeding the day before (Michael, Leeming & Dwyer, 2000). If drivers using the headway evaluation system had the performance of their peer group as a yardstick, the long-term gauge may have been more persuasive. For example, if the token system of the long-term gauge were replaced with a counter on which points accumulated over time, this value could be posted to a website in order to provide drivers with daily or weekly comparative feedback on their performance. Barkenbus (2010) indicates that drivers use fuel economy feedback devices to engage in a form of social competition to see who can drive the furthest on the least amount of fuel. Some drivers are keen to post this information online and to engage in discussion pertaining to their achievements. Barkenbus also considers the prospect of using social networking sites like MySpace and Facebook to facilitate social competition (Barkenbus, 2010). It is conceivable that safety feedback devices like the headway evaluation system could use social media to provide a similar experience. For example, this could be an experience in which drivers accumulate points toward a score that is then displayed on a leaderboard.

However, any system designed to foster social comparison should be carefully implemented so that only good performance is recognized. This will thwart the possibility of allowing risky drivers to compare themselves against other risky drivers, enabling a competition to be the most daring or reckless driver.

While the headway evaluation system may not promote the continued engagement of young drivers in its current form, it may have utility in situations where accurate headway feedback can be beneficial. For example, under poor visibility conditions such as driving in
dense fog, some studies have shown that drivers tend to follow more closely. Broughton et al. (2006) indicates that this effect is partly because drivers try to view the lead vehicle itself when other visual cues such as the roadway and the scenery are obscured (Broughton, Switzerm & Scott, 2006).

Another potential application for the present version of the headway evaluation system is driver training. In order to ensure that drivers maintain adequate headways, and to make it feasible to legally enforce a minimum headway, Taieb-Maimon recommends compulsory headway training prior to licensing. To facilitate proper training, Taieb-Maimon recommends the installation of headway measuring systems in driving instructor vehicles to ensure that the instructor can provide accurate feedback (Taieb-Maimon, 2007). The real-time headway gauge could provide both driving instructors and trainees with this precise level of feedback. Furthermore, unlike a simple distance measuring system, the headway evaluation system provides time headway relative to the driver’s speed. This eliminates the need for the instructor or the trainee to remember the distances that equate to a two second headway at different speeds.

Conclusions

Rear-end collisions represent a substantial portion of the crashes that occur on our roadways every year (Broughton et al., 2007; Lee et al., 2002). Many of these accidents are thought to stem from drivers maintaining inadequate headways, a common act otherwise known as tailgating (Broughton et al., 2007; Dingus et al., 1997). Verbal instruction is the primary method for teaching motorists to achieve safe following distances. However, drivers are generally poor at estimating their own time headway (Taieb-Maiomon & Shinar, 2001; Taieb-Maimon, 2007). For that reason, we first sought to examine the efficacy of instructing drivers to
maintain a minimum safe headway (Taieb-Maimon & Shinar, 2001) or to employ the two second rule (MTO, 2010). Therein, we demonstrated that learning drivers maintained headways that were well beyond the recommended 2 second headway, particularly when they were free to select what they perceived to be a minimum safe headway. This reflects the tendency for novice drivers to be more comfortable with larger safety margins (Duncan, 1991). When fully licensed drivers were asked to employ the two second rule (MTO, 2010), they displayed a tendency to overestimate their headway, albeit to a lesser extent than they have in previous investigations (Taieb-Maimon & Shinar, 2001). However, when fully licensed drivers were asked to adopt a minimum safe headway, they fell below the recommended headway of 2 seconds and well below the optimal minimum headway of 2.5 seconds. This indicated that fully licensed drivers could benefit from a headway evaluation system designed to encourage safer headways.

We also endeavored to compare the DS600c fixed based driving simulator to previous studies on real world car following in order to assess the extent to which it was a valid platform for developing and testing the headway evaluation system. The headways that drivers maintained in the simulator aligned with previous investigations that have measured driver headway in real vehicles (e.g. Taieb-Maimon & Shinar, 2001; Taieb-Maimon, 2007). Owing in part to the fidelity the DS600c simulator (Kemeny & Panerai, 2003), we found evidence to suggest that it was a suitable test bed for developing a system designed to address driver headway.

Our primary goal was to implement a headway evaluation system on an in-vehicle display. This system was designed to present drivers with real-time and long-term headway feedback with a view to encouraging them to achieve and maintain longer headways. This was undertaken as an alternative to automation which has the potential to undermine driver safety and warning systems which are often undesirable (Lee, 2007; Young et al., 2004). The headway
evaluation system aimed to capitalize on the potential for motorists to allow positive feedback to facilitate safe driving (Huang et al., 2005; Roetting et al., 2003) in the way that the mentorship of an experienced driver does (Lee, 2007; Duncan et al., 1991). The headways that drivers achieved while using the headway evaluation system exceeded those achieved by drivers maintaining a minimum safe headway or the two second rule. Furthermore, the headway evaluation system promoted headways that would allow the vast majority of the population to recognize and respond to rapid lead car deceleration promptly enough to avoid a collision (Wang & Song, 2009). This indicates that when drivers are using the system, it has the potential to mitigate rear-end collisions that stem from inadequate headway. That being said, including long-term feedback did not increase headway over real-time feedback alone. During the interview that followed the driving simulation, some motorists reported that they found the green tokens of the long-term gauge to be motivating. However, there were also motorists who indicated that the real-time gauge was sufficient for them to achieve longer headways.

Overall, the headway evaluation system was well received and there was evidence to suggest that the system was appealing to the drivers. While a substantial portion of drivers agreed that the system would be suitable for training purposes, they were not as receptive to the idea of continuing to use it in the future. This may have been a manifestation of the optimist bias in which young drivers fail to recognize their own susceptibility to collisions (White et al., 2011). In order to encourage engagement, the headway evaluation system may be improved by incorporating opportunities for social comparison in the way that fuel economy feedback devices do (Barkenbus, 2010). Potential applications for the current system include circumstances where accurate headway measurement is vital. This includes driver training where an instructor needs
to deliver precise feedback (Taieb-Maimon, 2007) and poor visibility conditions where the scenery and other cues that convey distance are obscured (Broughton et al., 2006).
References


Funchal: IEEE.


Clayton Vic, Australia.


**NASA Task Load Index**

Hart and Staveland’s NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

<table>
<thead>
<tr>
<th>Name</th>
<th>Task</th>
<th>Date</th>
</tr>
</thead>
</table>

Mental Demand

How mentally demanding was the task?

Very Low | Very High

Physical Demand

How physically demanding was the task?

Very Low | Very High

Temporal Demand

How hurried or rushed was the pace of the task?

Very Low | Very High

Performance

How successful were you in accomplishing what you were asked to do?

Perfect | Failure

Effort

How hard did you have to work to accomplish your level of performance?

Very Low | Very High

Frustration

How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low | Very High
APPENDIX B

In past, some participants have felt uneasy after participating in studies using a simulator. To help identify people who might be prone to this feeling, we would like to ask the following questions.

**PART B. Specific predictors**

1. Do you experience migraine headaches?
   
   Yes No

2. Do you experience claustrophobia (fear of closed in spaces)?
   
   Yes No

3. Do you have a history of motion sickness?
   
   Yes No

   If yes, please describe (where: car, boat, train, airplane) and when (recently vs. when a child):

4. Have you ever experienced dizziness or nausea while watching a movie in a widescreen (e.g. Silver City or Omnimax Theatre)??
   
   Yes No

   If yes, please describe ________

5. Do you experience dizziness or nausea while reading in a moving car?
   
   Yes No

6. Do you prefer to be the driver, compared to the passenger, because otherwise you experience dizziness or nausea?
   
   Yes No
If a participant answers yes to any of these questions, tell them that they may be at higher risk for problems resulting to simulator exposure. In particular, viewing a computer screen may cause eye-strain and eye-strain triggers migraines for some migraine sufferers; the confined space may be a challenge for claustrophobics; people who have had experiences of dizziness or nausea as a result of motion (especially if these are recent experiences) or viewing wide screen movies may experience similar symptoms in a simulator. However, the motion sickness experienced on a boat is much more typical in the population. We are especially worried about people who get carsick or train sick.

**PART C. General Medical history questions.**

1. Do you have heart problems or have you had a heart attack?
   
   Yes No
   
2. Do you experience lingering effects from stroke, tumor, or head trauma?
   
   Yes No
   
3. Do you suffer from epileptic seizures? Describe _____
   
   Yes No
   
3. Do you have any inner ear problems (vertigo)?
   
   Yes No
   
4. Do you have diabetes for which insulin is required?
   
   Yes No
   
5. Do you have problems with low blood sugar (hypoglycemia)?
   
   Yes No
   
6. Are currently taking medications that make you feel extremely nauseated or dizzy?
   
   Yes No
   
If a participant answers yes to any of these questions, indicate that they may be at higher risk for problems resulting to simulator exposure and ask them if they want to continue. If participants answer yes to 2 of these questions, do not permit them to go on into the second phase of the study.
APPENDIX C

Driving History Questionnaire

1. Do you own a car?
   a) Yes  b) No

2. Over the last three months, how many hours per week (on average) did you drive a car?
   _______ Hours

3. On a typical day, how many Km do you drive?
   _______ Km

4. What level of a valid driving license do you have?
   a) G1  b) G2  c) G (Full driver's license)  d) I do not have one

5. At what age did you begin to drive?
   _______ Years Old

6. For how many months (total) have you been driving?
   _______ Months (Try to be specific)

7. When was the last time you drove? (circle one)
   Today  This Week  Two Weeks  This Month  6 Months  1 Year  Beyond
   If beyond, indicate how long ago______________________________

8. Have you ever been in an accident?
   (You do not have to answer if you don't feel comfortable doing so)
   Yes  No

8 i) If yes, were you the driver?
   Yes  No

8 ii) Briefly describe the cause
   ________________________________
Screening and participant characteristics questionnaire
If you are willing to participate, we would like to find out a little about you before we start....

1. Name (please print): __________________________
   Last
   First

2. Sex:   Male   Female

3. When is your date of birth? ________________ (Month / Day / Year)

4. Have you ever been diagnosed with any problems with your eyes or vision?   Yes No
   If yes, what type of eye or vision problems? _______________________________

5. Have you ever been diagnosed with any problems with your ears or hearing?   Yes No
   If yes, what type of ear or hearing problems? ______________________________

6. Have you ever been diagnosed with Attention Deficit Disorder?   Yes No
   If so, are you currently taking any medications?   Yes No
   Which medications? _______________________________

7. Please indicate what sports you participate, or have participated, in.

   Hockey
   How many hours per week? ______________
   How many Years? ___________________________
   
   Soccer
   How many hours per week? ______________
   How many Years? ___________________________
   
   Baseball
   How many hours per week? ______________
   How many Years? ___________________________
   
   Basketball
   How many hours per week? ______________
   How many Years? ___________________________
   
   Gymnastics
   How many hours per week? ______________
   How many Years? ___________________________
   
   Dance
   How many hours per week? ______________
   How many Years? ___________________________
   
   Martial arts
   How many hours per week? ______________
   How many Years? ___________________________
   
   Other (please list)
   _________________________________________
   How many hours per week? ______________
   How many Years? ___________________________

8. Do you play video games? Please list the specific games that you play.
   _________________________________________
   How many hours per week do you play video games? ______________
   How many Years? ___________________________

9. Is there anything else that you think may be useful for us to know about you? If so, please tell us in the space below. _________________________________________
Device Acceptance Questionnaire

Please indicate the degree to which you agree or disagree with the following statements:

1) I think that this system is helpful to my driving.
   1  2  3  4  5  6  7
   1= Strongly Disagree  7 = Strongly Agree

2) I think that this system can help me to better understand safe driving.
   1  2  3  4  5  6  7
   1= Strongly Disagree  7 = Strongly Agree

3) I think that using this system while driving is a good choice
   1  2  3  4  5  6  7
   1= Strongly Disagree  7 = Strongly Agree

4) I think that the system that was provided is effective.
   1  2  3  4  5  6  7
   1= Strongly Disagree  7 = Strongly Agree
5) I think that this system is easy to use.

1 2 3 4 5 6 7

1 = Strongly Disagree 7 = Strongly Agree

6) I think that this system is convenient to use.

1 2 3 4 5 6 7

1 = Strongly Disagree 7 = Strongly Agree

7) I think that this system is easy to understand.

1 2 3 4 5 6 7

1 = Strongly Disagree 7 = Strongly Agree

8) I think that this system is appealing to use

1 2 3 4 5 6 7

1 = Strongly Disagree 7 = Strongly Agree

9) I think that this system can enhance my safe driving intentions.

1 2 3 4 5 6 7

1 = Strongly Disagree 7 = Strongly Agree

10) I would continue to use this system while driving in the future.

1 2 3 4 5 6 7

1 = Strongly Disagree 7 = Strongly Agree
11) I am willing to use this system to acquire driving skills.

1  2  3  4  5  6  7

1 = Strongly Disagree  7 = Strongly Agree

12) I think that this system provides a good approach to driver training.

1  2  3  4  5  6  7

1 = Strongly Disagree  7 = Strongly Agree
Device Acceptance Interview Questions

Note: These questions are to follow the device acceptance questionnaire

1) I’d just like to ask you about a few things that we didn’t cover in the device acceptance questionnaire. More generally, was there anything that you like or disliked about the system?

2) Is there anything that you would do differently?

If the participant hasn’t already mentioned the long-term gauge, ask the following question:

3) Was there anything that you liked or disliked about the green blocks at the top of the display?
### APPENDIX F

**Means, standard deviations, and inter-item correlations for device acceptance questionnaire.**

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<th>Questions</th>
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<th>$SD$</th>
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<th>9</th>
<th>10</th>
<th>11</th>
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<td>1. Helpful</td>
<td>4.95</td>
<td>1.22</td>
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<tr>
<td>2. Understand Safety</td>
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<td>1.17</td>
<td>.49*</td>
<td>-</td>
<td></td>
<td></td>
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<td>3. Good Choice</td>
<td>5.11</td>
<td>1.37</td>
<td>.53*</td>
<td>.69**</td>
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<td>4. Effective</td>
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<td>.58**</td>
<td>.71**</td>
<td>.79**</td>
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<td>5. Easy to Use</td>
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<td>7. Easy Understand</td>
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<td>.59</td>
<td>.20</td>
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<td>8. Appealing</td>
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<td>.74**</td>
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<td>9. Safe Intentions</td>
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<td>1.38</td>
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<td>.71**</td>
<td>.73**</td>
<td>.77**</td>
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<td>10. Use Future</td>
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<td>.85**</td>
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</tr>
<tr>
<td>11. Acquire Skills</td>
<td>5.11</td>
<td>1.76</td>
<td>.54*</td>
<td>.67**</td>
<td>.59**</td>
<td>.65**</td>
<td>.47*</td>
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<td>.64**</td>
<td>.86**</td>
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</tr>
<tr>
<td>12. Good Training</td>
<td>6.16</td>
<td>.96</td>
<td>.48*</td>
<td>.61**</td>
<td>.37</td>
<td>.49*</td>
<td>.29</td>
<td>.21</td>
<td>.49*</td>
<td>.45</td>
<td>.71**</td>
<td>.59**</td>
<td>.65**</td>
<td>-</td>
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</table>

*p<.05, **p<.001
HOW TO RUN THE DISPLAY GUI

Setting up the hardware

1. Plug the Display Computer into the router.
2. Plug the Authoring Computer into the router.

That’s it!

Setting up the software

The Authoring Computer
Open up a command prompt on the Authoring Computer. You can do this by going to Start -> Run and typing “cmd”, as below.

In this window, type “ipconfig” and hit enter.

This should show you two IPv4 addresses for this computer; one on the Local Area Network, and one on the Simulator Network.

Open the HyperDrive software and load the project. Edit the init script. Check that the IP address in this script matches the one on the Simulator Network in the command prompt (and make sure you’re not reading the Local Area Network IPv4 address, which will be different). I believe that these IP addresses are static, so this shouldn’t ever be a problem. If you do have to change the IP address, make sure that you save the project.
The Display Computer
Go ahead and open a command prompt on the Display Computer as well. Once again, type “ipconfig” to check that it has acquired an IPv4 address from the router. You can test this computer’s connection with the Authoring Computer by typing the command:

```
C:\Users\tom\>ping 192.168.1.6
```

but replace 192.168.1.6 with the IP address for the Local Area Network on the Authoring Computer. The results should look something like below.

```
Pinging google.ca [74.125.226.83] with 32 bytes of data:
Reply from 74.125.226.83: bytes=32 time=19ms TTL=56
Reply from 74.125.226.83: bytes=32 time=13ms TTL=56
Reply from 74.125.226.83: bytes=32 time=12ms TTL=56
Reply from 74.125.226.83: bytes=32 time=12ms TTL=56
Ping statistics for 74.125.226.83:
   Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
   Approximate round trip times in milli-seconds:
     Minimum = 12ms, Maximum = 19ms, Average = 14ms
```

If there is no connection, it will say something like “Request timed out” or “Destination host unreachable”, like in the screenshot below.

```
Pinging 192.168.1.6 with 32 bytes of data:
Reply from 192.168.1.4: Destination host unreachable.
Reply from 192.168.1.4: Destination host unreachable.
Reply from 192.168.1.4: Destination host unreachable.
Reply from 192.168.1.4: Destination host unreachable.
Ping statistics for 192.168.1.6:
   Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
```

If this happens then it’s likely just a loose connection, so make sure that all of the cables are plugged in properly. If that doesn’t help, try restarting the computers.

Running the software

Step 1: Starting the Connection Agent
In the command prompt on the Authoring Computer, browse to the directory where SockCOMM.jar is found.

In case you’re rusty with your DOS commands:

- `dir` — display the contents of the directory
- `cd` — change the directory (see example below), note that “cd ..” moves back one folder and “cd Desktop” changes to the Desktop folder
To make this easier, you can use Windows Explorer to find the correct path to SockCOMM first, and then use the cd command to get there in the command prompt. That saves having to do the exploring in DOS.

Once you're in the directory with SockCOMM.jar, use the following command to launch it:

```
C:sers\tom\desktop>java -jar SockCOMM.jar
```

This will launch the Connection Agent window. The advantage to running the program through the command prompt is that it will print out status and error messages that would otherwise be unavailable, which may be helpful in troubleshooting in the event of a problem.

Alternatively, you can just double-click on the SockCOMM icon using Windows Explorer, but then you miss out on the status and error messages.

**Step 2: Running the simulation**

Once the Connection Agent is running, you can run the simulation from the Dashboard. If you did have to change the IP address in the project's init script, make sure that you have loaded the latest version into Dashboard. Otherwise, there should be no problems with this step.

**Step 3: Connecting the Display**

On the Display Computer, use the command prompt to browse to the directory containing the DisplayGUI.jar file. Run the program using the following command:

```
C:sers\tom\java -jar DisplayGUI.jar
```

Once again, you can run this program by double-clicking the icon in Windows Explorer, but you'll miss out on some status and error messages.

Select the options you'd like for this simulation using the checkboxes, and then click the Connect to Simulator button. After clicking this button a prompt will appear asking for the IP address and port of the connection agent.
Enter the IP address of the Connection Agent and the port, separated by a colon. These values should be displayed on the Connection Agent itself. You want to connect to the port number associated with the DISPLAY.

**IP address of this Connection Agent is: 192.168.1.4 (heartofgold)**

**SIMULATOR: connected on port 35000**

**DISPLAY: connection open on port 10997**

After you click OK the screen should refresh and the gauges should be displayed.

That’s all!

**NOTE:** It is important that the steps be followed in this order, as the programs will likely encounter connection problems otherwise.
How the headway evaluation system Interfaces with the DS600c Simulator

Written by Tom Hall, the programmer of the headway evaluation system.