Effects of a Feedback-Reward System on Speeding and Tailgating Behaviours

by

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Abstract

This thesis investigates the effect of a feedback-reward system on speeding and tailgating behaviours. Data utilized in this study were collected from 37 participants (20 to 70 years old) through a field trial commissioned by Transport Canada. In this field trial, a feedback-reward system was investigated, which provided feedback and rewards to the drivers based on speed limit compliance and safe headway maintenance. The trial consisted of three phases: baseline (two weeks), intervention (twelve weeks), and post-intervention (two weeks). During the intervention phase, real-time feedback was provided on an in-vehicle display. Participants also accumulated reward points and could view related information on a special website.

Mixed linear models were built to investigate effects of the intervention. Results indicate that the feedback-reward system resulted in a significant increase in speed limit compliance, and this positive effect, although dampened, was still apparent after system removal. Further, when considering cases with no lead vehicle ahead, the positive effect persisted for high speed limit zones. Similarly, results on headway compliance rate indicate a positive intervention effect, however, this effect did not sustain after system removal.

In addition, a cluster analysis performed on the naturalistic driving data recorded during the baseline phase revealed two groups of drivers: lower risk and higher risk drivers. The results indicate that higher risk drivers benefitted more from the system.

These findings have implications for developing better aids to improve driving behaviour.

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Chapter 1

1 Introduction

Traffic crashes result in approximately 1.2 million deaths every year [1]. They also constitute the leading cause of death among people between the ages of 15 and 19, and are the second leading cause of death for 10 to 14 and 20 to 24 year olds [2].

Crashes occur for a variety of reasons. Human error is estimated to be the sole cause in 57% of all traffic crashes and a contributing factor in over 90% of them [3]. Inappropriate speed choice, gap acceptance decisions, close following distances, and improper visual scanning behaviours have been identified to increase crash risks [4-9]. These hazardous behaviours may stem from conscious choices resulting from risk taking tendencies (e.g., sensation seeking, willingness to engage in distracting activities) and/or from an inability to assess roadway demands due to factors such as inexperience in driving or perceptual/cognitive saturation. Therefore, modifying drivers' attitudes toward risky driving and encouraging safer behaviour can have a positive effect on road safety. In addition, aiding drivers to assess roadway demands can also have a positive effect on driver behaviour. One approach stemming from these perspectives is to use technologies to monitor driver actions and provide drivers with feedback [10].

A wide range of countermeasures are in effect such as law enforcement, variable message signs (VMS), educational messages, driver education programs, and engineering solutions such as speed bumps and roundabouts. Each countermeasure may help drivers to correct their behaviour. However, effects of such countermeasures usually attenuate over time and may even disappear after countermeasures become unavailable. For example, Wrapson, Harre, and Murrell [11] showed that the number of drivers who speed will decrease when the drivers see their own speed on a variable message sign or at least, the average speed of traffic. The speed reduction did not persist after the signs were removed, suggesting that drivers reduced their speed only while under surveillance. Similarly, traffic advisory information regarding adverse weather conditions can reduce speeds but the reduction will not persist if the information is no longer provided [12]. These studies indicate the importance of understanding whether the immediate effects of feedback will persist when the feedback is no longer available.

Further, many countermeasures are dependent on the environment, are not tailored to the behaviour of the individual driver, and may be absent in some situations. For example, previous studies suggest that traffic information and advice offered via variable message signs can affect drivers' route choice decisions and improve system performance under real-time traffic operations. According to Albrecht et al. [13], between 5 to 80% of drivers divert their routes based on information and route advice they receive via VMS. A major contributor to this variability is that unlike an in-vehicle navigation system, the information displayed through these signs is generic information (e.g., location of a crash, expected delay, and detour strategies) and is not personalized. According to a survey conducted by Peeta et al. [14], the response attitudes of truck and non-truck drivers to the route advice provided via a VMS were significantly different. Results indicated that being familiar with the alternate route is significantly important for truck drivers in route diversion decisions. Wardman et al. [15] also reported that the effectiveness of VMS can be highly dependent on driver characteristics or their network knowledge.

Emerging technology can circumvent the limits of current countermeasures. The safety advantages of advanced driver assistance systems (ADAS) such as intelligent speed adaptation (ISA) and adaptive cruise control (ACC) have been reported in many studies [16-19]. However, although unknown, it is of concern that these systems may also have negative consequences. For example, although adaptive cruise control can help drivers maintain both safe speed and headway time [16, 20], it might also result in a vigilance decrement. There is considerable evidence that automation can significantly decrease operator's mental workload and improve performance [21]. However, in some situations, this workload reduction can lead to an undesired level of mental underload [22]. Mental underload is at least as detrimental to performance as overload [22-24], and needs to be considered in the design of driver assistance systems [25]. Young et al. [22] described this performance degradation in their malleable attentional resources theory (MART), suggesting that when mental workload decreases, the attentional resources available to the driver will also temporarily diminish. Thus, there is less capacity to observe relevant cues in the environment which might result in a degraded performance. Over-reliance on the system is another potential negative consequence [26] of advanced driver assistance systems.

Intelligent Speed Adaptation Systems are another example of advanced driver assistance. These systems can be classified according to their level of automation ranging from advisory systems to intervening systems. Advisory systems simply warn drivers through auditory, visual, or haptic signals. In contrast, intervening systems take a certain degree of vehicle control over from the driver. The interventions can go as far as strictly preventing drivers from exceeding the speed limit. There is sufficient evidence to suggest that these devices can effectively reduce speeding [17-19, 27]; however, there is evidence that this positive effect may attenuate over time [28]. One possible reason for this attenuation is habituation, which is a decrease in the strength of the tendency to respond to stimuli that have become familiar due to repeated exposure [29]. For example, drivers may become habituated to in-vehicle signals and may start ignoring them more easily with increased levels of exposure. Another possible reason is the lack of follow-up programs that can keep the drivers interested in receiving feedback [30]. Toledo et al. [30] conducted a field study to monitor drivers, and investigated the effects of a web-based feedback system. The feedback included information on each driver's driving behaviour (e.g., extent and duration the driver exceeds pre-set speeds, exposure measure statistics such as the distance and time traveled by the driver, and trip-level risk index) as well as the same information averaged over all other study participants. This feedback system initially received high levels of attention; however, the number of log-ins decreased as time progressed. In addition to follow-up programs, Warner et al. [31] suggests that economic incentives can also result in a more sustained improvement with such feedback systems.

In this thesis, the short and long term effects of a dynamic feedback system, similar to ACC and ISA, in enhancing speed compliance and promoting safe headway times are studied. Further, the effect of economic incentives as an external motivation for behavioural modification is evaluated. Data utilized in this study were collected through an on-road field trial commissioned by Transport Canada, and were provided to us in kind. In this trial, named the SafeMiles Trial, 41 participant vehicles were instrumented with an in-vehicle display, a forward-looking radar unit, a radio link using a GSM (a wireless data system) – GPRS (General Packet Radio System) network, a TCP/IP connection to a remote host PC-web server, and a client connection to the remote host PC-web server to access data and manage the system's parameters. The trial was conducted in Winnipeg, MB, in 2009 [32, 33] and consisted of three phases: baseline (two weeks), intervention (twelve weeks), and post-intervention (two weeks). During the intervention phase, real-time visual feedback on speed and headway time was provided on an in-vehicle display. Participants also accumulated reward points and could view their driving summary and information on accumulated points on a special website.

A similar feedback-reward system was initially designed and evaluated in the Netherlands, via a quasi-controlled on-road experiment, the Belonitor Trial [34]. In both trials, percentage of kilometers covered at a safe speed and at a safe headway time improved during the intervention stage compared to the baseline [32, 34]. The SafeMiles Trial [32, 33] also revealed that speed compliance rates during the post-intervention stage were higher than they were in the baseline, suggesting a persistent effect of intervention on speeding, which appeared to be smaller than the effect observed when intervention was actually present. On the other hand, according to the results of both trials most drivers did not maintain the positive effect on their headway time when the intervention was no longer provided.

This thesis investigates whether this feedback-reward system assists the drivers in maintaining safe speeds and headway times and whether the positive effects, if there is any, sustain after intervention removal. Some descriptive statistics on speed and headway compliance rates were reported for both the Belonitor and SafeMiles Trials [32, 34]. In general, previous publications considered speed and headway compliance only as a binary variable, i.e., compliance vs. noncompliance. Compliance rate has a ceiling (i.e., %100), therefore, it may not be able to capture all relevant aspects of a behavioural change as well as measures of degree of noncompliance (e.g., amount of speeding when noncompliant). Further, the presence of a lead vehicle was not accounted for in the speeding analysis. Thus , in this thesis, in addition to the speed and headway compliance rates, the degree of speeding during noncompliant episodes both for the entire dataset as well as for data with no lead vehicle present, and actual values of headway time adopted by drivers during different phases of the trials for both compliance and non-compliance instances were investigated. Moreover, cluster analysis was conducted to find natural groupings among drivers and evaluate the effect of intervention on these different groups. The clustering was based on naturalistic driving data recorded during the baseline period.

The thesis includes five chapters. Chapter 1 provides background on speeding and tailgating behaviours. Further, the traditional countermeasures which aim to curtail these risky driving behaviours as well as the new approaches that are based on driver monitoring are discussed.

Chapter 2 presents the methodology used by Transport Canada to conduct the on-road experiment. The data analyses and the results are presented in Chapter 3. Chapter 4 summarizes and discusses the results, and contributions to the field, followed by suggestions for future research in Chapter 5.

1.1 Speeding

Speeding is a risky driving behaviour, which has been shown to be the number one road safety problem in many countries [35]. In legal terms, speeding is defined as exceeding the posted speed limit (PSL) or driving too fast for existing conditions. Speeding played a role in about 31% of all fatal crashes in 2007 [36], and was reported as a contributing factor in approximately 25% of fatalities and 20% of injuries in Canada [37]. A comprehensive analysis conducted on approximately 2,000 fatal crashes revealed that speed was a causal factor in 8% of crashes, and a possible cause of an additional 15% [38]. The results of the 100-car naturalistic driving study provide further support that speeding is a serious safety matter [28, 39]. In this naturalistic study, 109 vehicles were instrumented, and several parameters including vehicle speed, acceleration, and forward time to collision were collected for 12 to 13 months. The extent to which risky behaviours were associated with crashes, near crashes, or incidents were determined using odds ratios [40]. The results revealed that driving at an inappropriate speed was associated with approximately triple the odds of involvement in a crash or a near-crash, compared to driving at an appropriate speed (OR= 2.9, 95% CI= 1.7- 4.8). Inappropriate speed was defined as either speeding (exceeding the speed limit by 10 mph or more, or speeding in relation to current driving conditions) or driving slowly (below the speed limit by 10 mph or more, or in relation to other traffic).

Several studies have investigated the relationship between speed and relative risk of crash involvement. For example, Kloeden et al. [5] found that the risk of involvement in a fatal crash doubles with each 5 km/h increase in travelling speed above 60 km/h. One possible reason for the increase in speed leading to an increase in crash risk is the relation between the required reaction distance and vehicle speed. When a driver faces an emergency or a road feature that might require rapid response, a collection of actions including mental processing to identify the event and movement to perform the required response must be taken. The time taken to complete all these steps is known as the reaction time, and the reaction distance is the distance travelled by the vehicle during this amount of time. At higher speeds the reaction distance of the vehicle is larger, leaving less space for manoeuvring to avoid a crash.

Speeding also has been found to be a significant factor affecting crash injury severities. Moore et al. [41] reported a strong relationship between speed and serious head injuries or fatalities. Further, Kloeden et al. [42] reported that for speeds higher than 45 km/h, the injury risk increases exponentially. This finding can be explained by laws of physics which express the relationship between speed and kinetic energy, $E = \frac{1}{2} mv^2$, where E is energy, m is mass, and v is velocity [43]. According to this formula, the kinetic energy of a vehicle during the crash is a function of the square of the speed of the vehicle. Therefore, small changes in speed correspond to large changes in crash energy. In addition, a certain level of increase in speed will have a greater effect on kinetic energy in higher speeds (e.g., from 40 km/h to 50 km/h) than lower speeds (e.g., from 30 km/h to 40 km/h).

Overall, there is sufficient evidence to suggest that speeding is a key factor in a substantial portion of crashes and road traffic injuries; however, speeding appears to be a socially acceptable behaviour [44] and the prevalence of speeding remains high. This misalignment between driver's beliefs and behaviours is addressed in several studies. According to the results of a survey conducted in 2004 by the Australian Transport Safety Bureau, 59% of respondents cited speeding as one of the three main causal factors in crashes, and 39% named it as the primary contributing factor [45]. Similarly, analysis of self-reported data collected over 320 drivers indicated that although about two thirds of participants agreed that speeding is a risky behaviour and it is not safe to exceed the speed limit, more than half of the participants, i.e., 58.4%, preferred to exceed the 100 km/h speed limit [44]. Further, results of a study on driver attitudes on speeding and speed management in Canada indicated that about 70% of Canadian drivers admit to speeding at least occasionally [46]. In this self-reported study, the average degree of speeding on highways was estimated to be 12 km/h over the posted speed limit, and 10 km/h and 7 km/h on two lane highways/country roads and residential streets, respectively.

Speeding is a complex behaviour and drivers speed for a variety of reasons. According to McKenna [47], drivers who had been caught speeding tend to be feeling under time pressure, or having emotional reasons (thrill or anger). Drivers may also speed under the influence of other people, including role models, family, friends, and passengers who speed or have a favourable attitude towards speeding [48, 49]. In addition to these factors, drivers may also speed inadvertently. They might fail to realize at which speed they are travelling and engage in unintended speeding. According to the results of a survey conducted by Transport Canada, 51% of drivers who admitted to speeding at least occasionally, declared that in general they did not pay attention to the speed at which they were driving [46].

Perceptual speed adaptation is another reason for unintended speeding. For sudden changes in speed, drivers' perception of the new speed depends on whether their new speed is greater or less than the speed that they previously adapted to. Drivers who have been driving at a high speed may become habituated and overestimate the degree to which they are lowering their speed, i.e., their perceived speed change is greater than the actual change as in highway hypnosis. This underestimation of perceived speed has a direct proportional relation to the time spent at the previously adopted higher speed level [50, 51].

In sum, there is sufficient evidence suggesting that despite the growing awareness about speeding as being a road safety issue, speeding remains common among many drivers. Therefore, developing an effective method to address this issue can significantly benefit road safety.

1.2 Tailgating

Another human behaviour of concern which contributes to a major proportion of road crashes is tailgating. The main type of crash that results from tailgating is the rear-end crash. Rear-end crashes are one of the most commonly observed crash type. In Canada, rear-end crashes constituted approximately 25% of all crashes in 2008 [52]. Similarly, in the U.S., National Highway Traffic Safety Administration (NHTSA) reported that approximately 30% of all crashes are rear-end crashes [53]. For instance, 30.4% of all police-reported U.S. crashes during 2006-2008 were rear-end crashes, resulting in more than 2,200 deaths and approximately half a million injuries each year [54]. Driver inattention and following a lead vehicle too closely have been found as the two primary causal factors associated with rear-end crashes [39, 55-57]. In particular, Hendricks et al. [58] estimated that inattention, short headway distance, and improper look out contributed to 23% of the 723 U.S. crashes they examined. Although there is some evidence suggesting that inattention is a greater contributing factor for this type of crash [28, 56], short headway time is found to be the major causal factor associated with a fatal consequence [59].

According to police reports in the Netherlands, following too closely is one of the top ten causes of crashes, and it is a causal factor in 40% of all freeway crashes [60]. Further, Knipling et al. [56] reported that headway that is too short to react appropriately to a lead vehicle's sudden braking was the primary cause in 7% and contributing factor in 19% of the rear-end crashes they examined. Short headways can also accentuate the formation of traffic waves, which can then result in crashes [60]. Evans et al. [61] also studied the relation between crash involvement and headway, and reported that drivers who were previously involved in a crash were more likely to maintain shorter headways than drivers without a crash record.

According to Evans [62], drivers tend to maintain short headway times for three potential reasons. First, drivers may believe that a sudden deceleration by a lead vehicle occurs rarely. Second, they may expect a lead vehicle to maintain a constant speed, and assume that there is no risk of collision as long as they match the speed of the lead vehicle. And finally, their past experiences may reinforce that driving at a short headway is fairly safe. Other researchers have suggested another potential reason for adopting an unsafe headway: the inability of drivers to make an accurate estimation of headway [63-65].

Headway between two successive vehicles can be defined in terms of distance or time. The distance headway is the bumper to bumper distance between the lead and the following vehicles. The headway time is the distance headway divided by the speed of the following vehicle, and represents the time it would take for the following vehicle to reach to the current position of the lead vehicle. Distance headway is a function of speed and increases with speed. In contrast, headway time is independent of vehicle speed. Therefore, providing a single headway instruction in terms of seconds rather than meters can act as a more efficient way to teach safe headway maintenance [64, 65]. In most licensing manuals, headway time of 2 seconds or more is defined as the safe headway time (e.g., Ontario Drivers' Handbook, 2007), and the guideline to reach this safe headway is to count "21, 22" from the moment the lead vehicle passes a stationary object up to the time the driver reaches the same object. However, in real driving situations, drivers maintain shorter headways. Analyses of observational data in the United States indicate that headway times of 1 seconds or less are more typical than headway times of 2 seconds or more

[61, 65, 66]. According to Song et al. [67], during rush hours, more than 60% of drivers maintain a headway time of less than 2 seconds.

Drivers generally make poor estimates of headway in both time and distance. Headway time estimation errors of 20% to 42% are reported in previous studies [68-70]. The results from the analyses of a field trial data revealed that all participants tended to greatly overestimate headway times, and 80% underestimated the distance headway [65]. In this study, the closest headway that the drivers believed they could drive safely was self-reported to be 2.1 seconds on the average, when it was actually 0.66 seconds. Even worse, the overestimation increased with increasing speeds. The self-reported minimum safe headway ranged from 1.93 seconds at 50 km/h to 2.61 seconds at 100 km/h speed limit zones while the observed headway stayed fairly constant across different speed limits.

Headway overestimation can be explained by two possible reasons. First, Taieb-Maimon et al. [65] showed that when drivers use the counting technique to estimate the headway time, they usually count faster than they should have. Second, although drivers are taught that a headway time of 2 seconds or more is safe, they usually do not estimate the headway time explicitly, and maintain a headway that they perceive as safe.

Given that drivers are unable to estimate headway time or distance accurately and that current countermeasures and training techniques seem to be inadequate, technological devices which provide feedback to drivers based on unsafe headways can potentially improve headway compliance.

1.3 Countermeasures for Addressing Speeding and Tailgating Behaviours

A wide range of countermeasures are in effect to limit speeding and tailgating behaviours. In general, these countermeasures fall into three main approaches commonly referred to as the three E’s: Engineering, Enforcement, and Education.

The engineering approach typically involves physical measures and changes to the roadway infrastructure to alter driver’s behaviour. The traditional engineering methods which are used to limit speeding fall into three categories: traffic control devices (e.g., stop signs and speed limit signs), traffic calming devices (e.g., speed humps, rumble strips, and roundabouts), and roadway markings (e.g., transverse markings and crosswalks). Previous studies indicated that these methods in general have an impact on reducing driving speed and subsequently the amount of crashes. For example, it has been shown that small roundabouts were an effective countermeasure to reduce speeding [71, 72]. Van Minnen [72] reported that roundabouts reduce total number of crashes by about 50% and the number of casualties by 80%. In addition, speed humps are commonly used in many countries and have been shown to have a positive impact [73]. However, speed humps have also become a concern in the area of emergency transportation. According to emergency response agencies and community groups, speed humps can result in an increase in the amount of time for an emergency vehicle to respond to calls, and also influence passenger comfort [74-76]. In order to address this concern, two modified design of speed humps have been introduced, namely speed slots and speed cushions. Similar to speed humps, speed slots and speed cushions are raised areas across the road. However, they are designed with a separation in the hump to allow emergency response vehicles to avoid the hump. Although the passenger discomfort was significantly reduced with these solutions, these designs were not as effective as speed humps in reducing speeds. For example Layfield et al. [77] reported that 55% of all cars and 90% of all buses in their study attempted to avoid the speed cushions by centrally straddling the device. Further, according to Pau [78], speed humps might contribute to risky and improper driving behaviours, such as moving in the park or opposite lane to avoid the humps.

Engineering solutions are also applied to reduce tailgating behaviour. Given that drivers are unable to correctly estimate headway, devices such as regularly-spaced markings (dots or chevrons) are introduced to help drivers in headway estimation. For example, if the dots are 25 meters apart, the driver can maintain 50 meters ahead by driving such that two dots are visible at all times. According to Minnesota Department of Transportation, these markings increased average headway time from 2.32 to 2.52 seconds [79]. However, in general, there is limited evidence on the effects of markings on crash reduction. Further, for lower speed traffic, such road markings would be too distantly spaced and may result in traffic congestion [80].

Advisory and warning signs are also effective countermeasures used to improve tailgating behaviour. Helliar-Symons [81] conducted a field trial at Ascot, England, and examined the effect of a roadside warning sign on tailgating behaviour. In this study, the inter-vehicle gap was measured, and a warning sign was illuminated if the gap was less than a pre-set level. The results revealed that the proportion of drivers adopting headway times that are less than 1 second decreased by about 30%. In another study, Michael et al. [82] evaluated a hand-held sign which advised the drivers to not tailgate. The sign was held by an assistant who stood on the sidewalk facing the oncoming traffic. According to the results, the intervention was effective only when the consequence of tailgating was implied in the message (e.g., “help prevent crashes, please don’t tailgate” rather than “please don’t tailgate”), and it increased the average headway time from 2.11 seconds to 2.29 seconds. These studies in general did not examine the long term effects of the advisory/warning signs, and the crash reduction associated with the intervention.

In general, although many of these physical measures and traffic calming approaches are effective in improving road safety and reducing risky behaviours, they are financially expensive. The cost can include project expenses, from implementation to maintenance, as well as liability claims. Further, some drivers may become frustrated and confused upon encountering unfamiliar engineering solutions, although the frustration may gradually decrease with increased familiarity with the devices [83].

The second traditional countermeasure for addressing speeding and tailgating behaviours is enforcement. Two main methods of speed enforcement are physical policing and automated speed enforcement. Physical policing uses manned observation and apprehension units which are randomised in time and location over the road network. In the second method, speed offenders are detected using speed cameras which can be at fixed locations (fixed cameras) or can be rotated over different locations (mobile cameras). Previous studies which evaluated the safety effects of speed enforcement suggest that enforcement in general affects driving speed and decreases speeding-related crashes [84, 85]. A review of the literature indicates that automated speed enforcement contributed to a 2-15% reduction in the magnitude of speed and a 9-50% reduction in crashes [85]. One issue for using stationary enforcement is that the observed effect is often local and short lived. This phenomenon is referred to as the “halo effect” by Shinar [43], and means that the effect can be found during a given period of time and/or at a certain distance from the spot where the speed enforcement is carried out. One possible solution to overcome the halo effect is to increase the sense of uncertainty by using non-visible and mobile automated enforcement. However, according to Rodier et al. [85], automated enforcement programs might violate constitutional rights and protections, such as the right of privacy. The admissibility of photo evidence is another issue for automated enforcement. Sometimes it is also necessary to collect a statement from a witness who testifies that the picture is an accurate description of what has happened, which may not be practical in many cases[86].

Enforcement is also applied for tailgating. Given that short headways contribute to rear-end crashes, a minimum following headway required by law is introduced in several countries. Two commonly recommended safe headway times are 2 and 3 seconds. For example in Canada, the Driver's Handbook describes 2 seconds or more as a reasonably safe headway. According to the European Transport Safety Council [87], the recommended headways inside and outside urban areas are 2 and 3 seconds, respectively. Further, headway time less than 1 second is considered as illegal in many countries. For example, according to Taieb-Maimon et al. [88], in Israel, drivers receive tickets for headway times less than 1 second. Although there is some evidence that enforcement can affect driver's tailgaiting behaviour, it is almost never applied by police officers except when a crash occurs. According to Micheal et al. [82], officers will routinely cite following too closely only if it can be identified as readily as speeding or driving under the influence. At this time, there is no objective method for identifying "following too closely" that can be used to provide convincing evidence in a court of law. Decision about the appropriate headway time, based on which the driver could be penalised, is another issue that needs careful consideration. For example, although 2 seconds or more are known as safe headway times, penalising the drivers who do not comply with the 2-seconds rule is not appropriate since such headways are extremely common and almost every driver could be penalised. On the other hand, choice of shorter headway times, e.g., 1 second, as criterion for an offence might provide the impression that some short headway times, e.g., 1.1 seconds, are acceptable and safe, which is not necessarily correct. Another difficulty for using enforcement as a countermeasure is staffing, as it is not always economically feasible to enlarge the police force.

Public information and education programs are the third approach used to reduce speeding and tailgating behaviours, which aim to inform drivers on new safety programs as well as the importance of driving slowly and maintaining safe headways. Public information programs are typically referred to as mass media programs, while education programs involve direct, face-to-face contact with a specific audience. Such programs have been used extensively in the highway safety field; however, it has been reported that they have limited success when they are not combined with other prevention programs such as enforcement [89, 90]. According to Williams et al. [89], education can particularly be effective when it is used to promote "new knowledge".

In general, a wide range of traditional approaches such as enforcement, traffic control devices, roadway markings, educational messages, and driver educational programs have been used to curtail hazardous driving behaviours. Although many of these countermeasures can help drivers correct their behaviour, they are dependent on the environment, are not tailored to the behaviour of the individual drivers, and their effects usually attenuate over time and/or when countermeasures are not present. Emerging technology can circumvent the limits of current countermeasures, and may provide effective means by which to alert drivers about unsafe behaviours. In the following section, some of these driver assistance devices are discussed.

1.4 Feedback/Warning Systems

A number of short-term on-road and simulation studies have been conducted in recent years to examine the effect of various in-vehicle monitoring systems and feedback/warning devices. For example, Toledo et al. [30] conducted a field study using an In-Vehicle Driver Recorder (IVDR) system to monitor drivers, and investigated the effect of off-line feedback on driving behaviour. The experiment included two phases. The first phase involved collecting data with no feedback. Drivers were aware of the installed system; however, they were not informed about the nature of the devices or their purpose. In the second phase, drivers learned about the characteristics of the system. In addition, the drivers received access codes to a personal webpage, through which they could see information on their own driving behaviours as well as the same information averaged over all other study participants. According to the results of this study, the awareness of being monitored had a significant positive effect on behaviour, and the improvement enhanced after drivers were provided with the feedback (i.e., they logged in the webpages). However, the positive effects did not sustained as time progressed and the number of webpage log-ins decreased significantly over time, suggesting that providing only off-line feedback without follow-up activities may not be sufficient.

In another study, Brookhuis et al. [17] examined the effect of an Intelligent Speed Adaptation system on drivers' speeding behaviour. ISA is a type of an Advanced Driver Assistance System which aims to help drivers adapt their speeds according to the posted speed limit. ISA systems can be classified according to their level of automation, ranging from advisory systems, which simply warn drivers through auditory, visual, or haptic signals, to intervening systems, which exert some level of control over the vehicle. The interventions can go as far as strictly preventing drivers from exceeding the speed limit. The study conducted by Brookhuis et al. [17] tested an advisory system which provided visual and auditory feedback. The visual feedback was graded: green indicated speed limit compliance, yellow warned that the speed limit was exceeded, and red was illuminated when the speed limit was exceeded by more than 10%. Further, an auditory feedback accompanied the red light onset indicating a definite violation status. Overall, the system decreased the average speed by 4 km/h. Further, the amount of time during which the drivers drove 10% over the speed limit significantly decreased.

The Swedish large-scale field trial is one of the most comprehensive ISA studies. This trial was conducted by the Swedish National Road Administration (SNRA) from 1999 to 2002, in four Swedish municipalities [18]. Three different ISA systems were examined in the study: advisory ISA (tested in Umea, Sweden), which provided both audio and visual warning signals when the posted speed limit was exceeded; informative ISA (tested in Borlange and Lidkoping, Sweden), which informed the driver about the posted speed limit in addition to the audio and visual warnings; and active accelerator pedal (tested in Lund and Lidkoping, Sweden), which applied a counter pressure to the accelerator pedal when above the speed limit, resulting in the driver having to press the pedal three to five times harder than normal. About 5,000 vehicles participated in the study and the study design was essentially the same at the four trial sites. Baseline driving and subjective data were recorded within one month before the system activation. The ISA system was then activated for eighteen months. During this eighteen-month trial phase, driving data were collected for only a total of two months. The first month of data collection (i.e., the first post-activation period) started approximately after the first month following system activation. The second month of data collection (i.e., the second post-activation period) was performed at the eighteenth month. For all three system models, the rate of speed violations observed during the first post-activation period was significantly lower than that observed during the baseline period. This reduction ranged from 10-20% across different systems and speed limit zones, and it was estimated that traffic injuries could be reduced by 20-30% if an ISA system were installed in all vehicles. This positive effect was still apparent during the second post-activation period, however, it diminished. One possible reason for this diminishing effect is habituation. According to classical conditioning, habituation is a decrease in the strength of the tendency to respond to stimuli that have become familiar due to repeated exposure [29]. After repeated exposure to the visual and auditory signals, the drivers in this

Swedish study might have become habituated and been able to ignore the signals easily. Warner et al. [31] suggested that besides habituation, another possible reason for drivers' tendency to ignore the warning signals can be a technical problem which occurred during the study and decreased the reliability of the systems. The authors also suggested that other measures such as economic incentives can result in a more sustained improvement.

Similarly, following distance warning systems are used to limit tailgating behaviour and aid drivers to avoid rear-end crashes. The effectiveness of these systems to aid drivers in maintaining safe following distances have been examined in several studies. For example, Ben-Yaacov et al. [64] studied the effect of an auditory warning on following distance. The study included an on-road experiment divided into four phases: before, during, immediately after, and six months after exposure to the system. The phases spanned between 20 and 70 kilometers (about 15 and 50 minutes). After exposure to the system, the amount of time drivers spent at the danger zone, defined as headway time ≤ 0.8 seconds, significantly decreased from 22.8% to 3.5%. Further, the positive effect, although dampened, was still apparent after system removal, and there was no significant difference between the two follow-up phases (i.e., immediately after and six months after exposure).

Shinar et al. [91] conducted an on-road experiment to evaluate a 3-week exposure to a real-time feedback system, and found that average headway time and amount of time spent within the defined safe headway time significantly increased during the exposure phase. Feedback consisted of a visual (a warning light turned on for headway time ≤ 1.2 seconds) and an auditory component (a buzzer turned on for headway time ≤ 0.8 seconds). The results demonstrated a 25% decrease in the amount of time drivers maintained headway time below 0.8 seconds, and a 14% increase in the amount of time drivers maintained headway time above 1.2 seconds. The pattern of results was similar across different speed limit zones. These results supported that headway feedback can improve tailgating behaviour; however, long-term effects of the system was not addressed. In a third study conducted by Regan et al. [27], the following distance warning system decreased the proportion of time drivers maintained headways below 0.8 seconds from 6% to 1%; however, this reduction was not significant. In addition to these three studies which revealed potential for following distance warning systems, further studies and development are needed before such systems can be implemented at large scale. For example, receiving warnings when another vehicle cuts in front of the driver may result in frustration and the system designers need to consider such nuisance alarms.

1.5 Economic Incentives

One approach to increase drivers' motivation to adapt their driving behaviour according to feedback is to utilize incentives. Incentives can significantly influence behaviour [92, 93], and rewarding desirable behaviours is usually more effective than penalizing undesirable behaviours [94]. Rewarding can result in lasting behavioural modification, however, penalizing changes behaviour only temporarily and needs to be applied consistently in order to maintain its effect. Further, penalizing might also induce a negative behaviour[95].

There are various studies which have used incentive-based strategies to motivate behavioural changes. For example, it has been reported that positive incentives can significantly increase seat belt use; however, this effect usually maintains for only a few weeks [96-98]. In a study of 95 drivers, Hultkrantz et al. [99] examined the interaction of economic incentives with the effectiveness of an ISA system. The incentive included a bonus for safe driving and a charge for speed violations. This study lasted for two months. A high or low monthly initial bonus (500 or 200 Swedish Krona, SEK) was assigned to drivers randomly, and a reduction ranging from 0 to 2 SEK was applied for each minute the driver exceeded the posted speed limit. The penalty increased with the degree of speeding, and drivers were assigned randomly to no, low, or high penalty groups. The reduction in bonus for the high penalty group was twice as much as that for the low penalty group. The results revealed that speed violations significantly decreased by about 7-10% during the experiment. During the first month of the experiment, no significant difference was found between the penalty and the no penalty groups. However, during the second month, the proportion of time drivers exceeded more than 10% over the speed limit was significantly lower for drivers who were penalized. It was also reported that during the second month the speed violation reduction for drivers who were assigned to the lower bonus group was greater than that for drivers who received more bonus. This difference was significant at 80%. According to Hultkrantz et al. [99], drivers with the high bonus to begin with may have realized that their behaviour had a very small impact on their monthly net payment.

Harms et al. [100] also investigated the effect of an ISA system in combination with economic incentives on speeding behaviour. In this study, the incentive was the potential of receiving a

30% discount on car insurance, and the ISA system included both visual and auditory feedback. The visual feedback was displayed through an on-board unit and informed drivers about the current speed limit. When a driver exceeded the speed limit more than 5 km/h for more than 6 seconds, an auditory warning was provided. If the driver continued to speed, the warning was repeated at each 6th second. If the signal was activated for the third time in a row, a penalty point was applied. Each penalty point reduced the 30% insurance discount by 7 cents. The study included four treatment groups: ISA only, incentive only, ISA and incentive, and the control group. The speeding behaviour improved significantly for all three treatment groups compared to the control group, and this effect was apparent during the 12 months of system exposure. Moreover, it was reported that the reduction of speeding in two groups that received visual and auditory warnings was significantly more than the group which only received the incentive.

Overall, the potential to be rewarded financially is a viable external motivation for improving driving behaviour. According to Hultkrantz et al. [99] and Harms et al. [99, 100], the combination of an advisory system and incentives can significantly decrease speeding behaviour. However, neither study investigated the long term effects of such an intervention on driver's behaviour.

Chapter 2

2 Methodology

Data utilized in this study were collected through the SafeMiles project. SafeMiles is a field operational trial, commissioned by Transport Canada and conducted by G.W. Taylor Consulting, in Winnipeg, MB, over a four-month period from mid-August to mid-November in 2009. This trial was similar to a field trial conducted in the Netherlands in 2005, the Belonitor Trial [34]. In the current field trial, a feedback- reward system was evaluated to investigate the effect of rewards in combination with feedback on driving behaviour. The system financially rewarded the drivers based on safe headway maintenance and speed limit compliance. These criteria were measured continuously through the use of GPS/GIS, a forward-looking radar unit, and an on-board computer. The trial consisted of three phases: baseline (two weeks), intervention (twelve weeks), and post-intervention (two weeks). During the intervention phase, real-time feedback was provided on an in-vehicle display. Participants also accumulated reward points and could view related information on a special website.

2.1 Participants

Thirty-seven participants (20 males and 17 females) across four age groups 20-29 (n= 9), 30-39 (n=7), 40-49 (n= 9), and 50+ (n= 12) completed the study. Participants were recruited through direct marketing, media announcement, and the Center for Sustainable Transportation website. They had to be at least 20-years old, hold a valid class five driver's license (i.e., fully licensed), consider themselves as the primary driver of their vehicle, and drive at least 300 km per week. In addition, the participant’s vehicle had to be gasoline fuelled and have a model year of at least 1996. Forty-one drivers were originally recruited for the study; however, data from four drivers were excluded from the analysis due to reasons such as stolen equipment and poor GPS reception.

2.2 Apparatus

Participant vehicles were instrumented with an in-vehicle device, a forward-looking radar unit (Figure 1a), a radio link using a GSM (a wireless data system) – GPRS (General Packet Radio System) network, a TCP/IP connection to a remote host PC-web server, and a client connection to the remote host PC-web server to access data and manage the system's parameters. The in-vehicle device included an integrated display (Figure 1b), an on-board diagnostics interface (OBDII), and an internal GPS device that included posted speed limit information. The vehicle diagnostic information was accessed instantaneously using data gained from the vehicle's OBDII interface, and was transferred through a GSM-GPRS modem to a backend office system. The in-vehicle display included symbols for compliance in speed, compliance in headway time, compliance in both (total compliance), and operational status information on GPS signal lock, GSM-GPRS network availability, radar unit, and memory card (Figures 1b, 2). Data were collected at 1 Hz.

(a)

(b)

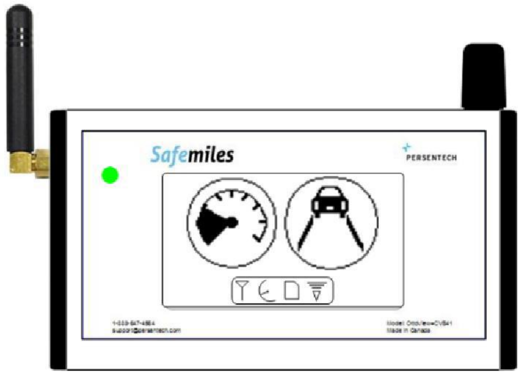
Figure 1. (a) Radar installation in enclosure, (b) in-vehicle display

2.3 Procedure

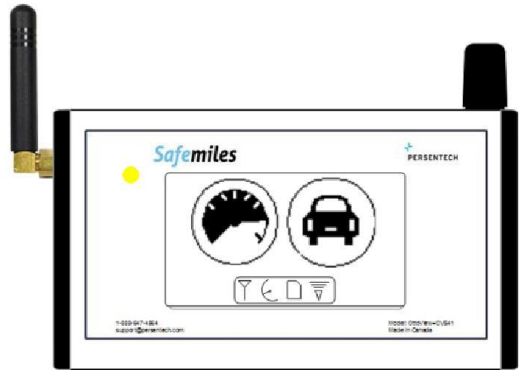
The feedback-reward system provided feedback and rewarded participants based on safe headway maintenance (headway time > 1.2 s) as well as driver's compliance with speed limits (GPS based speed ≤ posted speed limit + 2 km/h). The threshold for safe headway time used in the Belonitor Trial [34] was 1.3 seconds as it was recommended by Griffioen-Young et al. [101]; however, the participants complained about other drivers cutting in front of them. Thus, the headway time threshold was set to 1.2 seconds in the SafeMiles Trial.

These two metrics were monitored continuously, and compliance status was then visually provided to the driver through an indicator light on the in-vehicle display as well as graphical symbols indicating speed and headway compliance status separately. When the drivers were both speed and headway compliant, a green LED light was illuminated (Figure 2a), which turned to yellow when the drivers were not compliant in either speed, or headway, or both (Figure 2b). A speedometer symbol was used to indicate speed compliance: there were two realizations of this symbol as demonstrated in Figures 2a (compliant) and 2b (noncompliant). Similarly, there were two realizations of the headway compliance symbol: a distant lead vehicle icon for compliance (Figure 2a) and a closer lead vehicle icon for noncompliance (Figure 2b).

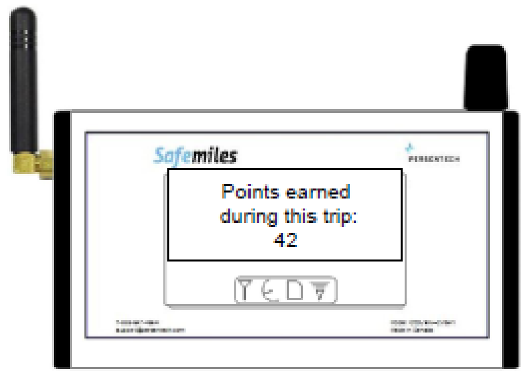
A compliance point was obtained when both speed and headway were compliant for 15 seconds. If there was no vehicle in front (beyond the range of the radar - 120 meters), only speed limit compliance was assessed. The points obtained during a trip were presented to the driver on the in-vehicle display when the vehicle was stopped for more than 5 seconds or when the engine was turned off (Figure 2c). The driving summary and information on accumulated points were provided to the participants on a website. Rewards were the only compensation provided to the drivers for participating in the experiment and could be claimed as gift cards for a variety of goods and services such as consumer electronics and resort packages. During the intervention phase, two reward redemption weeks were defined: the first week of September and the first week of October. Further, participants could redeem the balance of their accounts at the end of the intervention period. Overall, the average value of reward per participant was $307, ranging from $25 to $935.



(a)



(b)



(c)

Figure 2. In-vehicle display: (a) the green light (top left corner) indicated a total compliant status, (b) the yellow light (top left corner) indicated that at least one of the criteria was not met, (c) the points displayed at the end of trip

In general, the objective of the SafeMiles Trial was to create a replicate of the Belonitor Trial which included four weeks of pre- and post-intervention phases and a 14 week intervention phase. However, due to concerns of mid-winter effects on the post-intervention phase, the SafeMiles Trial periods were shortened:

1. Baseline phase of two weeks:

The baseline phase was conducted from August 3 to 16, 2009. This phase involved collecting baseline data with no compliance feedback or rewards. The participants were only provided with status operational icons (Figure 3).

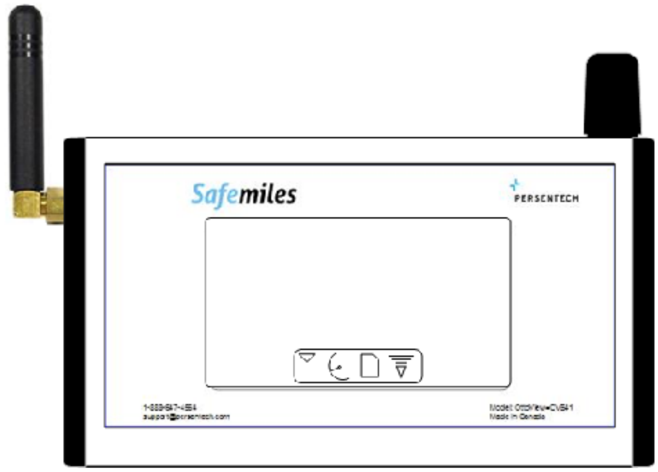


Figure 3. In-vehicle display during the baseline phase

2. Intervention phase of 12 weeks:

The intervention phase started on August 17 and continued to November 9, 2009. During this 12-week intervention phase, feedback-reward system and the website were initialized, and participants received feedback on their speeding and car following behaviour (Figure 2). As mentioned previously, during this phase, there were two reward redemption weeks: the first week of September and the first week of October. In addition, the drivers could redeem the remaining balance in their accounts at the end of the intervention period.

3. Post-intervention phase of two weeks:

The post-intervention phase was from November 9 to 22, 2009. During these two weeks, the feedback-reward system and the website were deactivated and the participants did not earn any points; however, monitoring of data continued. Similar to the baseline phase, the participants were provided with the display showing the status icons (Figure 3).

In addition to the driving data, subjective data including self-reported demographic information as well as attitudes about driving in general, and about speeding and following too closely in particular were collected through four on-line questionnaires (Appendix A). The questionnaires were filled out online at the following times:

1. Solicitation: general questions about the participant’s vehicle, vehicle use, and demographic questions.

2. After the baseline phase: questions on driving attitudes and the installation process.

3. After the intervention phase: driving attitude questions and opinions on experience with the SafeMiles display.

4. After the post-intervention phase: driving attitudes and opinions on the SafeMiles experience, and acceptance of the system.

Chapter 3

3 Data Analysis and Results

In order to investigate the short and long term effects of the feedback-reward system on speeding and tailgating behaviours, mixed linear models were built on the SafeMiles data. Moreover, average linkage hierarchical clustering was used to further understand individual differences and to explore natural groupings among drivers.

A mixed linear model is a statistical model which contains both fixed and random effects, and can handle correlated observations[102]. Various variance covariance structures can be fitted in the mixed linear model framework and the best fit can be selected using goodness of fit criteria such as the Bayesian Information Criterion (BIC) [103]. For parameter estimation Restricted Maximum Likelihood (REML) was used. Restricted Maximum Likelihood is a variant of Maximum Likelihood (ML), and produces efficient estimators for unbalanced designs where the groups formed by the factors are not necessarily equal in size. For large samples REML and ML estimations are the same, however, for smaller ones REML is less biased [102].

As mentioned previously, some descriptive statistics on speed and headway compliance rates were reported for both the Belonitor and SafeMiles Trials. However, previous publications considered speed and headway compliance only as a binary variable, i.e., compliance vs. noncompliance, and the presence of a lead vehicle was not accounted for in the speeding analysis. This chapter is divided into four sections: speeding behaviour, tailgating behaviour, cluster analysis, and questionnaires. In these sections, the speed and headway compliance rates, the degree of speeding during noncompliant episodes both for the entire dataset as well as for data with no lead vehicle present, and actual values of headway time adopted by drivers during different phases of the trials for both compliance and non-compliance instances are reported. Moreover, cluster analysis was conducted to find natural groupings among drivers and evaluate the effect of the intervention on these different groups. The clustering was based on naturalistic driving data recorded during the baseline period.

3.1 Speeding Behaviour

3.1.1 Statistical Model

Mixed linear models (PROC MIXED statement in SAS 9.2) were built to investigate if and how intervention affected speeding behaviour. Speeding behaviour was operationalized as speed compliance rate and degree of speeding during instances when drivers were not within the safe speed criterion (GPS based speed ≤ PSL + 2 km/h). In addition to the intervention, the models statistically controlled for other factors, namely age, gender, and speed limit zone. To control for the traffic flow effect, models were built on the entire dataset as well as on the subset of the data with no lead vehicle present. No lead vehicle presence was defined as situations when the radar did not detect a lead vehicle in less than 120 meters ahead.

Data for 30 km/h speed limit zones were excluded from the analysis due to insufficient number of observations. In all analyses, driving time within each combination of experimental phase (baseline, intervention, post-intervention) and speed limit zone (50, 60, 70, 80, 90, 100 km/h) was considered as a covariate to control for exposure to different speed limits and experimental phases. Generally, the analyses were conducted at the experimental phase level or at a weekly level of aggregation.

Before analysis, the dependent variables were aggregated to the level of phase and speed limit interaction. Thus, each driver could have up to 18 observations (3 study phases x 6 speed limits) adding up to 666 total number of observations (18 observations per driver x 37 drivers). Note that some drivers were not observed to drive in certain speed limit-phase combinations. Further, additional analyses were conducted to assess time effects on the dependent variables. For these analyses, the independent variables were speed limit zone and time. Aggregation of dependent variables was done accordingly.

For all analyses, appropriate variance covariance structures were selected based on the Bayesian Information Criterion (BIC) [103]. Moreover, assumptions of normality and homogeneity of variance were examined through residual plots (histograms, normal probability plots, plots of residuals versus predicted values and versus explanatory variables) as well as normality and homogeneity of variance tests. Further, multicollinearity among the explanatory variables was examined through variance inflation factors and tolerance. When necessary, transformations were applied to correct for problems of non normality and heteroskedasticity.

In the following sections, boxplots are provided to convey the reader the shape of the distributions. These plots present the range (minimum and maximum), the first and the third quartiles, the median, the mean, and the potential outliers. An observation which fell 1.5 times the interquartile range away from the first and third quartiles was identified as a potential outlier. The inter quartile range corresponds to the difference between the 75th percentile (third quartile) and the 25th percentile (first quartile).

3.1.2 Speed Limit Compliance

Speed limit compliance rate was defined as the ratio of the compliant time (GPS based speed ≤ PSL + 2 km/h) over the total time spent driving within each experimental phase and speed limit combination. This rate was compared across age, gender, and posted speed limit for the three study phases. Total driving time within each experimental phase – speed limit combination was considered as a covariate to control for exposure to different speed limits and experimental phases. All predictors and their two-way interactions were entered in the model and the final model parameters were determined through backward selection.

3.1.2.1 *Entire Data*

In general, speed compliance rate was significantly affected by phase ($F(2, 72)=27.54$, $p<.0001$) and speed limit ($F(5, 159)=5.10$, $p=.0002$). However, gender, driving time, and their interactions with other predictor variables were not significant ($p>.05$) (Table 1). In particular, after exposure to the intervention, the speed compliance rate significantly increased by an estimated 10.5% (95% CI: 7.67, 13.4), from 85.1% to 95.6%. Although this rate dropped to 91.7% during the post intervention phase, it was still significantly higher than that during the baseline (Figure 4, Table 2). The interaction between driver's age and speed limit was also significant ($F(15,159)=1.87$, $p=.03$). In particular, the 40s age group was less speed compliant than all other age groups in 90 km/h speed limit zones (40s vs. 20s: $t(159)= -3.45$, $p=.0007$; 40s vs. 30s: $t(159)= -3.42$, $p=.0008$; 40s vs. 50+: $t(159)= -7.54$, $p<.0001$) (Figure 5).

Table 1. Speed compliance rate: mixed linear model results over the entire dataset

Explanatory variable	Num df	Den df	F value	p-value
Phase	2	72	27.54	<.0001*
Speed limit	5	159	5.10	<.0002*
Gender	1	32	1.79	.19
Age group	3	32	1.20	<.33
Driving time	1	541	.95	.33
Phase x Speed limit	10	311	1.08	.38
Age group x Speed limit	15	159	1.87	.03*
Gender x Speed limit	5	159	1.07	.38

*Significant at p<.05

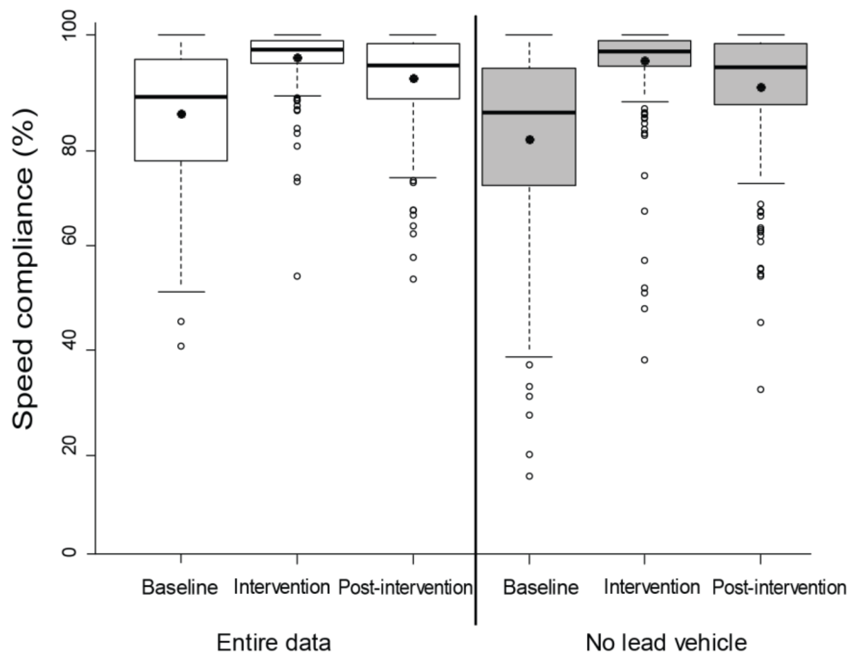


Figure 4. Speed limit compliance rate across three experimental phases for the entire data as well as for cases during which there was no lead vehicle

Table 2. Pair-wise comparisons of speed limit compliance rates between experimental phases; the entire dataset used in the analysis

Comparison	Estimate	df	t value	p-value	95% CI
Intervention vs. Baseline	10.53	72	7.33	<.0001*	7.67, 13.4
Post-intervention vs. Baseline	7.14	72	4.03	<.0001*	3.61, 10.68
Post-intervention vs. Intervention	-3.4	72	-2.52	.01*	-6.1, -.71

*Significant at p<.05

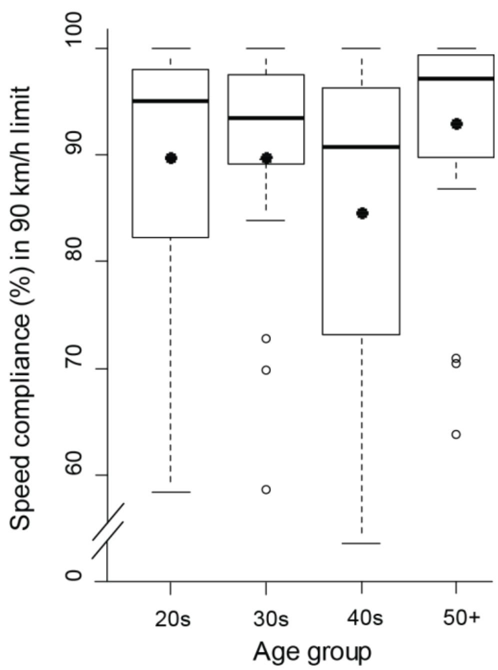


Figure 5. Speed limit compliance rate across four age groups in 90 km/h speed limit zones; entire data

Figure 6 presents the speed compliance rates at the weekly level of aggregation. These rates were calculated as the ratio of the compliant time (GPS based speed ≤ PSL + 2 km/h) over the total time spent within each week and speed limit combination. Immediately after exposure to the intervention, the average speed compliance increased from 84.5% to 95.2%, and this increase was apparent throughout the twelve weeks of intervention. There was no significant difference between average speed compliance over the first and second halves of the intervention period (t(174)=-.35, p=.72). In the baseline phase, speed compliance in the second week was significantly higher than it was in the first week (t(174)=-5.58, p<.0001). There was no significant difference between the first and second weeks of the post-intervention period (t(174)=-.62, p=.54).

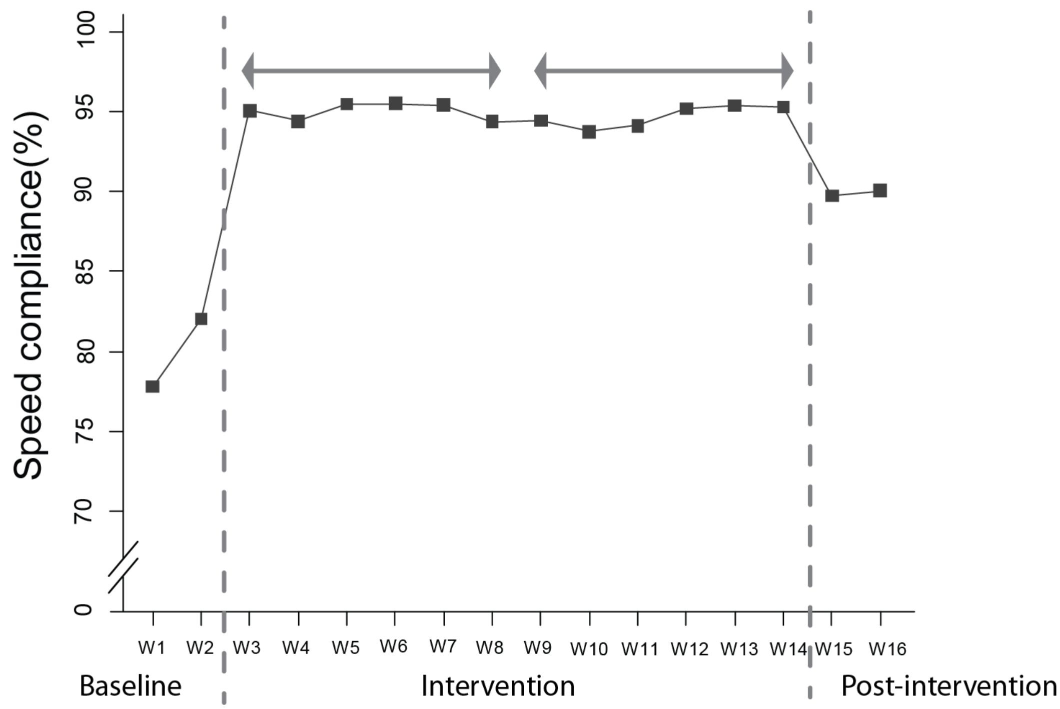


Figure 6. Speed compliance rate across sixteen weeks of the experiment averaged across all drivers for the entire data

3.1.2.2 *No Lead Vehicle Data*

It should be noted that the analysis involving the entire dataset might be misleading to some extent given its uninformative nature on the opportunity to speed (i.e., non-presence of a lead vehicle). In order to control for the traffic flow effect, a mixed linear model was built on a subset of data for which a lead vehicle was not present. This subset included 75% of the entire data. Main effects of phase, (F(2, 72)=26.46, p<.0001), speed limit (F(5,165)=5.08, p= .0002), and their interaction (F(10,328)=3.32, p= .0004) were all significant (Table 3). Figure 7 presents box plots for the interaction effect. According to follow-up contrasts, regardless of speed limit, drivers drove within the speed limit significantly more in the intervention phase than they did in the baseline period. The difference between the baseline and the post-intervention periods was also significant for higher speed limit zones, namely 70, 80, 90, and 100 km/h for which the positive effects of feedback sustained (Table 4). Similar to the results obtained from the analysis of the entire dataset, the main effect of gender and its interaction with other variables were not significant (Figure 8).

Table 3. Speed compliance rate, mixed linear model results over the no lead vehicle data

Explanatory variable	Num df	Den df	F value	p-value
Phase	2	72	26.46	<.0001*
Speed limit	5	165	5.08	.0002*
Gender	1	32	1.81	.19
Age group	3	32	.5	.68
Driving time	1	564	2.29	.13
Phase x Speed limit	10	328	3.32	.0004*
Age group x Speed limit	15	165	.97	.48

*Significant at p<.05

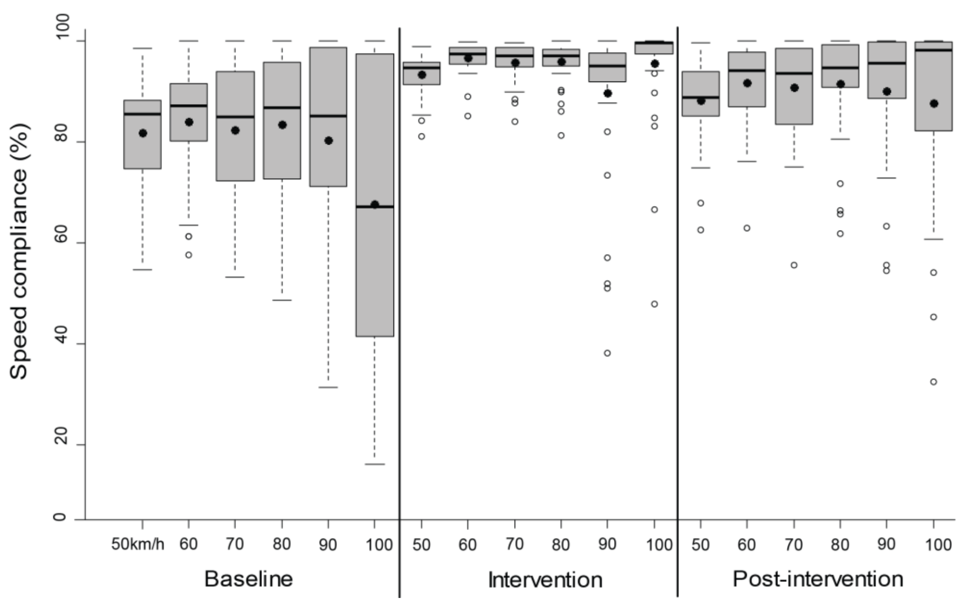


Figure 7. Speed compliance rate across experimental phases and speed limits for no lead vehicle data

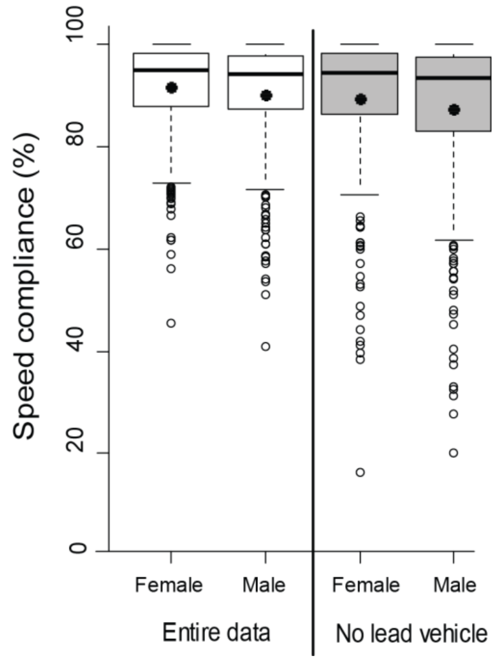


Figure 8. Speed compliance rate across gender for the entire data as well as cases during which there was no lead vehicle

Speed compliance rates aggregated at the weekly level were also calculated for the subset of the data with no lead vehicle. Immediately after exposure to the feedback and reward system, the average speed compliance increased by an estimated 13% (95% CI: 11.29, 14.49), from 82% to 95 %, and this increase was apparent throughout the intervention phase. There was no significant difference between average speed compliance over the first and second halves of the intervention period (t(174)=.22, p=.83). In the baseline phase, speed compliance in the second week was significantly higher than it was in the first week (t(174)= 4.26, p<.0001). However, there was no statistical difference between the first and second weeks of the post-intervention period (t(174)= .55, p=.62) (Figure 9).

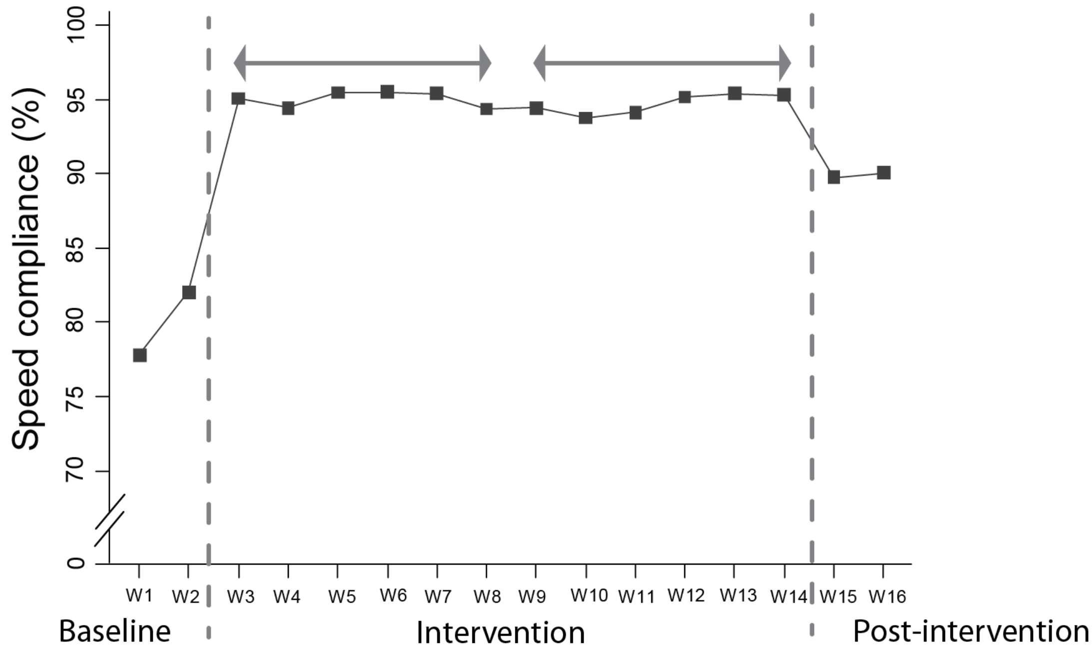


Figure 9. Speed compliance rate across sixteen weeks of the experiment averaged across all drivers for instances when there was no lead vehicle

In sum, results show that the feedback-reward system increased speed compliance rate. The positive benefits observed with intervention sustained even after system was removed. However, there was a decline in the amount of compliance from the intervention to the post-intervention phase. Further analysis conducted on the subset of the entire data, in which no lead vehicle was present revealed that the intervention effect was the same. However, when intervention was removed, the positive benefits were found to sustain only for high speed limits, namely 70, 80, 90 and 100 km/h speed limit zones.

Table 4. Pair-wise comparison of speed compliance rate between experimental phases and speed limit zones over the no lead vehicle data

Comparison	Speed limit	Estimate	df	t value	p-value	95%CI
Intervention vs.- Baseline						
	50	10.34	328	3.3	.001*	4.17, 16.5
	60	11.93	328	3.88	.0001	5.87, 17.99
	70	13.2	328	4.32	<.0001*	7.19, 19.21
	80	12.44	328	3.99	<.0001*	6.30, 18.58
	90	8.9	328	2.82	.005*	2.7, 15.1
	100	26.78	328	8.22	<.0001*	20.37, 33.19
Post-intervention vs. Baseline						
	50	3.37	328	1.58	.1	-.8, 9.94
	60	6.37	328	1.91	.06	-.18, 12.94
	70	8.4	328	2.52	.01*	1.84, 14.96
	80	8.44	328	2.48	.01*	1.75, 15.13
	90	10.45	328	2.97	.003*	3.51, 17.37
	100	20.92	328	5.77	<.0001*	13.78, 28.06
Post-intervention vs. Intervention						
	50	-3.96	328	-1.64	.1	-8.72, .80
	60	-4.39	328	-1.86	.06	-9.03, .25
	70	-4.79	328	-2.06	.04*	-9.38, -.21
	80	-4.01	328	-1.7	.09	-8.62, .62
	90	1.54	328	.62	.53	-3.33, 6.42
	100	-5.86	328	-2.27	.02*	-10.94, -.77

* Significant at p<.05

3.1.3 Maximum Deviation From Posted Speed Limit When Noncompliant

Degree of speeding for noncompliant cases was defined as the maximum deviation from posted speed limit in a stretch of road with a constant posted limit driven non-stop. The average maximum deviation from posted speed limit (averaged across posted speed limit and experimental phase combinations) was compared across age, gender, and posted speed limit for the three study phases. Total driving time within each experimental phase – speed limit combination was considered as a covariate. A logarithmic transformation was applied to correct problems of non-normality and heteroskedasticity. Backward selection was used to enter the predictors and their two-way interactions in the model.

3.1.3.1 *Entire Data*

The mixed linear model built on the entire data revealed that the main effect of phase was significant (F(2,72)=5.61, p=.005) (Table 5): maximum deviation from posted speed limit was significantly lower in the intervention phase in comparison to the baseline phase (t(72)=-3.33, p=.001); however, the difference was only about 1.5 km/h. This effect sustained after feedback and reward were removed (post-feedback vs. baseline: t(72)=-2.01, p=.04) (Figure 10, Table 6).

Table 5. Maximum deviation from PSL: mixed linear model results over the entire data

Explanatory variable	Num df	Den df	F value	p-value
Phase	2	72	5.61	.005*
Speed limit	5	157	12.48	<.0001*
Gender	1	29	1.08	.31
Age group	3	29	.54	.66
Driving time	1	528	.25	.61
Gender x Speed limit	5	157	2.33	.04*
Age group x Speed limit	15	157	2.57	.002*
Age group x Gender	3	29	3.3	.03*

*Significant at p<.05

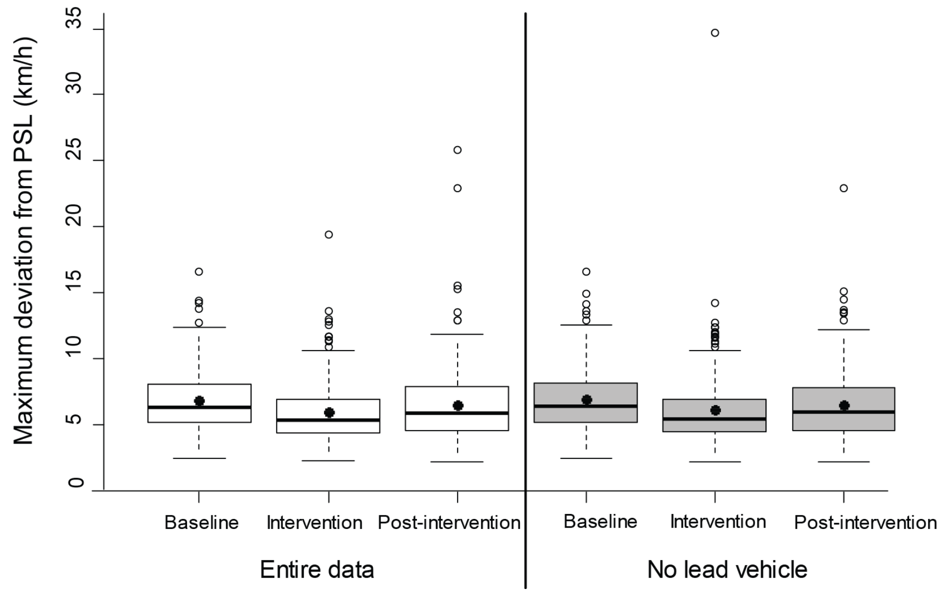


Figure 10. . Maximum deviation from PSL across three experimental phases for the entire data as well as for cases during which there was no lead vehicle

Table 6. Pair-wise comparisons of maximum deviation from PSL between experimental phases over the entire dataset

Comparison	Estimate	df	t value	p-value	95% CI
Intervention vs. Baseline	-.15	72	-3.33	.001*	-.25, -.06
Post-intervention vs. Baseline	-.12	72	-2.01	.04*	-.23, -.0007
Post-intervention vs. Intervention	. 04	72	.68	.5	-.07, .14

*Significant at p<.05

The main effect of speed limit (F(5,157)=12.48, p<.0001) and its interaction with age group (F(15,157)=2.57, p=.002) and gender (F(5,157)=2.33, p=.04) were significant. The age effect was apparent only for 100 km/h speed limit with 40s group reaching lower maximum speed values than all other age groups (40s vs. 20s: t(157)=-4.53, p<.0001; 40s vs. 30s: t(157)=-2.67, p=.008; 40s vs. 50+s: t(157)=-4.33, p<.0001) (Figure 11). Moreover, males reached higher speed values than females in 70 km/h speed limit zones when not compliant with the speed limit (t(157)=-2.06, p=.04) (Figure 12).

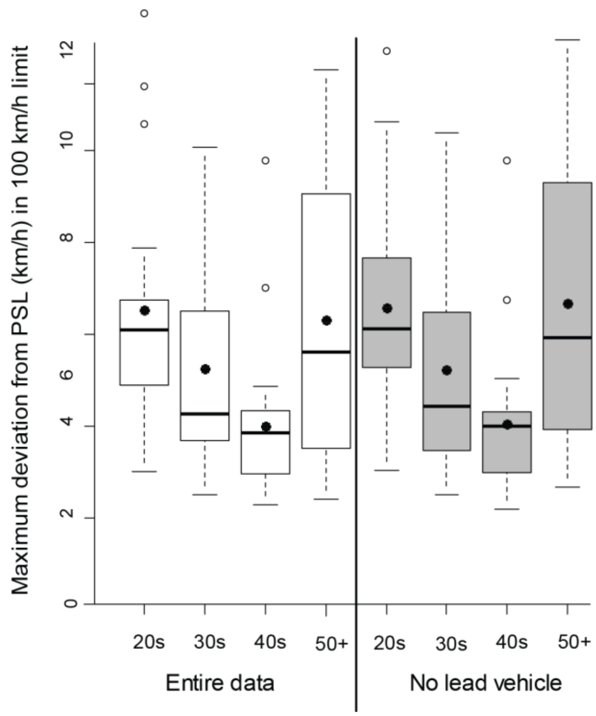


Figure 11. Maximum deviation from PSL across four age groups in 100 km/h speed limit zones

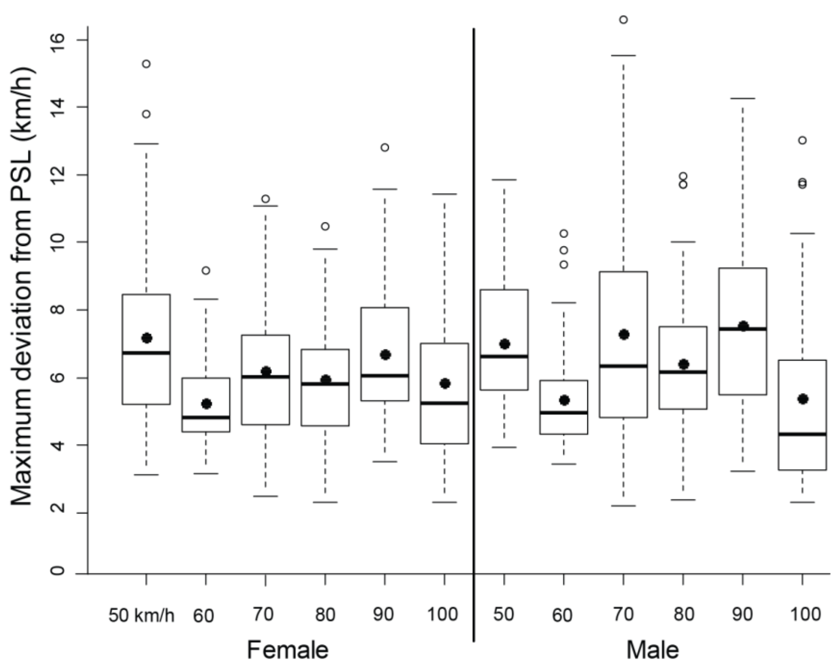


Figure 12. Maximum deviation from PSL across gender and PSL for the entire data

3.1.3.2 *No Lead Vehicle Data*

Similar to the results obtained from the entire dataset, for the no lead vehicle data, experimental phase was significant as a main effect (F(2,70)=4.20, p=.02) (Figure 10, Table 7). Maximum deviation from posted speed limit in intervention (t(70)=-2.80, p=0.007) and post-intervention (t(70)=-2.06, p=0.04) phases was significantly lower than it was in the baseline phase (Table 8).

The main effect of speed limit (F(5,156)=14.89, p<.0001), and its interaction with age group (F(15,156)=2.74, p=.0009) and gender (F(5,156)=2.86, p=.02) were also significant. In 100 km/h speed limit zones, the 40s age group had the lowest maximum deviation from posted speed limit (40 vs. 20s: t(156)=-4.42, p<.0001; 40s vs. 30s: t(156)=-2.36, p=.02; 40s vs. 50+s: t(156)=-4.75, p<.0001) (Figure 11). Further, maximum deviation from posted speed limit for males was significantly higher than it was for females in 70 km/h speed limit zones (t(156)=-2.08, p=0.04) (Figure 13). As can be seen in Figures 10 to13, the no lead vehicle data has almost the same distribution as the entire dataset, suggesting that the highest speed values during noncompliant states were most likely reached when there was no lead vehicle ahead.

Overall, analysis of maximum deviation from the posted speed limit showed that when the drivers were noncompliant, a significant main effect of intervention was observed on the degree of speeding, and this positive effect sustained in the post-intervention phase. Results obtained from the subset of data with no lead vehicle presence revealed the same findings.

Table 7. Maximum deviation from PSL: mixed linear model results over the no lead vehicle data

Explanatory variable	Num df	Den df	F value	p-value
Phase	2	70	4.20	.02*
Speed limit	5	156	14.89	<.0001*
Gender	1	29	1.03	.32
Age group	3	29	.69	.57
Driving time	1	519	.15	.7
Gender x Speed limit	5	156	2.86	.02*
Age group x Speed limit	15	156	2.74	.0009*
Age group x Gender	3	29	2.74	.06

*Significant at p<.05

Table 8. Pair-wise comparison of maximum deviation from PSL between experimental phases: no lead vehicle data

Comparison	Estimate	df	t value	p-value	95% CI
Intervention vs. Baseline	-.13	70	-2.8	.007*	-.23, -.04
Post-intervention vs. Baseline	-.13	70	-2.06	.04*	-.25, -.004
Post-intervention vs. Intervention	. 009	70	.17	.87	-.1, .12

*Significant at p<.05

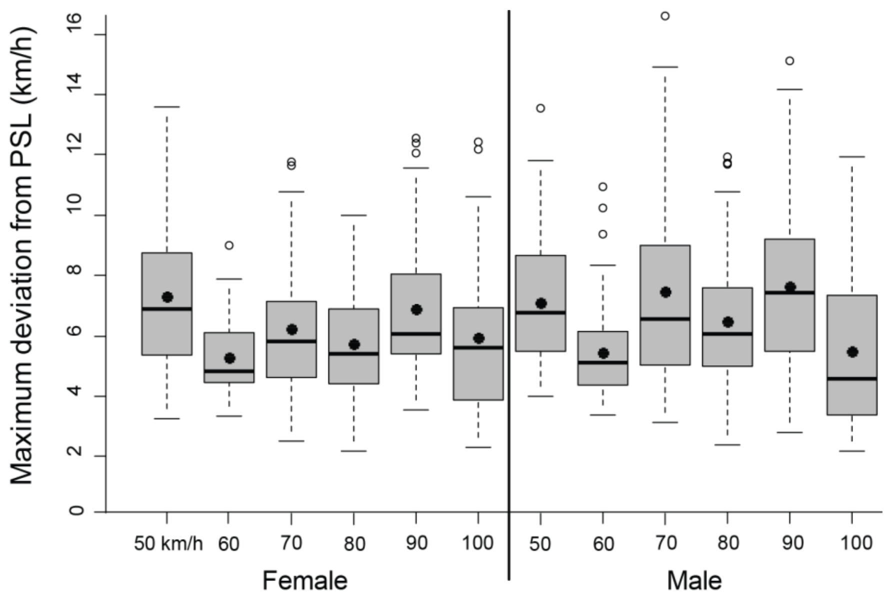


Figure 13. Maximum deviation from PSL across gender and PSL for no lead vehicle data

3.2 Tailgating Behaviour

3.2.1 Statistical Model

Mixed linear models (PROC MIXED statement in SAS 9.2) were built to investigate the effects of the intervention on tailgating behaviour in the presence of a lead vehicle which was operationalized as headway time compliance rate and average headway time. In addition to the intervention, the models statistically controlled for other factors, namely driver age, driver gender, and speed limit zone.

In all analyses, driving time within each experimental phase (baseline, intervention, post-intervention) and speed limit zone (50, 60, 70, 80, 90, 100 km/h) combination when there was a lead vehicle present was considered as a covariate to control for exposure to car following situations within different speed limits and experimental phases. Similar to the analyses of speeding behaviour, the analyses of car following behaviour were also conducted at the experimental phase level or at a weekly level of aggregation. Before analyses, the dependent variables were aggregated to the level of phase and speed limit interaction. Thus, each driver could have up to 18 observations (3 study phases x 6 speed limits) adding up to 666 total number of observations (18 observations per driver x 37 drivers). However, some drivers were not observed to drive in certain speed limit-phase combinations. Additional analyses were conducted to assess time effects on the dependent variables. For these analyses, the independent variables were speed limit zone and time, and the aggregation of dependent variables was done accordingly.

For all analyses, appropriate variance covariance structures were selected based on the Bayesian Information Criterion (BIC) [103]. Moreover, assumptions of normality and homogeneity of variance were examined through residual plots (histograms, normal probability plots, plots of residuals versus predicted values and versus explanatory variables) as well as normality and homogeneity of variance tests. Further, multicollinearity among the explanatory variables was examined through variance inflation factors and tolerance. When necessary, transformations were applied to correct for problems of non normality and heteroskedasticity.

In the following sections, boxplots are provided to convey the reader the shape of the distributions. These plots present the range (minimum and maximum), the first and the third quartiles, the median, the mean, and the potential outliers. An observation which fell 1.5 times the interquartile range away from the first and third quartiles was identified as a potential outlier. The inter quartile range corresponds to the difference between the 75^{th} percentile (third quartile) and the 25^{th} percentile (first quartile).

Similar to the analyses of speeding behaviour , data for 30 km/h speed limit zones were excluded from all analyses due to insufficient number of observations within this speed limit zone.

3.2.2 Headway Time Compliance

The headway time compliance rate was defined as the ratio of the compliant time (headway time > 1.2 s) over the total time spent following a car within each experimental phase and speed limit combination. This rate was compared across age, gender, and posted speed limit for the three study phases. The analysis revealed that headway time compliance rate was significantly associated with phase ($F(2, 72)=31.78$, $p<.0001$), speed limit ($F(5, 165)=8.01$, $p<.0001$), gender ($F(1,32)=4.46$, $p=.04$), and age group ($F(3,32)= 6.22$, $p<.002$) (Table 9). In the baseline phase, drivers were compliant on average 81.0% of the time. During the intervention phase, this rate increased by an estimated 9.6% (95% CI: 4.7, 14.5) to 90.6% ($t(72)=3.88$, $p=.0002$), and after feedback-reward removal, it dropped to 84.3%, which was not significantly different from the baseline phase ($t(72)=1.16$, $p=.25$) (Figure 14). As illustrated in Figure 15, drivers were more headway compliant in 50 km/h speed limit zones than in higher speed limit zones (Table 10).

Table 9. Headway time compliance rate: mixed linear model results

Explanatory variable	Num df	Den df	F value	p-value
Phase	2	72	31.78	<.0001*
Speed limit	5	165	8.01	<.0001*
Gender	1	32	4.46	.04*
Age group	3	32	6.22	<.002*
Driving time	1	563	0.73	.40
Phase x Speed limit	10	328	0.94	.49
Age group x Speed limit	15	165	1.16	.30

*Significant at p<.05

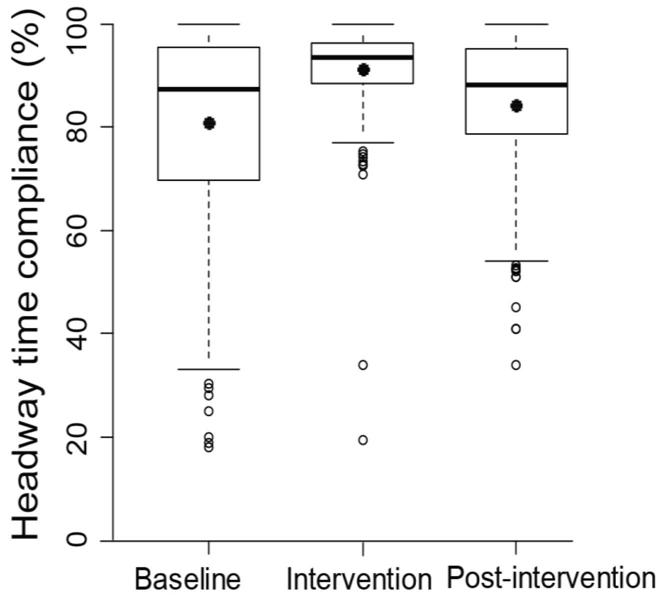


Figure 14. Headway time compliance rate across the experimental phases

As shown in Figure 16, females were significantly more headway compliant than males (female: 88%, male: 83%, t(32)=2.11, p=.04). Further, the 30s age group, on the average, had lower compliance rates than all other age groups (Table 10).

Table 10. Pair-wise comparisons of headway time compliance rate for phase, speed limit, gender, and age group

Explanatory variable	Comparison	Estimate	df	t value	p-value	95%CI
Phase						
	Intervention vs. Baseline	9.56	72	3.88	.0002*	4.65, 14.46
	Post-intervention vs. Baseline	3.03	72	1.16	.25	-2.16, 8.23
	Post-intervention vs. Intervention	-6.52	72	-3.67	.0005*	-10.06, -2.98
Posted speed limit						
	50 vs. 60	3.96	165	2.67	.008*	1.03, 6.89
	50 vs. 70	5.27	165	3.51	.0006*	2.31, 8.24
	50 vs. 80	8.52	165	5.67	<.0001*	5.55, 11.49
	50 vs. 90	5.01	165	3.11	.002*	1.83, 8.18
	50 vs. 100	8.2	165	5.07	<.0001*	5.01, 11.39
	60 vs. 70	1.31	165	,85	.4	-1.72, 4.34
	60 vs. 80	4.56	165	2.98	.003*	1.53, 7.58
	60 vs. 90	1.04	165	.64	.5	-2.2, 4.29
	60 vs. 100	3.2	165	1.93	.05	-.08, 6.47
	70 vs. 80	3.25	165	2.19	.03*	.32, 6.17
	70 vs. 90	-.27	165	-.17	.86	-3.36, 2.82
	70 vs. 100	2.93	165	1.84	.07	-.21, 6.1
	80 vs. 90	-3.51	165	-2.23	.03*	-6.62, -.41
	80 vs. 100	-.32	165	-.2	.8	-3.47, 2.83
	90 vs. 100	3.2	165	1.93	.05	-.08, 6.47
Gender						
	Female vs. Male	3.46	32	2.11	.04*	.12, 6.8
Age group						
	20s vs. 30s	7.54	32	3.23	.003*	2.79, 12.29
	20s vs. 40s	.13	32	.05	.96	-4.87, 5.13
	20s vs. 50+	-.7	32	-.33	.74	-5.04, 3.64
	30s vs. 40s	-7.41	32	-3.11	.004*	-12.26, -2.56
	30s vs. 50+	-8.24	32	-4.02	.0003*	-12.42, -4.06
	40s vs. 50+	-.83	32	-.38	.71	-5.32, 3.66

* Significant at p<.05

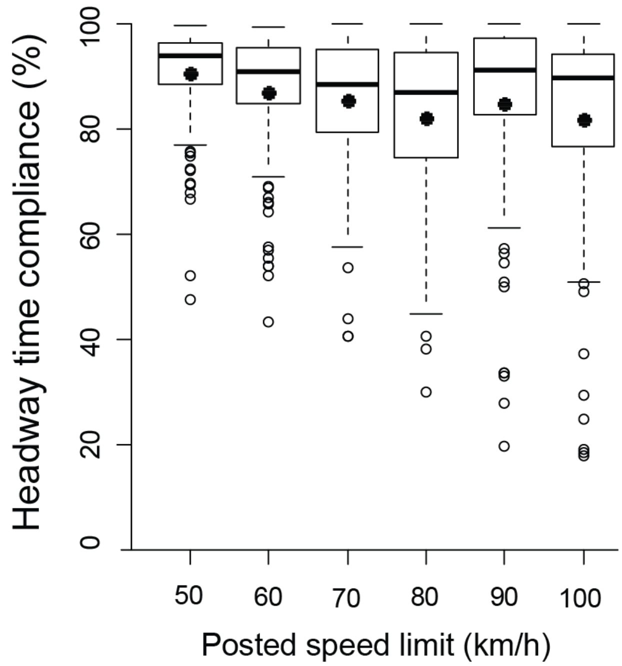


Figure 15. Headway time compliance rate across posted speed limit zones

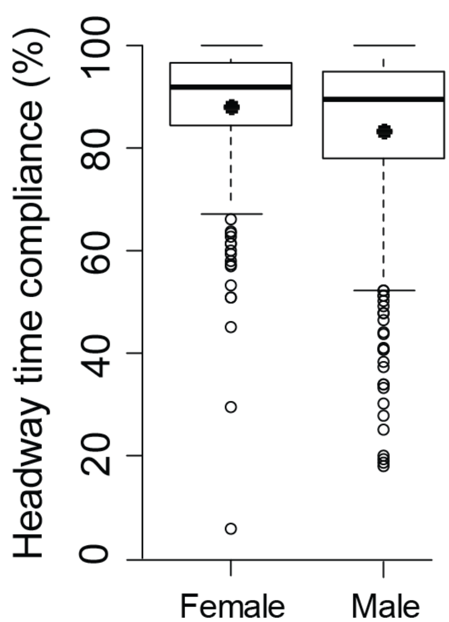


Figure 16. Headway time compliance rate across gender

Figure 17 presents the headway time compliance rates at the weekly level of aggregation. Weekly headway time compliance rates were calculated as the ratio of the compliant time (headway time > 1.2 s) over the total time spent following a car within each week and speed limit combination. Immediately after exposure to the intervention, the average headway compliance rate increased from 82.7% to 92.1%; however, after six weeks, there was a drop to 88.5%. The headway time compliance rate was significantly lower in the second half of the intervention phase than it was in the first half (t(108)=-6.96, p<.0001). However, the compliance rate in the second half of the intervention phase was still higher than it was in the baseline (t(108)=9.04, p<.0001). There were no statistical differences between the first and second weeks for the baseline (t(31)=-1.46, p=.15) and post-intervention (t(35)=1.62, p=.11) phases.

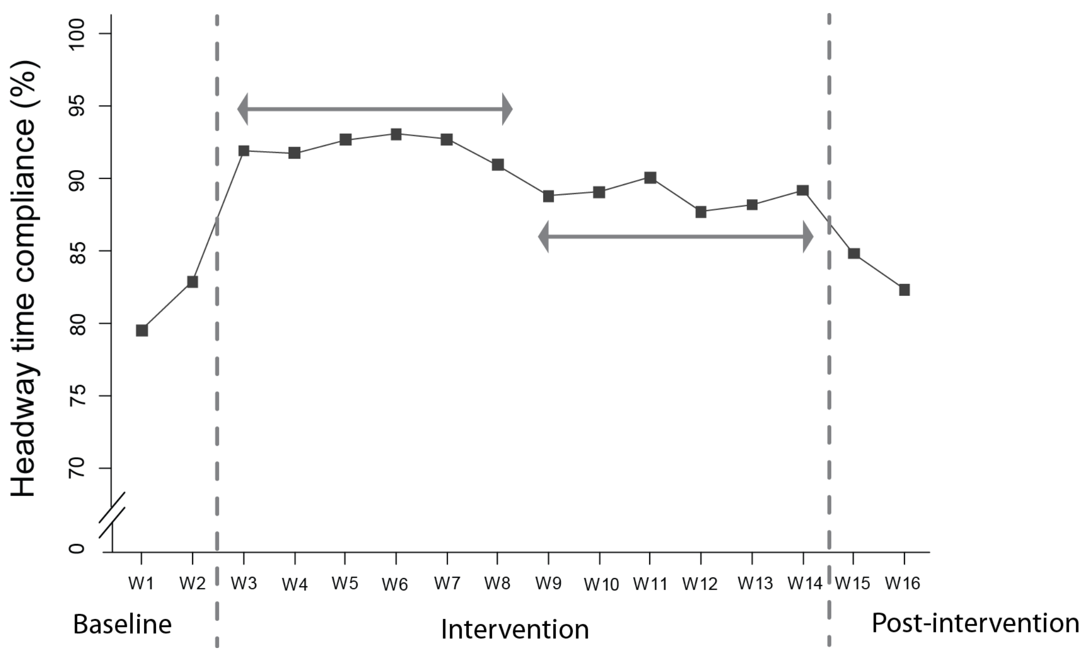


Figure 17. Headway time compliance rate across sixteen weeks of the experiment averaged across all drivers

3.2.3 Average Headway Time

The average headway time (averaged across speed limit and experimental phase combinations) was examined across age, gender, and posted speed limit for the three experimental phases. The analysis yielded significant main effects of phase (F(2,72)=13.70, p<.0001), speed limit (F(5,165)=46.33, p<.0001), and driving time (F(1,572)=4.24, p=.04) (Table 11). The average headway time was 2.61 seconds in the intervention phase compared to 2.46 seconds in the baseline. However, this improvement was not statistically significant, and after intervention removal average headway time significantly decreased to 2.36 seconds (post-intervention vs. baseline: t(72)= -3.35, p=.001; post-intervention vs. intervention: t(72)=-5.16, p<.0001) (Figure 18, Table 12).

Table 11. Average headway time: mixed linear model results over the entire data

Explanatory variable	Num df	Den df	F value	p-value
Phase	2	72	13.70	<.0001*
Speed limit	5	165	46.33	<.0001*
Gender	1	32	1.38	.25
Age group	3	32	.07	.98
Driving time	1	572	4.24	.04*
Age group x Speed limit	15	165	1.64	.07
Driving time x Phase	5	572	3.59	.03*

*Significant at p<.05

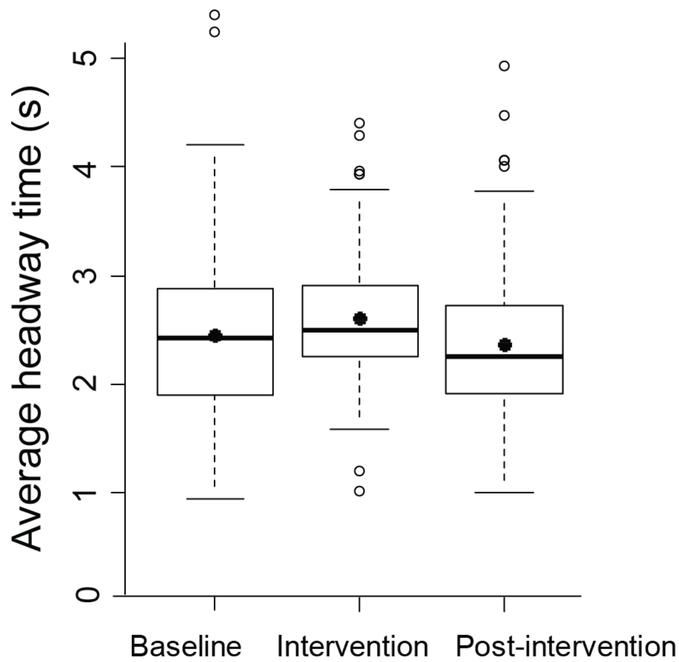


Figure 18. Average headway time across three experimental phases for the entire data

The average headway time appeared to decrease with increasing speed limits, from 3.06 seconds at 50 km/h speed limit zones to 2.20 seconds at 100 km/h speed limit zones (Figure 19). The interaction between driving time and phase was also significant ($F(2,572)=3.59$, $p=.03$). In the baseline phase, a one-minute increase in driving time contributed to a .002 seconds decrease in average headway time ($t(572)=-2.69$, $p=.0074$). No significant effect of driving time was found in intervention and post-intervention phases.

Table 12. Pair-wise comparison of average headway time between experimental phases over the entire data

Comparison	Estimate	df	t value	p-value	95%CI
Intervention vs. Baseline	.09157	72	1.69	.0946	-.016, .2
Post-intervention vs. Baseline	-.1847	72	-3.35	.0013*	-.29, -.07
Post-intervention vs. Intervention	-.2762	72	-5.16	<.0001*	-.38,-.17

* Significant at p<.05

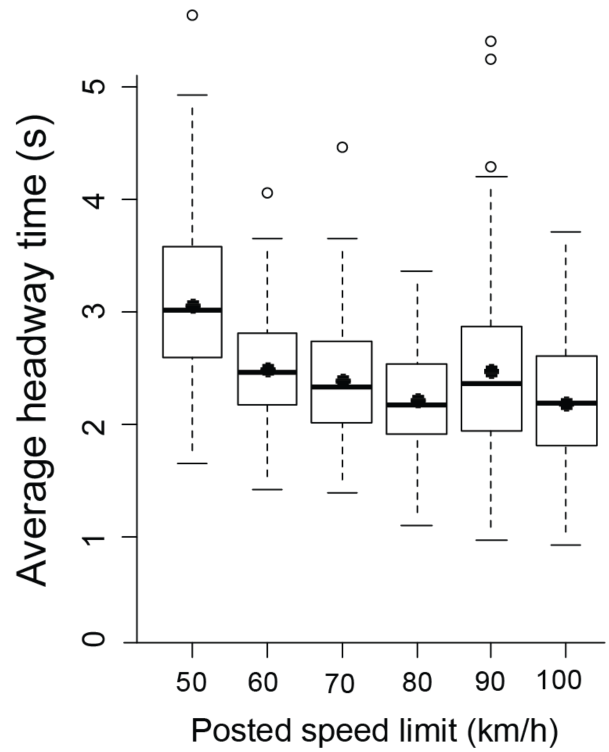


Figure 19. Average headway time across speed limit zones

Weekly average headway times calculated by averaging headway times within each week and speed limit combination are presented in Figure 20. In the first half of the intervention phase, the average headway time was significantly higher compared to the baseline (t(108)=6.63, p<.0001). However, this positive effect was not apparent for the second half of the intervention phase (t(108)=1.49, p=.14). Moreover, there were no statistical differences between the first and second weeks of the baseline (t(31)=-1.46, p=.15) and post-intervention (t(35)=.06, p=.35) phases.

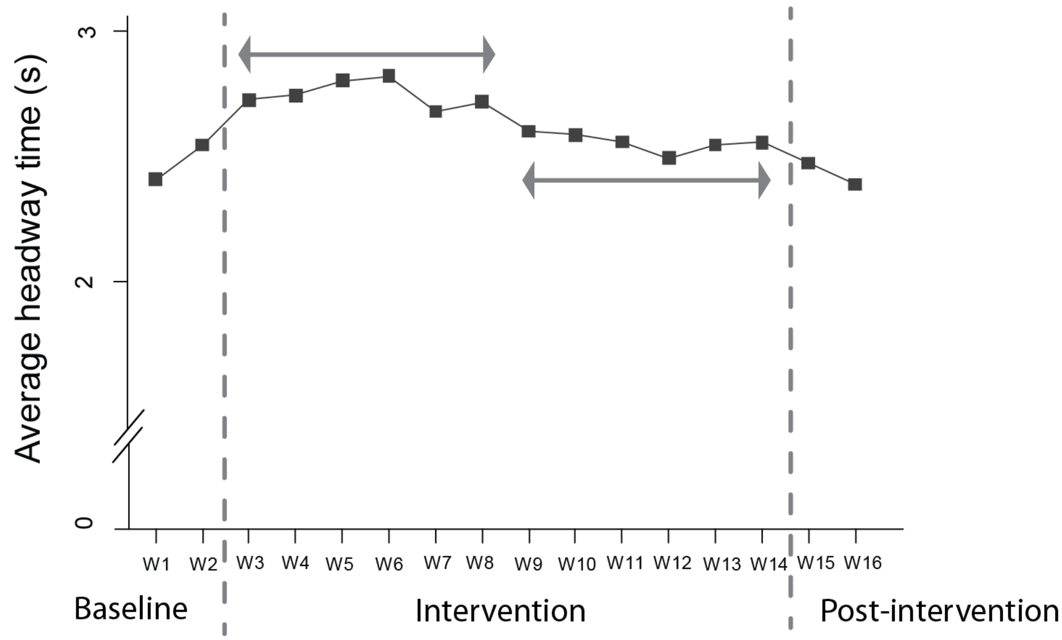


Figure 20. Average headway time across sixteen weeks of the experiment averaged across all drivers

3.2.3.1 *Average Headway Time During Compliance vs. Noncompliance*

Given that the effect of intervention on headway time might be washed out due to the averaging of headway time over the entire dataset, mixed linear models were built over two subsets of the data: compliance and noncompliance data. The subset of data for which drivers were not within the safe headway time (noncompliance) included about 10% of the entire dataset. The average headway time during these instances was examined across age, gender, and posted speed limit for the three experimental phases. The analysis yielded significant main effects of phase ($F(2,70)=23.18$, $p<.0001$), speed limit ($F(5,179)=6.54$, $p<.0001$), and driving time ($F(1,545)=11.91$, $p=.0006$). The interaction between phase and gender was also significant ($F(2,70)=3.91$, $p=.02$) (Table 13). During all phases, the average headway time for females appeared to be higher than males. However, this difference was significant only during the baseline period ($t(70)=3.09$, $p=.003$). In the intervention phase, the average headway time significantly increased for both genders, however after feedback-reward removal this positive effect only sustained for males (Figure 21, Table 14).

Table 13. Average headway time, mixed linear model results over non-compliance data

Explanatory variable	Num df	Den df	F value	p-value
Phase	2	70	23.18	<.0001*
Speed limit	5	179	6.54	<.0001*
Gender	1	29	2.90	.10
Age group	3	29	1.12	.36
Driving time	1	545	11.91	.0006*
Phase x Speed limit	10	302	.76	.67
Phase x Gender	2	70	3.91	.02*
Gender x Age group	3	29	2.13	.12
Driving time x Speed limit	5	545	2.03	.07

* Significant at p<.05

Table 14. Pair-wise comparisons of average headway time between experimental phase x gender over the non-compliance data

Comparison		Estimate	df	t value	p-value	95% CI
Intervention vs. Baseline						
	Female	.03	70	3.24	.002*	.01, .05
	Male	.05	70	6.74	<.0001*	.04, .07
Post-intervention vs. Baseline						
	Female	.007	70	.73	.47	-.01, .02
	Male	.04	70	4.61	<.0001*	.02, .05
Post-intervention vs. Intervention						
	Female	-.02	70	-2.39	.02*	-.04, -.004
	Male	-.02	70	4.61	<.0001*	-.03, -.0007

* Significant at p<.05

The average headway time during noncompliance appeared to decrease with increasing speed limits, from 1.03 seconds at 50 km/h speed limit zones to 0.98 seconds at 100 km/h speed limit zones (Figure 22). Further, a one-minute increase in driving time contributed to a 0.002 seconds decrease in average headway time during noncompliance (t(545)=-3.45, p=.0006).

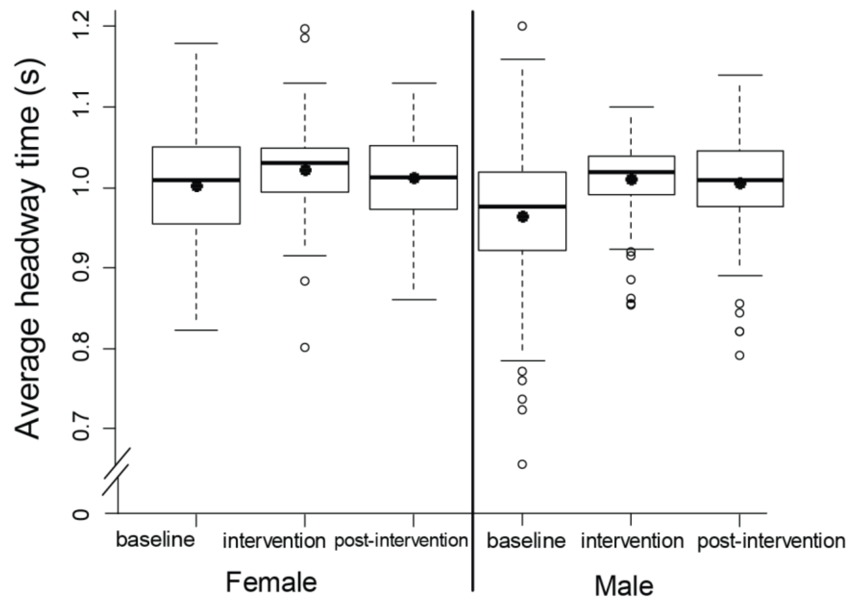


Figure 21. Average headway time across gender and experimental phases for non-compliance data

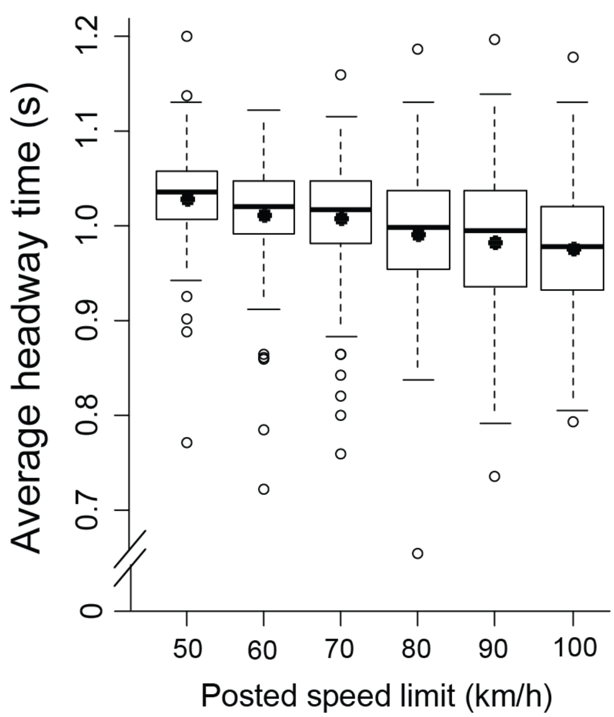


Figure 22. Average headway time across speed limits for non-compliance data

The average headway time was also examined for situations during which drivers were maintaining a safe headway time (compliance). In general, drivers were headway compliant in about 90% of the car following situations. Analysis of headway time during compliance revealed almost similar results as the analysis over the entire dataset. As it is illustrated in Table 15, main effects of phase ($F(2,64)=13.11$, $p<.0001$) and speed limit($F(5,180)=50.46$, $p<.0001$) were significant. After exposure to the intervention, the average headway time increased on average from 2.72 seconds to 2.75 seconds, although this improvement was not significant (Figure 23, Table 16).

Table 15. Average headway time, mixed linear model results over the compliance data

Explanatory variable	Num df	Den df	F value	p-value
Phase	2	64	13.11	<.0001*
Speed limit	5	180	50.46	<.0001*
Gender	1	32	.57	.46
Age group	3	32	.03	.99
Driving time	1	566	.82	.36
Phase x Speed limit	10	327	1.4	.18
Phase x Age group	6	64	1.79	.11

*Significant at p<.05

Table 16. Pair-wise comparisons of average headway time between experimental phases over the compliance data

Comparison	Estimate	df	t value	p-value	95%CI
Intervention vs. Baseline	.05	64	1.02	.31	-.05, .15
Post-intervention vs. Baseline	-.17	64	-4.18	<.0001*	-.26, -.09
Post-intervention vs. Intervention	-.22	64	-4.52	<.0001*	-.32,-.13

* Significant at p<.05

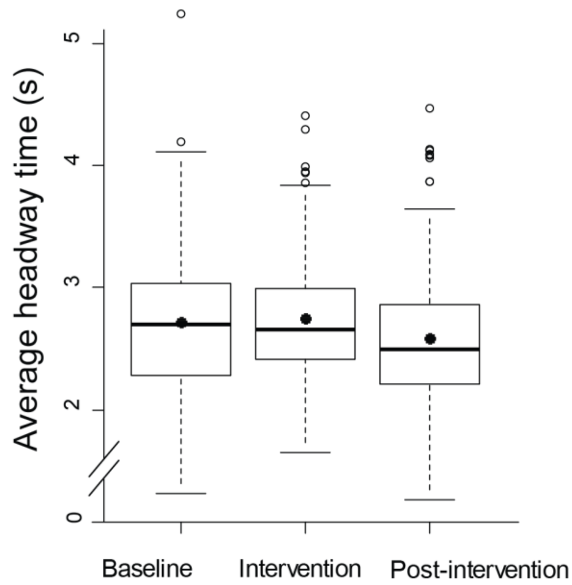


Figure 23. Average headway time across experimental phases for compliance data

The average headway time appeared to decrease with increasing speed limits, from 3.23 seconds at 50 km/h speed limit zones to 2.40 seconds at 100 km/h speed limit zones (Figure 24).

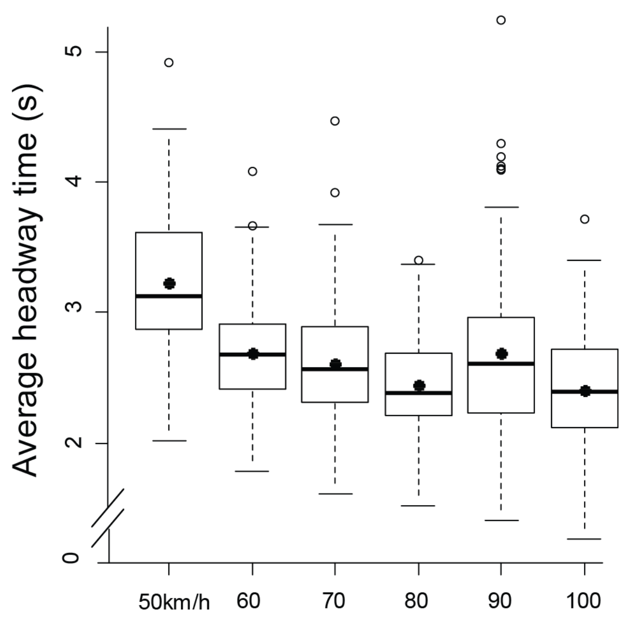


Figure 24. Average headway time across speed limit zones for compliance data

In sum, according to analysis on the entire dataset, the average headway time in the intervention phase was higher than baseline. However, this positive effect was not significant. Further analysis was conducted on two subsets of the entire data, compliance and noncompliance data. Results for headway time during compliance were almost identical to the results for the entire dataset. When noncompliant cases were considered, average headway times were in general significantly higher in the intervention phase compared to the baseline and this benefit sustained for male drivers when the intervention was removed. Further, during all phases, the average headway time for females was higher than males. However, this difference was statistically significant only during the baseline period.

3.3 Cluster Analysis

The average linkage hierarchical clustering was applied to the baseline data from the 37 drivers to further understand individual differences and to explore natural groupings among drivers. This analytical technique is an agglomerative, bottom-up clustering procedure, which starts with every single object in a single cluster by itself, and successively merges clusters according to a distance measure [104]. The distance between two clusters is computed as the average of pair-wise distances of all pairs of objects from different clusters.

The clustering was based on naturalistic driving data recorded in the baseline period. Thus, in order to find significant groups present in the data, several clustering models were conducted based on different driving variables including speed and headway compliance rates over both the entire data as well as the subset of data with no lead vehicle present, degree of speeding, and average headway time. Then, best candidates were selected by examining the associated dendrograms. In addition, subjective data such as drivers' attitudes about their driving styles, speeding, and following too closely as well as self-reported crash and moving violation records were used in the cluster analysis. However, no well-separated clusters with high degree of similarity were found.

The final two variables used to classify the drivers were the speed and headway compliance rates during the baseline. Clustering of data was performed using the PROC CLUSTER procedure in SAS 9.2. Since variables with large variances tend to have a larger effect on the resulting clusters than those with small variances, the variables were standardized by inclusion of the STD option in PROC CLUSTER.

As illustrated in Figure 25, Cluster A included twenty one drivers (12 females and 9 males) and was characterized by high scores on both speed and headway compliance rates observed during the baseline period. On the other hand, sixteen drivers (5 females and 11 males) in Cluster B had lower scores in speed and headway compliance rates. These differences were statistically significant as it will be presented in the upcoming paragraphs.

As it was discussed in the literature review, speeding and following too closely are among main causal factors associated with crashes [28, 39, 55, 57], therefore, it would appear that drivers in Cluster A tend to be at a lower crash risk than drivers in Cluster B, and were labeled as the lower risk group. On the other hand, Cluster B was labeled as the higher risk group due to the lower rates in speed and headway compliance. Characteristics of the two clusters are summarized in Table 17.

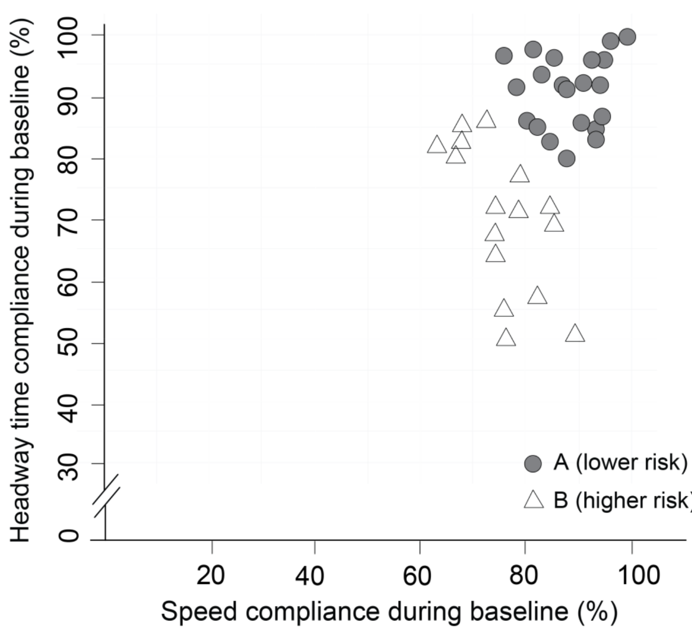


Figure 25. Representation of each driver based on cluster membership

Table 17. Characteristics of clusters

	N	Mean speed compliance in baseline	Mean headway compliance in baseline	% of male	% of each age group			
					20s	30s	40s	50s
Cluster A (lower risk)	21	89.1	89.9	42.9	33.3	4.8	19.1	42.9
Cluster B (higher risk)	16	79.4	69.6	68.8	6.3	50.0	18.8	25.0

To further understand the possible cause behind the classification, statistical tests were applied on relevant explanatory variables, namely gender, age group, and number of crash and moving violation within the last five years, which were not used to generate the clusters. Since the dependent variable was binary (Cluster A or B), binary logistic regression was used. As illustrated in Table 18, no significant effects were found.

Table 18. Binary logistic regression results for cluster membership

Explanatory variable	df	Wald Chi-Square	p-value
Gender	1	2.88	.09
Age group	3	7.59	.06
Number of crash experiences within 5 years	5	4.7	.44
Number of moving violation experiences	6	2.24	.89

*Significant at $p<.05$

Two mixed linear models were fitted using speed and headway time compliance rate as response variables and driving time as exposure. The effects of intervention, driver age, driver gender, speed limit zone, clusters, and their two-way interactions were investigated.

The analysis of speed compliance revealed an interaction effect of experimental phase and cluster ($F(2,70)= 5.89$, $p=.004$). As illustrated in Figure 26, although the speed compliance rate for lower risk drivers was significantly greater than that of the higher risk group during the baseline phase ($t(70)= 4.07$, $p= .0001$), this difference was not significant after exposure to the intervention (intervention: $t(70)= .95$, $p=.34$; post-intervention: $t(70)= 1.62$, $p=.11$) (Table 19). For lower risk drivers, the speed compliance rate increased from 89.13% to 96.4% during the intervention phase ($t(70)= 4.51$, $p<.0001$), and after intervention removal decreased to 93.52%, which was still significantly higher than the baseline ($t(70)= 2.21$, $p=.03$). For higher risk drivers, an estimated increase of 15% (95% CI: 11.56, 18.79), from 79.41% to 94.73%, was revealed during the intervention phase which was significantly larger than that for lower risk drivers (t(70)= 3.41, p=.001). And after the intervention removal, speed compliance rate decreased to 89.18% which was still 10% higher than that during the baseline period (t(70)= 4.47, p<.0001) (Table 17).

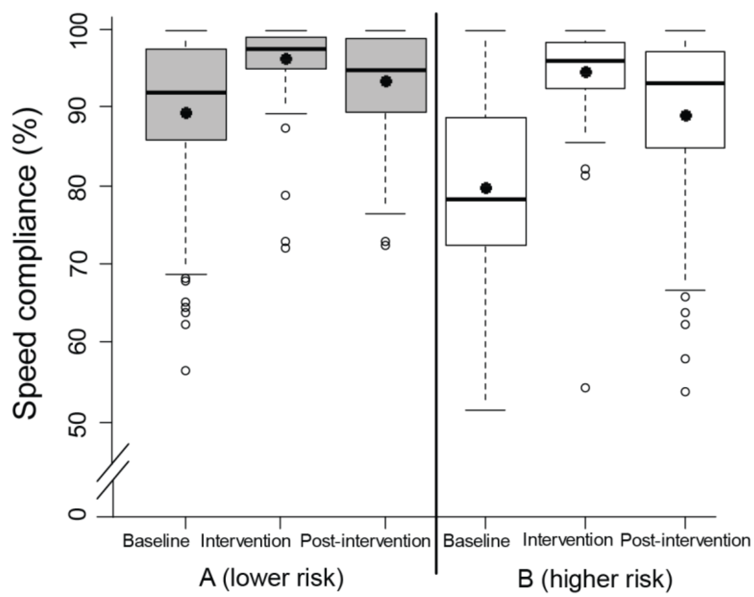


Figure 26. Speed compliance rate across experimental phases and clusters

Table 19. Pair-wise comparisons of speed compliance rate between clusters within each experimental phase

Comparison		Estimate	df	t value	p-value	95%CI
A (lower risk) vs. B (higher risk)						
	Baseline	9.35	70	4.07	.0001*	4.77, 13.93
	Intervention	1.21	70	.95	.34	-1.32, 3.74
	Post- intervention	3.56	70	1.62	.11	-.82, 7.94

* Significant at p<.05

Table 20. Pair-wise comparisons of speed compliance rate between experimental phases within each cluster

Comparison	Estimate	df	t value	p-value	95%CI
A (lower risk)					
Intervention vs. Baseline	7.03	70	4.51	<.0001*	3.9, 10.13
Post-intervention vs. Baseline	4.31	70	2.21	.03*	.42, 8.19
Post-intervention vs. Intervention	-2.72	70	-1.81	.07	-5.71, .27
B (higher risk)					
Intervention vs. Baseline	15.17	70	8.37	<.0001*	11.56, 18.79
Post-intervention vs. Baseline	10.1	70	4.47	<.0001*	5.59, 14.61
Post-intervention vs. Intervention	-5.1	70	-2.93	.004*	-8.52, -1.62

* Significant at p<.05

Similar to the results obtained from speed compliance analysis, an interaction effect between experimental phase and cluster was revealed for headway time compliance (F(2,70)= 6.97, p=.002). During all phases, headway time compliance rate of lower risk drivers appeared to be greater than that of higher risk drivers (Figure 27). This difference was only significant during the baseline phase (t(70)= 5.05, p<.0001, Table 21). After exposure to the feedback-reward system, the average headway time compliance rate for lower risk drivers increased by an estimated 3.7% (95% CI: -1.58, 8.91) from 89.88% to 93.52%; however, this increase was not significant (t(70)= 1.39, p=.17). During the post-intervention phase this rate dropped to 86.88%, which was lower than that during the baseline (t(70)= -.98, p=.33). Compared to the lower risk drivers, the increase of headway time compliance rate during the intervention phase was about 15% (95% CI: 6.63, 22.57) larger for higher risk drivers (Intervention-Baseline for higher risk vs. Intervention-Baseline for lower risk: t(70)= 3.65, p=.0005). For higher risk drivers, an increase of 18.3% (95% CI: 12.27, 24.26) from 69.58% to 88.07% (t(70)= 6.08, p<.0001) in headway time compliance rate was observed during the intervention phase. After the intervention removal, the compliance rate decreased to 80.69%, however, it was still significantly higher than that during the baseline period (t(70)=3.2, p=.002) (Table22).

Table 21. Pair-wise comparisons of headway compliance rate between clusters within each experimental phase

Comparison		Estimate	df	t value	p-value	95%CI
A (lower risk) vs. B (higher risk)						
	Baseline	19.02	70	5.05	<.0001*	11.51, 26.53
	Intervention	4.42	70	1.9	.06	-.21, 9.05
	Post- intervention	5.18	70	1.64	.11	-.1.12, 11.5

* Significant at p<.05

Table 22. Pair-wise comparisons of headway compliance rate between experimental phases within each cluster

Comparison		Estimate	df	t value	p-value	95%CI
A (lower risk)						
	Intervention vs. Baseline	3.67	70	1.39	.17	-1.58, 8.91
	Post-intervention vs. Baseline	-2.9	70	-.98	.33	-8.84, 3.03
	Post-intervention vs. Intervention	-6.57	70	-2.93	.005*	-11.05, -2.09
B (higher risk)						
	Intervention vs. Baseline	18.27	70	6.08	<.0001*	12.27, 24.26
	Post-intervention vs. Baseline	10.93	70	3.2	<.002*	4.11, 17.75
	Post-intervention vs. Intervention	-7.33	70	-2.82	.006*	-12.51, -2.15

* Significant at p<.05

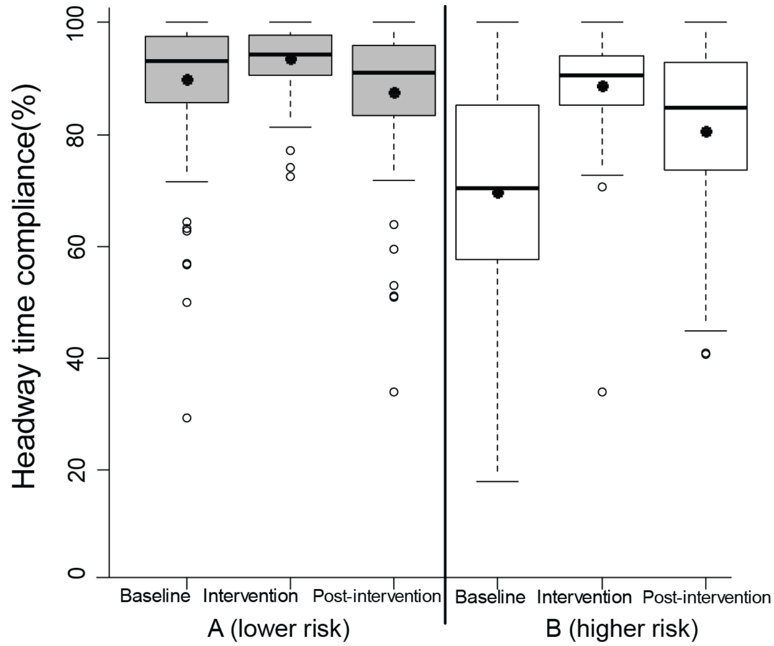


Figure 27. Headway time compliance across experimental phases and clusters

Overall, results of the clustering based on naturalistic driving data revealed two well separated clusters between drivers: Cluster A (lower risk) and Cluster B (higher risk). The speed compliance rates for both lower and higher risk drivers significantly increased after exposure to the intervention. This positive effect sustained for both groups after the system was removed. Similarly, the headway time compliance rate significantly increased for higher risk drivers during the intervention phase. However, the observed increase for lower risk drivers who were significantly more headway and speed compliant to begin with was not significant. For higher risk drivers, an increase of 18.5% in headway time compliance rate was observed during the intervention phase. This effect, although dampened, sustained after the system was removed.

3.4 Questionnaires

As mentioned previously, four questionnaires were filled out online at the following times (Appendix A):

1. Solicitation: general questions about the participant's vehicle, vehicle use, and demographic questions.

2. After the baseline phase: questions on driving attitudes and the installation process.

3. After the intervention phase: driving attitude questions and opinions on experience with the SafeMiles display.

4. After the post-intervention phase: driving attitudes and opinions on the SafeMiles experience, and acceptance of the system.

In the following section the participant responses from the last three questionnaires are presented.

3.4.1 After the Baseline Phase

As indicated in Table 23, the majority of drivers (60.5%) were occasional point collectors, and 77% of participants indicated that they like the type of rewards that they could potentially earn in the SafeMiles project. However, the three most frequently cited reasons (more than one choice was allowed) for participants to volunteer for the SafeMiles Trial were: to find out if the system will influence their behavior (68%), to find out how their current driving performance will score (66%), and out of curiosity (66%). Receiving rewards was the fourth most frequently indicated reason (50%).

Seventy six percent of participants stated that they would check their speed compliance status on the in-vehicle display once or a few time per minute, whereas 66% indicated the same for headway compliance status (Table 24). Further, almost all participants (97% for speed and 100% for headway) stated that they will adjust their driving behavior in accordance with the SafeMiles system.

Table 23. Questionnaire administered after the baseline phase

Question	Response Percent (%)	Response Count
What is most important to you when choosing a new car? (you may check several answers)		
sufficient space	52.9	18
comfort (for instance comfortable seats, air conditioning, quiet)	88.2	30
safety	55.9	19
sporty	20.6	7
status	8.8	3
other	29.4	10
Do you have cruise control in the car?		
yes	94.9	37
no	5.1	2
Do you collect affinity points such as frequent flyer, gas, shopping, etc.?		
yes, I'm a real points collector	36.8	14
I collect points occasionally	60.5	23
no, I never collect points	2.6	1
Which of the following statements describes you best?		
if I collect points, it's mostly for the reward	73.7	28
if I collect points, it's mostly because I like collecting	10.5	4
I mostly collect points for someone else	13.2	5
I'm not interested in collecting, if I do it, it's mostly because I think it's a shame to not use the free points	2.6	1
What do you think of the rewards you can earn with the SafeMiles program?		
I like the rewards I can get with the points	76.3	29
I don't like the rewards I can get with the points	0.0	0
I'm not sure yet whether I like the rewards I can get with the points	23.7	9
Why did you volunteer to participate in the SafeMiles trial? (you can check several answers)		
because I will receive rewards	50.0	19
out of curiosity	65.8	25
to find out if my current driving performance will score	65.8	25
on the advice of someone	5.3	2
because I want to find out if it will influence me	68.4	26
because I like technical gadgets	31.6	12
because I like telling others about it	18.4	7
because I like to participate in contests	7.9	3
because the system may keep me from speeding	39.5	15
because the system may help me to stay at a sufficient distance from the car in front of me	34.2	13
other	18.4	7

Table 24. Questionnaire administered after the baseline phase (cont.)

Question	Response Percent (%)	Response Count
How often do you think you will check the SafeMiles display to see if you are speeding?		
once or a few times per minute	76.3	29
once or a few times every fifteen minutes	15.8	6
once or a few times per hour	2.6	1
once or a few times per day	2.6	1
once or a few times per week	0.0	0
once or a few times per month	0.0	0
never or hardly ever	2.6	1
How often do you think you will check the SafeMiles display to see if you are keeping sufficient distance to the vehicle in front?		
once or a few times per minute	65.8	25
once or a few times every fifteen minutes	18.4	7
once or a few times per hour	7.9	3
once or a few times per day	0.0	0
once or a few times per week	2.6	1
once or a few times per month	0.0	0
never or hardly ever	5.3	2
How often do you think you will check the website www.SafeMiles.net to see how many points you have earned?		
about once a day	36.8	4
about once a week	44.7	5
about once a month	15.8	1
Do you expect to adjust your driving style if the SafeMiles display indicates that you are driving too fast?		
yes, I expect that I will drive slower	97.4	37
no, I don't expect that I will change my speed	2.6	1
Do you expect to adjust your driving style if the SafeMiles display indicates that you are following the vehicle in front of you too closely?		
yes, I expect that I will increase the distance	100	38
no, I don't expect that I will change my following distance	0.0	0
For which reason do you think you will change your driving behaviour because of the SafeMiles program?		
because of the rewards	21.1	8
because of the information that I get while driving the car	71.1	27
because others find it important	5.3	2
I am certain that I will not adjust my behaviour	2.6	1
other	7.8	3

3.4.2 After the Intervention Phase

After the twelve-week intervention phase, participants were sent an email prompting them to complete another on-line questionnaire. As indicated in Table 25, participants in general felt “very” (49%) or “somewhat” (44%) positive about the SafeMiles system. Opinions on different aspects of the system (based on 5-point Likert Scales) are provided in Table 26.

In general about 93% of drivers indicated that they “always” or “often” reduced their speed when the display indicated non-compliance (Table 25). The two most frequently cited reasons for reducing speed were: because it was safer to drive within the speed limit (68%), and it limited the chance of getting a fine for speeding (60%). Further, being under time pressure was selected by the highest number of participants (62%) as the most important reason for not slowing down, followed by negative reactions from other drivers (41%) (Table 27).

As illustrated in Table 28, 82% of participants thought that the minimum headway time that they were asked to maintain during the experiment (1.2 seconds) was “exactly right” or “somewhat too big”, with 5% perceiving it as “much too big”. Overall, 83% of drivers selected safety as one of the most important reasons for increasing headway; “receiving rewards” came second with 43% of drivers selecting it. In addition, 75% of drivers indicated that the primary reason for not increasing headway when provided with feedback was the other vehicles cutting in.

Table 25. Questionnaire administered after the intervention phase

Question	Response Percent (%)	Response Count
In general, what is your opinion of the SafeMiles system? (here we mean the device itself and its operation, not the installation or the rewards)		
very positive	48.8	29
somewhat positive	43.9	18
neutral	2.4	1
somewhat negative	4.9	2
very negative	0.0	0
Has your own driving behaviour changed lately compared with the first weeks that the SafeMiles system was working?		
I've started to pay more attention to the display	29.3	12
I pay as much attention to the display as in the beginning	43.9	18
I've started to pay less attention to the display	26.8	11
Are you under the impression that the SafeMiles system identifies the correct speed limits (as they are posted)?		
always	12.2	5
mostly	80.5	33
sometimes	7.3	3
hardly ever	0.0	0
Has the number of times you check the SafeMiles display to see whether you are speeding changed since the start of the SafeMiles trial?		
yes, I have started to check the display more often	26.8	11
yes, I have started to check the display less often	29.3	12
no, I check the display just as often	43.9	18
Do you reduce your speed if the SafeMiles display indicates that you are speeding?		
yes, almost always	70.7	29
yes, often	22.0	9
yes, sometimes	7.3	3
no, almost never	0.0	0
it hardly ever/never happens that the display indicates that I am speeding	0.0	0
it hardly ever/never happens that I check my speed on the display	0.0	0

Table 26. Questionnaire administered after the intervention phase: opinions on different system aspects

Answer Options	Response Percent (%) 1	2	3	4	5	count
What do you think of the following aspects of the SafeMiles system?						
Ease of reading the display was poor -> good	5	5	10	12	68	41
How the system worked overall poor -> good	2	5	22	44	27	41
The amount the display distracted you while driving? a little -> a lot	45	23	25	8	0	40
When driving with the system you feel calm -> restless	41	20	32	5	2	41
When driving with the system you feel relaxed -> strenuous	34	29	24	10	2	41
Driving with the system is easy -> hard	71	10	12	2	5	41
Driving with the system is not tiring -> tiring	73	10	12	0	5	41
Because of the system my fuel consumption has decreased -> increased	16	21	55	3	5	38
Because of the system my drives are shorter - > longer	0	0	79	13	8	38
Because of the system when I drive I feel less hurried -> more hurried	28	5	46	15	5	39

Table 27. Questionnaire administered after the intervention phase (cont.)

Question	Response Percent (%)	Response Count
For you personally, what are the most important reasons to reduce your driving speed if the SafeMiles display indicates that you are speeding? (you can check several answers)		
because I think it is safer to drive the speed limit	67.7	27
because I think it's a challenge or a game to drive the speed limit	35.0	14
to limit the chance of getting a fine for speeding	60.0	24
because the yellow light irritates me	20.0	8
because my passenger(s) think it's important	10.0	4
other	20	8
For you personally, what are the most important reasons to NOT reduce your driving speed if the SafeMiles display indicates that you are speeding? (you can check several answers)		
because I'm in a hurry/want to arrive on time	62.1	18
because I think my speed is still safe	27.6	8
because I don't care for collecting points	0.0	0
because I don’t want to be a follower in traffic	10.3	3
because then I get negative reactions from other drivers	41.4	12
because driving the speed the SafeMiles display indicates, is not 'comfortable'.	13.8	4
because I think the speed the SafeMiles display advises is less safe than the speed I usually go	3.4	1
because I do not care for the SafeMiles system	0.0	0
other	55.17	16

Table 28. Questionnaire administered after the intervention phase (cont.)

Question	Response Percent (%)	Response Count
What do you think of the indication of the following distance on the SafeMiles display?		
very correct	27.5	11
somewhat correct	55.0	22
somewhat incorrect	17.5	7
very incorrect	0.0	0
Has the number of times you check the SafeMiles display to see if you are following too closely changed since the beginning of the SafeMiles trial?		
yes, I am checking the display more often	26.8	11
yes, I am checking the display less often	19.5	8
no, I check the display just as often	53.7	22
What do you think of the following distance the SafeMiles display likes you to keep?		
much too big	4.9	0
somewhat too big	41.5	3
exactly right	41.5	12
somewhat too small	9.8	4
much too small	2.4	1
In your opinion, what are the most important reasons to increase your following distance if the SafeMiles display indicates that you are following the vehicle in front of you too closely? (you can check several answers)		
to collect points	42.5	17
because I think it's safer to keep the suggested following distance	82.5	33
because I think it's a challenge or a game to keep the suggested following distance	30.0	12
to limit the chances to get a fine for following too closely	7.5	3
because the yellow light irritates me	25.0	10
because my passenger(s) think it's important	10.0	4
other	10.0	4
For you personally, what are the most important reasons to NOT increase the distance to the car in front of you, when the SafeMiles display indicates that you are following too closely? (you can check several answers)		
because I follow closely for a reason, for instance to indicate to the car in front of me that I want to pass	12.9	4
because I think that my following distance is safe	25.8	8
if I keep enough distance other cars will cut in, and then I will follow those cars too closely	74.2	23
because I do not care for collecting points	0.0	0
because I do not care for the SafeMiles system (I do not like being told what following distance to drive)	0.0	0
other	25.8	8

3.4.3 After the Post-intervention Phase

The final questionnaire was emailed to the drivers immediately after the post-intervention phase. Ninety two percent of drivers thought that they were “much” or “somewhat” more speed compliant during the SafeMiles Trial compared to before the trial. Further, 77% of drivers stated that they increased their following distance “much” or “somewhat” more after the SafeMiles Trial (Table 29).

In general, all drivers indicated that they would appreciate to be rewarded for safe driving. Ninety two percent thought that information displays should be installed in vehicles by the manufacturers (Table 29). Further, 62% stated that they would want an information display in their car which particularly focuses on speed and following distance.

Table 29. Questionnaire administered after the post-intervention phase

Question	Response Percent (%)	Response Count
Do you find that you stick to the speed limit more, during the SafeMiles trial compared to before the trial?		
yes, much better	47.5	19
yes, somewhat better	45.0	18
no, I stick to the speed limit anyway	0.0	0
no, it did not change the speed at which I usually drive	7.5	3
Do you find that you have increased your following distance since the SafeMiles trial compared with before the trial?		
yes, much more	12.5	5
yes, somewhat more	65.0	26
no, I keep the same following distance	22.5	9
no, I've decreased my following distance	0.0	0
How do you like driving without the speed limit information given by the SafeMiles display?		
I very much miss the speed limit information	25.0	10
I somewhat miss the speed limit information	70.0	28
I don't miss the speed limit information	5.0	2
How do you like driving and not collecting points and rewards with the SafeMiles system?		
I very much miss the points and rewards	50.0	20
I somewhat miss the points and rewards	37.5	15
I don't miss the points and rewards	12.5	5
Would you like to have a display in your car that indicates whether you are speeding or following too closely while you are driving?		
yes, but I would only appreciate information on speeding	22.5	9
yes, but I would only appreciate information on following too closely	0.0	0
yes, I would appreciate information on speeding as well as following too closely	62.5	25
it doesn't really matter to me	15.0	6
no, I would not appreciate that, because …	0.0	0
Do you think manufacturers should have to equip their vehicles with such an information display?		
yes, I think it is a good idea	92.5	37
no, I do not think it is a good idea	7.5	3

Chapter 4

4 Discussion

This thesis investigates the short and long term effects of a feedback-reward system in enhancing speed compliance and promoting safe headway times. To this end, data collected through an on-road experiment commissioned by Transport Canada were utilized. This on-road experiment, SafeMiles Trial, collected data from four age groups (20s, 30s, 40s, and 50+) and consisted of three phases: baseline, intervention, and post-intervention. During the intervention phase, participants were provided with feedback on their headway maintenance as well as their speed compliance and were also rewarded financially.

4.1 Speeding Behaviour

Mixed linear models were built to investigate if and how intervention affected speeding behaviour. Speeding behaviour was operationalized as speed compliance rate and degree of speeding during instances when drivers were not within the safe speed criterion (GPS based speed $\leq$ PSL + 2 km/h). In addition to the intervention, the models statistically controlled for other factors, namely age, gender, and speed limit zone (50, 60, 70, 80, 90, 100 km/h). To control for the traffic flow effect, models were built on the entire dataset as well as on the subset of the data with no lead vehicle presence. The analyses were conducted at the experimental phase level as well as at a weekly level of aggregation. The findings have been published and presented in Merrikhpour, Donmez, and Battista [105].

Overall, the results indicate that the feedback-reward system increased speed compliance rate. The positive benefits observed with the intervention sustained even after the system was removed. However, there was a decline in the amount of compliance from the intervention to the post-intervention phase. These results are in line with the findings reported from the SafeMiles [32, 33] and the Belonitor Trials [34]. Further analysis was conducted on a subset of the entire data, in which no lead vehicle was present. This additional analysis is arguably more informative of speed limit compliance given the opportunity to speed when there is no vehicle present ahead. The intervention effect was the same. However, when intervention was removed, the positive benefits were found to sustain only for high speed limits, namely 70, 80, 90 and 100 km/h speed limit zones. The persistence of positive feedback effects at large speed limit zones rather than smaller ones would arguably provide a greater benefit to safety given the faster reaction times required and the higher crash severity outcomes associated with larger speeds [42, 43, 106].

Our analyses at the weekly level of aggregation for both the entire and the no lead vehicle data revealed that the intervention effect was apparent throughout the twelve weeks of intervention, and there was no significant difference between average speed compliance over the first and second halves of the intervention period. These findings are consistent with the results of Harms et al. [100], who investigated the effects of an ISA system in combination with economic incentives. On the other hand, the results of the large-scale Swedish field trial indicated that although ISA systems have a positive effect, this effect can attenuate over time [18]. Thus, one explanation for the persistence effect found in this thesis can be the presence of economic incentives. This argument is also supported by subjective accounts from the participants as all participants stated that they appreciated to be rewarded for good driving. Similarly, Warner et al. [31] suggested that economic incentives can result in a more sustained improvement. However, it should be noted that the post-intervention phase in the current study was two weeks. Although no decreasing trend for speed compliance rate was revealed from the first to the second week of the post-intervention phase, investigating drivers' adaptation to the system over a longer period of time is necessary.

When drivers were noncompliant, a significant main effect of intervention was observed on the degree of speeding measured through the maximum deviation from the posted speed limit, and this positive effect sustained in the post-intervention phase. Results obtained from the subset of data with no lead vehicle presence revealed the same findings, suggesting that maximum speed values during noncompliance likely were reached when there was no lead vehicle ahead.

Compared to other age groups, drivers in their 40s appeared to be less speed compliant at 90km/h speed limit zones but when noncompliant they reached lower speeds in 100km/h speed limit zones. Although differences have been reported across age groups regarding choices of speed with older drivers maintaining lower speeds than younger drivers [107], the current study did not reveal major differences. The lack of significant age effects is likely due to the participant ages ranging from young to mid-age without a clear older group. Further, lack of statistical power due to age inherently being a between subject variable is another explanation.

4.2 Tailgating Behaviour

Mixed linear models were built to investigate the effects of the intervention on tailgating behaviour in the presence of a lead vehicle. The dependent variables used were headway time compliance rate and average headway time. In addition to the intervention, the models statistically controlled for other factors, namely driver age, gender, and speed limit zone. In all analyses, driving time within each experimental phase (baseline, intervention, post-intervention) and speed limit zone (50, 60, 70, 80, 90, 100 km/h) combination when there was a lead vehicle present was considered as a covariate to control for exposure to car following conditions within different speed limits and experimental phases. Similar to the analyses of speeding behaviour, the analyses of car following behaviour were also conducted at the experimental phase level or at a weekly level of aggregation. The findings have been published and presented in Merrikhpour, Donmez, and Battista [108].

In general results on headway compliance are in line with speed limit compliance results, with the intervention having a positive effect on compliance. In particular, the headway time compliance rate significantly increased by about 10% in the intervention phase. However, this positive effect did not sustain when the feedback-reward system was deactivated. The compliance rate after system deactivation was on the average only 3.3% higher than the compliance rate before exposure to the system. These findings are consistent with the results published from the Belonitor Trial conducted in the Netherlands [34] and another recent study by Young, et al. [109].

Our analysis also revealed that during the second half of the intervention phase, the headway compliance rate decreased markedly, although it stayed still significantly higher than it was in the baseline. Moreover, the average headway time increased significantly in the first six weeks of the intervention phase; however, this positive effect was not apparent in the second six weeks. According to subjective data, 75% of drivers indicated that the primary reason for not increasing the headway time was the other vehicles cutting in.

When noncompliant cases were considered, average headway times were in general significantly higher in the intervention period compared to the baseline. This benefit sustained for male drivers when the intervention was removed. These results suggest that although some drivers were not compliant at times when feedback was present, there was still a positive effect of feedback on the degree of noncompliance.

Shinar and Schechtman [91] also found that feedback generated a significant increase in average headway times as well as compliance rates. The feedback in [91] consisted of a visual (a warning light turned on for headway time ≤ 1.2 seconds) and an auditory component (a buzzer turned on for headway time ≤ 0.8 seconds) and resulted in a 7.4% increase in headway compliance rates (defined the same way as in this thesis). It should be noted that there appears to be differences between the Israeli drivers investigated in [91] and the Canadian drivers investigated in our study. Our participants were considerably more conservative to begin with (2.45 seconds average headway time and a 81.0% compliance rate in the baseline condition) than the participants of Shinar and Schechtman [91] (1.24 seconds average headway time and a 57% compliance rate in the baseline condition). Potential reasons for this difference are various, including safety culture, traffic environment, and roadway infrastructure. For example, in a study conducted by Ozkan et al. [110], frequency of aggressive (including an interpersonally aggressive component) and ordinary violations (deliberate deviation from the highway code without an aggressive aim) were examined in the UK, Finland, the Netherlands, Greece, Turkey, and Iran. The results showed that, Greek drivers committed aggressive violations more frequently than did Turkish and Iranian drivers, while Finnish, British, and Dutch drivers committed aggressive violations the least frequently. Further, Finnish, British, Dutch, and Iranian drivers committed ordinary violations more frequently than did Greek and Turkish drivers.

Another interesting finding was that the average headway time decreased with increasing speed limits, from 3.06 seconds at 50 km/h speed limit zones to 2.20 seconds at 100 km/h speed limit zones. Research has shown that drivers are generally not good at estimating headway accurately [63-65]. According to Taieb-Maimon et al. [65] drivers tend to largely overestimate headway time, and the error in estimation is larger for higher speeds. This differential error in headway time estimation can potentially explain why drivers in our study maintained lower headway times in higher speeds.

4.3 Cluster Analysis

The average linkage hierarchical clustering was applied to data from the 37 drivers to further understand individual differences and to explore natural groupings among drivers. The clustering was based on naturalistic driving data recorded in the baseline period. The two variables used to classify the drivers were the speed and headway compliance rates during the baseline. According to the results, two clusters were identified. Cluster A (lower risk) included 21drivers and was characterized by significantly higher scores on both speed and headway compliance rates observed during the baseline period. On the other hand, 16 drivers in Cluster B (higher risk) had lower scores in speed and headway compliance rates.

Two mixed linear models were fitted using speed and headway time compliance rate as response variables and driving time as exposure. The effects of intervention, driver age, driver gender, speed limit zone, clusters, and their two-way interactions were investigated.

Overall, the results on speed compliance indicated that during the intervention phase, the speed compliance rates for both lower and higher risk groups significantly increased, suggesting that both groups of drivers can benefit from the intervention. As desired, compared to the lower risk drivers, the increase of speed compliance rate during the intervention phase was about 8% larger for higher risk drivers. In fact, the compliance rate of the higher risk drivers reached to the level of compliance observed for the lower risk group.

Similarly, the headway time compliance rate appeared to increase for both groups during the intervention phase. However, this increase (3.6%) was not significant for the lower risk drivers who were significantly more headway and speed compliant to begin with. For higher risk drivers an increase of 18.5% in headway time compliance rate was observed during the intervention phase. This effect, although dampened, sustained after the system was removed. Similar to the results obtained for speed compliance, the headway compliance rates of the two clusters after exposure to the system did not result in a statistical significant difference.

In summary, the results indicate that the feedback-reward system can be an effective countermeasure and can improve speeding and tailgating behaviours. As to whether the observed benefit was due to the feedback, the reward, or the combination of the two, several questions were included in the questionnaires. According to survey data, the three most frequently cited reasons (more than one choice was allowed) for participants to volunteer for the SafeMiles Trial were: to find out if the system will influence their behavior (68%), to find out how their current driving performance will score (66%), and out of curiosity (66%). Reward was the fourth most frequently indicated reason (50%). Further, 80% of participants stated that they were highly affected by real-time feedback, and 40% indicated that the obtained points which were presented on the in-vehicle display had a large influence in their behaviour. Therefore, according to the subjective data the point-based feedback may have a larger effect on driving behaviour than the economic incentives. Further research is needed to test this hypothesis.

Chapter 5

5 Conclusion and Future Research

Traffic crashes result in approximately 1.2 million deaths every year [1]. Human error is estimated to be the sole cause in 57% of all traffic crashes and a contributing factor in over 90% of them [3]. Speeding and tailgating behaviours are two human behaviours of concern which contribute to a major proportion of crashes [36-38, 55-58]. This thesis investigated the effect of a feedback-reward system on these two risky behaviours. The feedback-reward system resulted in a significant increase in speed limit compliance, and this positive effect, although dampened, was still apparent after system removal. Further, when considering cases with no lead vehicle ahead, the positive effect persisted for high speed limit zones. Similarly, results on headway compliance rate indicated a positive intervention effect, however, this effect did not sustain after system removal. In addition, a cluster analysis revealed two groups of drivers that differed based on naturalistic driving recorded during the baseline: lower risk and higher risk drivers. As one would desire, the higher risk drivers benefitted more from the system.

Although promising results were revealed, it is not clear if the observed benefits are due to either feedback, or reward, or both. Therefore, future research should isolate the contributions of feedback and reward components of the system.

Furthermore, potential unintended negative consequences of the system should also be investigated. According to survey data of the large-scale Swedish field trial [18] presented earlier in the thesis, different levels of automation can affect various dimensions of workload in different ways. For example, results indicated that the drivers who used the ISA feel more “in the way of others” than those without ISA. This applies to a somewhat higher degree for drivers of intervening and informative systems than warning system. Further, another ISA study revealed that self-reported data indicated that drivers with an intervening system perceived higher levels of mental demand and experienced higher frustration levels compared to drivers without an ISA system [19]. Future research is needed to thoroughly evaluate the potential negative consequences of the SafeMiles system, such as unintended levels of workload or distraction.

In the current study, speeding behaviour analyses were conducted on both the entire dataset and the subset of the data with no lead vehicle presence. Further analysis on the subset of data with lead vehicle presence is needed to investigate the speeding behavior particularly for car following situations.

Another important research question which needs to be addressed is long-term adaption to the system. The post-intervention phase in the current study was two weeks. Although no significant decreasing trend for speed and headway compliance rates was revealed during the first and second weeks of the post-intervention phase, investigating drivers' adaptation to the system over a longer period of time is necessary.

The feedback system evaluated in the current study provided drivers with visual feedback. Given that auditory signals or a combination of visual and auditory feedback have been shown to have promising results [17, 18, 64], further research should certainly investigate the appropriate modality of feedback. Further, as mentioned previously, in the current study, the participants' ages ranged from young to mid-age without a clear older group. The lack of significant findings across age groups may be due to this limitation. Last but not least, the optimal reward structure and reward type should also be investigated for best behavioural change results.

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6 Appendices

Appendix A. Questionnaires

SafeMiles #1 Solicitation

1. Welcome to the SafeMiles Participation Application

Transport Canada is conducting a research trial of in-vehicle technology that is aimed at improving driving and road safety through providing incentives to drive within the speed limits and maintain adequate headway (distance to the vehicle ahead). The Centre for Sustainable Transportation at the University of Winnipeg, is soliciting Winnipeg area drivers to participate in the study.

A small information system will installed on the participant's vehicle which continuously informs you of the local speed limit and your headway. To encourage you to be more compliant in your driving, the program will reward you with good driving points for the time when your obeying the speed limit and headway distance. These points can then be redeemed for gift certificates and specific rewards. We expect that the average participant will receive the equivalent of $300 for their participation over a 16 week period.

For this trial, we are enlisting a sample of 50 drivers of all ages from the Winnipeg area. We are looking for 1996 or newer model year vehicles that are driven more than 300 km per week.

In the following questionnaire, you will be asked to provide a few facts about yourself and your driving behaviour. The information you provide will determine if you fit our selection profile.

Any information provided will be kept completely confidential pursuant to federal government privacy rules. If you are selected, we will send you an e-mail or call you to set up the next step.

1. Do you want to apply for participation?

◯ Yes ◯ No

2. The SafeMiles Demonstration

Rush, rush, rush …

We are all in a rush. Each day millions of people in the Canada spend part of their day driving. During the past decades road use has increased at greater rate than the capacity of our road network. The results are clearly visible: congested roads and irritated drivers – a state that is not exactly conducive to road safety.

Building more roads to ease the flow is not always the best solution because of the costs, disruption and time delays. Therefore, governments have been exploring ways to utilise the existing infrastructure in a better, more efficient, safer and more environmentally conscious way. Increasingly, the technology we have at our disposal gives us the opportunity to find new solutions.

Every year tailgating and speeding are causes of many road accidents and traffic jams. Inevitably, road users come frustrated by this behaviour. With its positive approach the SafeMiles system contributes to the alleviation of these problems. Drivers are rewarded if they stay within the speed limit and keep a safe distance from the car in front.

Changing or influencing behaviour can be realised through two opposite techniques: rewarding and punishing. Through rewards, desired behaviour is stimulated and made attractive. For this to be successful, the reward should be given promptly and consistently. In this way, the system remains transparent and fair, with the recipient knowing exactly what to expect and when to expect it.

This is precisely what the SafeMiles demonstration is all about!

Changes in behaviour can also be encouraged by punishing undesired behaviour. This principle lies behind the Canadian road rules enforcement system as it stands today. The disadvantage of a penalty system is that the person being punished is made aware of their wrongdoing in a negative way and thus, are less likely to moderate their behaviour.

This research trial is a replication of a trial of one that was undertaken by the Dutch Directorate-General of Public Works and Water Management (Rijkwaterstaat) in 2005 which aimed to evaluate the effects of a rewards-based feedback system in changing driving behaviour. The "Belonitor", a contraction of the words 'belonen' (to reward) and 'monitoren' (to monitor), was a very successful pilot of the idea of providing information in the form of real-time driving behaviour feedback and a carrot – financial rewards for "good driving".

In order to evaluate the possibilities of the technology and incentive techniques, Transport Canada has contracted with group of companies which includes GW Taylor Consulting, Persen Technologies Ltd., and the Centre for Sustainable Transportation to develop and test a similar system to evaluate its performance here in Canada. We have selected the SafeMiles name for the Canadian trial.

HOW THE SYSTEM WORKS

The on-board equipment measures two aspects of driving behaviour – speed and headway. The equipment consists of three components:

* a device called OttoView-CVS41, that includes an integrated display, Global Position System (GPS) receiver, a vehicle diagnostic instrument, a wireless transmitter, and a digital speed map of Winnipeg and the surrounding area
* a connection to the vehicle's on-board diagnostic system to measure fuel use
* a small radar distance sensor

Through four icons, the display shows whether driving behaviour is "correct". At the correct speed a small green icon illuminates; if the speed limit is exceeded a yellow one illuminates. The same applies to the minimum safe distance from the car in front: green for the correct distance, yellow when you are too close. Speed and distance are assessed every second and when you have driven for 15s of consecutive compliant driving, you are credited with 1 point. Your trip point total is displayed when the ignition is turned off. At the end of every trip, the data is sent from the vehicle to a website which provides a total of all you points and in

3.

THE 3 PHASES OF THE TRIAL

In order to accurately measure the effect of the reward system, the test is divided into three phases:

1st phase: pre-trial baseline ---- 2 weeks
This phase involves the observation of driving behaviour. The in-vehicle equipment records the vehicle activity but the participants receive no feedback or reward points.

2nd phase: Trial phase ----- 12 weeks
In this phase, the participant receives feedback and reward points for driving correctly.

3rd phase: post-trial baseline ----- 2 weeks
In the final phase, driving behaviour is observed, but as in phase one without feedback or the possibility of earning reward points. This phase gives an indication of whether the behaviour change in the previous phase persisted.

The Rewards

Through limiting their speeds to below the posted speed limit and maintaining reasonable headway to the vehicle in front, the participants will earn “good driving” points. For every fifteen seconds of correct driving behaviour (meeting both criteria) participants received one “good driving” point. These points can then be redeemed for a selection of goods and services.

In order to prevent participants from driving more to earn extra points, the behaviour points were adjusted so what we reward is an increase in the percentage of their driving that is “good”.

A typical participant is expected to earn the equivalent of $300 over the course of the 16 week trial.

This what the display inside will look like.

2. Do you want to continue?

◯ Yes

◯ No

3. Name

First ____________________

Last ____________________

4. What is your gender?

- ◯ Male
- ◯ Female

5. What is your age?

- ◯ 16-19
- ◯ 20-24
- ◯ 25-29
- ◯ 30-34
- ◯ 35-39
- ◯ 40-44
- ◯ 45-49
- ◯ 50-54
- ◯ 55-59
- ◯ 60-64
- ◯ 65-69
- ◯ 70-74
- ◯ 75-79
- ◯ 80-84
- ◯ 85+

6. Please provide your e-mail address so we can get in touch with you.

7. Please provide a contact phone number.

8. What is your home address?

Address

Apartment or Unit Number

City

Postal Code

4. Home and Work

A few questions about your household and work.

9. Please describe your household situation?

	0	1	2	3	4	5	more than 5
Adults	☐	☐	☐	☐	☐	☐	☐
Drivers	☐	☐	☐	☐	☐	☐	☐
Children (under 5 years)	☐	☐	☐	☐	☐	☐	☐
Children (5-10 years)	☐	☐	☐	☐	☐	☐	☐
Children (11-16 years)	☐	☐	☐	☐	☐	☐	☐

10. What is your household total income?

- ◯ Less than $10,000/yr
- ◯ $10-20,000
- ◯ $20-30,000
- ◯ $30-40,000
- ◯ $40-50,000
- ◯ $50-60,000
- ◯ $60-70,000
- ◯ $70-80,000
- ◯ $80-90,000
- ◯ $90-100,000
- ◯ $100-110,000
- ◯ $110-120,000
- ◯ more than $120,000/yr

11. What is your employment status?

- ◯ Employee (full or part time)
- ◯ Self-employed
- ◯ Homemaker
- ◯ Student
- ◯ Retired
- ◯ Unemployed

Other (please specify)

12. If you work, where is your office location?

- ◯ Downtown Winnipeg
- ◯ Winnipeg East inside the Perimeter
- ◯ Winnipeg South inside the Perimeter
- ◯ Winnipeg West inside the Perimeter
- ◯ Winnipeg North inside the Perimeter
- ◯ East of Winnipeg
- ◯ South of Winnipeg
- ◯ West of Winnipeg
- ◯ North of Winnipeg
- ◯ Home office

Other (please specify)

____

13. What is the highest level of schooling that you have completed?

- ◯ Some high school
- ◯ Graduated from high school (grade 12-13)
- ◯ Vocational/Technical college
- ◯ Private college graduate
- ◯ Some university
- ◯ Bachelor’s degree
- ◯ Graduate degree

5. Your vehicle and driving habits

We are looking for participants of all types but we do want people whose vehicles are driven a fair amount. A rough criteria for appropriate usage would be that the vehicle uses over a tank of gas per a week or more than 300 km. If your vehicle is not used this much, we thank you for your interest but we are not able to use your participation in this survey.

14. What vehicle would be driven during this trial?

Make ____________________

Model ____________________

15. Model year

- ◯ 1996
- ◯ 1997
- ◯ 1998
- ◯ 1999
- ◯ 2000
- ◯ 2001
- ◯ 2002
- ◯ 2003
- ◯ 2004
- ◯ 2005
- ◯ 2006
- ◯ 2007
- ◯ 2008
- ◯ 2009

16. Transmission type

- ◯ Manual
- ◯ Automatic

17. Engine size (number of cylinders)

- ◯ 4
- ◯ 6
- ◯ 8

18. Thinking about a normal week, please estimate the distance (km) travelled.

- ◯ less than 300
- ◯ 301-400
- ◯ 401-500
- ◯ 501-600
- ◯ 601-700
- ◯ over 700

19. Thinking of the normal week, how much fuel (Litres) would you purchase?

- ◯ under 50
- ◯ 51-80
- ◯ 81-100
- ◯ 101-120
- ◯ 121-140
- ◯ more than 140

20. How many drivers use this vehicle?

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ more than 4

21. Please select the type of usage that is typical in a week.(Select as many as are appropriate.)

- ☐ Commuting
- ☐ Business
- ☐ Shopping
- ☐ Social
- ☐ Recreational
- ☐ Ex-city driving
- ☐ Long distance trip

22. If the vehicle is used for commuting, what is the one-way distance or time for the commute trip?

	under 10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	over 90
Distance (km)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Time (min)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

23. Over a three month period, how often would you make a long trip of more than 100 km?

- ◯ Almost never
- ◯ 1-5
- ◯ 5-10
- ◯ 10-15
- ◯ 15-20
- ◯ over 20

24. What class of driving licence do you hold?

- ◯ 5: non-commercial car or light truck
- ◯ 1-4: commercial vehicles
- ◯ GDL: Level 2 graduated licence

25. How many years have you had a driver's licence?

- ◯ under 5
- ◯ 5-10
- ◯ 11-25
- ◯ more than 25

26. How many traffic collisions with damage or injury have you been involved in as a driver?

	0	1	2	3	4	5	more than 5
within the last year	☐	☐	☐	☐	☐	☐	☐
1-3 years	☐	☐	☐	☐	☐	☐	☐
3-5 years	☐	☐	☐	☐	☐	☐	☐
more than 5 years ago	☐	☐	☐	☐	☐	☐	☐

27. How many speeding or moving violation tickets have you had?

	1	2	3	4	5	more than 5
Within the last year	☐	☐	☐	☐	☐	☐
1-3 years	☐	☐	☐	☐	☐	☐
3-5 years	☐	☐	☐	☐	☐	☐
more than 5 years ago	☐	☐	☐	☐	☐	☐

28. Have you ever participated in a driving behaviour modification program?

◯ Yes ◯ No

6. The Driving Experience

Now we would like to have you tell us your opinions of how you view the driving experience. Remember, there are no "right" answers.

29. Do you like driving? I think driving is

- ○ very unpleasant
- ○ somewhat unpleasant
- ○ not pleasant nor unpleasant
- ○ somewhat pleasant
- ○ very pleasant

30. How would you characterize your driving style? (CHECK THE BOX BETWEEN TWO TERMS THAT MOSTLY REFLECTS YOUR DRIVING STYLE)

	o	o	o	o	o
relaxed -> tense	☐	☐	☐	☐	☐
calm -> restless	☐	☐	☐	☐	☐
fast -> slow	☐	☐	☐	☐	☐
attentive -> inattentive	☐	☐	☐	☐	☐
safe -> unsafe	☐	☐	☐	☐	☐
aggressive -> courteous	☐	☐	☐	☐	☐

31. As a driver, do you get annoyed with other drivers? (YOU CAN CHECK AS MANY ANSWERS AS YOU LIKE)

- ☐ yes, I get annoyed with drivers that stay in the left lane of the highway for too long
- ☐ yes, I get annoyed with drivers that drive too slow on a 80km-road
- ☐ yes, I get annoyed with drivers that drive too fast
- ☐ yes, I get annoyed with drivers that merge too slowly onto the highway
- ☐ yes, I get annoyed with drivers that tailgate
- ☐ yes, I get annoyed with drivers that pass on the right
- ☐ yes, I get annoyed with drivers that flash their lights
- ☐ yes, I get annoyed with trucks that pass each other while going only marginally faster
- ☐ yes, I get annoyed with trucks that move to the left lane to pass without checking
- ☐ yes, I get annoyed with motorcyclists
- ☐ no, I never get annoyed with other drivers

yes, I get annoyed with

____

32. Do you collect affinity points such as Aeroplan, Air Miles, PetroPoints, etc.?

- ◯ yes, I'm a real points collector
- ◯ I collect points occasionally
- ◯ no, I do not collect points

33. Would you appreciate being rewarded for good driving behaviour?

- ◯ yes, I would appreciate that
- ◯ it would not make much difference to me
- ◯ no, I would not appreciate that

34. If you were to be rewarded for good driving behaviour, which kind of rewards would you appreciate the most? (YOU CAN CHECK SEVERAL ANSWERS)

- ☐ extra accessories for my car
- ☐ special activities (such as a cook who prepares a meal in my house, a flying lesson)
- ☐ discounts on my insurance premium
- ☐ discounts on fuel purchases
- ☐ discounts on store purchases
- ☐ collecting points (for instance Air miles)
- ☐ money deposited in my bank account
- ☐ a minimal reward (for instance appreciation of the employer or the possibility to win a contest)

Other (please specify)

35. At what speed do you usually drive on a clear day and when there is little or no traffic on the road?

	80	85	90	95	100	105	110	115	120	125	>125
on the divided highway with a speed limit of 100 km/hr	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
on a two-lane 80km/hr highway	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

36. Would you like to have a display in your car that indicates whether you are speeding or not while you are driving?

- ◯ yes, I would appreciate that
- ◯ it would not matter to me
- ◯ no, I would not appreciate that

37. Would you expect to adjust your speed if a display indicates that you are going too fast?

- ◯ yes, I expect that I will drive slower
- ◯ no, I don't expect I will change my speed

38. In general, do you think that you keep enough of a following distance?

- ◯ most of the time
- ◯ sometimes
- ◯ mostly not

39. Would you like to have a display in your car that indicates whether you are following the vehicle in front of you too closely while you are driving?

- ◯ yes, I would appreciate that
- ◯ it would not matter to me
- ◯ no, I would not appreciate that

40. Would you expect to adjust your speed if a display indicates that you are following too closely?

- ◯ yes, I expect I will increase the following distance
- ◯ no, I expect I won't change my following distance

41. How did you find out about the SafeMiles trial?

- ◯ A friend or colleague
- ◯ Media article or report
- ◯ Phone call or e-mail from the Centre for Sustainable Transportation
- ◯ Other

Other (please specify)

[ ]

7.

Finally, we would like a to ask a few questions about the rewards for being involved in the trial.

42. For the trial, your vehicle would have installed a system much like a small radio or iPod but with a forward looking radar system mounted on a bracket attached to the front licence. Would this be acceptable?

- ◯ Yes
- ◯ No

Not sure because ...

43. The installation (and removal at the end of the trial) of the equipment will at a local car stereo shop, be scheduled for a day convenient for you and takes about 30 minutes. Is this acceptable?

- ◯ Yes
- ◯ No

Not sure because

44. After the equipment is installed there will be a period of 2 weeks where nothing happens but we collect data on your driving activity. After the baseline period, the system will start to provide you with feedback about your driving speed and headway and you will earn points when you are driving compliantly. At the end of 12 weeks, the system will stop providing feedback and we will again monitor your driving for another 2 weeks. During the trial you will be required to complete 3 on-line questionnaires similar to this one.

Is this acceptable to you? Please note this answer does not commit you to participate.

- ◯ Yes
- ◯ No

Not sure because ...

45. We intend to compensate you for your efforts and participation in the trial by issuing SafeMiles points based on your "good driving" behaviour. On average, we would expect to distribute rewards with a value of over $300 per participant during the 16 weeks of the active trial. If you are above the average in driving compliance, you will get more points - if you are below, you will get fewer.

Is this type of reward scheme acceptable?

- ◯ Yes
- ◯ No

Not sure because ...

8. Thanks!

So that's it for now. If you decided not to apply , thanks for you time and interest. If you did complete the application then our staff will get back to you in the next few weeks to let you know if we would like your participation in the trial.

Thank you for your interest and drive safely.

If you want more information please contact us at (888) 647-4564

SafeMiles #2 End of Baseline

1. Welcome to the SafeMiles Trial

In the next few days, you will notice that your SafeMiles display will be automatically activated, at which point you will see the display indicating correct or incorrect speed and headway. For every 15 seconds of compliance with both speed and headway above 15 km/h, you will receive one compliance point. The compliance or driving points for a trip are displayed when a vehicle is stopped for at least 10 seconds or after the ignition has been turned off.

The data is continuously sent to our www.safemiles.net site and when you log-in, you will be able to see your driving history and your reward point total. These reward points are calculated based on the compliance points and an adjustment equation that corrects for high vehicle usage.

As we start the trial, we would like you to complete the following questionnaire. Two more questionnaires will be administered. One at the end of the rewards period in November and one when the equipment is removed.

Thank you for participating in the trial, safe driving and we hope you enjoy the challenge of earning SafeMiles points.

1. What is your first and last name?

[ ]

2. What is your SafeMile log in user name?

[ ]

2. Your Vehicle

3. What is most important to you when choosing a new car? (you may check several answers)

- [ ] sufficient space
- [ ] comfort (for instance comfortable seats, air-conditioning, quiet)
- [x] safety
- [ ] sporty
- [ ] status

Other (please specify)

[ ]

4. Do you have cruise control in the car?

○ Yes ○ No

11. How would you characterize your driving style? (check the rating between the two terms that mostly reflects your driving style)

	o	o	o	o	o
relaxed o o o tense	☐	☐	☐	☐	☐
calm o o o restless	☐	☐	☐	☐	☐
slow o o o fast	☐	☐	☐	☐	☐
attentive o o o not attentive	☐	☐	☐	☐	☐
safe o o o unsafe	☐	☐	☐	☐	☐
courteous o o o aggressive	☐	☐	☐	☐	☐

12. As a driver, do you get annoyed with other drivers? (you can check as many answers as you wish)

☐ no, I never get annoyed with other drivers

☐ yes, I get annoyed with drivers that stay in the left lane of the highway for too long

☐ yes, I get annoyed with drivers that drive too slow on a two-lane 80km/h highway

☐ yes, I get annoyed with drivers that drive too fast

☐ yes, I get annoyed with drivers that merge onto the highway too slowly

☐ yes, I get annoyed with drivers that tailgate

☐ yes, I get annoyed with drivers that pass on the right

☐ yes, I get annoyed with drivers that flash their lights

☐ yes, I get annoyed with trucks that pass each other while going only marginally faster

☐ yes, I get annoyed with trucks that move to the left lane to pass without checking

☐ yes, I get annoyed with motorcyclists

Yes, I get annoyed with:

[ ]

13. At what speed do you usually drive on a 100km/hr highway, on a clear day and when there is no traffic on the road?

km/h [ ]

14. At what speed do you usually drive on a two-lane 80km/hr-highway, on a clear day and when there is no traffic on the road?

km/h [ ]

15. Do you flash your high beam when others are driving too slowly?

- ◯ Yes
- ◯ No

16. Do you think driving is tiring?

- ◯ Mostly yes
- ◯ Sometimes
- ◯ Seldom

17. For you personally, is it a problem

	a big problem	somewhat of a problem	no problem
if drivers drive faster than the speed limit?	☐	☐	☐
for society as a whole if drivers drive faster than the speed limit?	☐	☐	☐
if drivers follow each other too closely?	☐	☐	☐
for society as a whole if drivers are following each other too closely?	☐	☐	☐

4. Points and Rewards

18. Do you collect affinity points such as frequent flyer, gas, shopping, etc.?

- ◯ yes, I'm a real points collector
- ◯ I collect points occasionally
- ◯ no, I never collect points (go to question 18)

19. Which of the following statements describes you best?

- ◯ if I collect points, it's mostly for the reward
- ◯ if I collect points, it's mostly because I like collecting
- ◯ I mostly collect points for someone else
- ◯ I'm not interested in collecting, if I do it, it's mostly because I think it's a shame to not use the free points

20. What do you think of the rewards you can earn with the SafeMiles program?

- ◯ I like the rewards I can get with the points
- ◯ I don't like the rewards I can get with the points
- ◯ I'm not sure yet whether I like the rewards I can get with the points

5. SafeMiles Program

21. Why did you volunteer to participate in the SafeMiles trial? (you can check several answers)

- [ ] because I will receive rewards
- [ ] out of curiosity
- [ ] to find out how my current driving performance scores
- [ ] on the advice of someone
- [ ] because I want to find out if it will influence me
- [ ] because I like technical gadgets
- [ ] because I like telling others about it
- [ ] because I like to participate in contests
- [ ] because the system may keep me from speeding
- [ ] because the system may help me to stay at a sufficient distance from the car in front of me

Other (please specify)

22. How often do you think you will check the SafeMiles display to see if you are speeding?

- ○ once or a few times per minute
- ○ once or a few times every fifteen minutes
- ○ once or a few times per hour
- ○ once or a few times per day
- ○ once or a few times per week
- ○ once or a few times per month
- ○ never or hardly ever

23. How often do you think you will check the SafeMiles display to see if you are keeping sufficient distance to the vehicle in front?

- ◯ once or a few times per minute
- ◯ once or a few times every fifteen minutes
- ◯ once or a few times per hour
- ◯ once or a few times per day
- ◯ once or a few times per week
- ◯ once or a few times per month
- ◯ never or hardly ever

24. How often do you think you will check the website www.SafeMiles.net to see how many points you have earned?

◯ about once a day ◯ about once a week ◯ about once a month ◯ never or hardly ever

25. Do you expect to adjust your driving style if the SafeMiles display indicates that you are driving too fast?

- ◯ yes, I expect that I will drive slower
- ◯ no, I don't expect that I will change my speed

26. Do you expect to adjust your driving style if the SafeMiles display indicates that you are following the vehicle in front of you too closely?

◯ yes, I expect that I will increase the distance ◯ no, I don't expect that I will change my following distance

27. For which reason do you think you will change your driving behaviour because of the SafeMiles program?

- ◯ because of the rewards
- ◯ because of the information that I get while driving the car
- ◯ because others find it important
- ◯ I am certain that I will not adjust my behaviour

Other (please specify)

6. Installer Comments

28. What did you think of the installation time and procedure?

◯ Inconvenient ◯ Acceptable ◯ Very Easy

29. If you have any comments or remarks, you are welcome to make them here.

That's the end of this questionnaire!

Thank you for your participation!

SafeMiles #3 End of Feedback Period

1. Your Experiences With The Trial

The SafeMiles activated phase is now over and your display will no longer display SafeMiles information. We will however, be recording driving data for the next two weeks after which you will be scheduled for a equipment removal appointment. We would now like you to complete the following questionnaire on your experience with the SafeMiles program.

Please Note: All questions in this questionnaire relate to your experiences DURING the feedback/rewards portion of the SafeMiles trial.

*** 1. Your first and last name?**

*** 2. Your SafeMiles log in user name?**

3. In general, what is your opinion of the SafeMiles system? (here we mean the device itself and its operation, not the installation or the rewards)

○ very positive ○ somewhat positive ○ neutral ○ somewhat negative ○ very negative

Specific comments?

4. How was your experience with the installation of the SafeMiles system?

○ very positive ○ somewhat positive ○ neutral ○ somewhat negative ○ very negative

Specific comments?

SafeMiles #3 End of Feedback Period

5. What do you think of the following aspects of the SafeMiles system? (check the circle between the two terms that expresses your opinion the best)

	1	2	3	4	5
Ease of reading the display was poor -> good	◯	◯	◯	◯	◯
How the system worked overall poor -> good	◯	◯	◯	◯	◯
The amount the display distracted you while driving? a little -> a lot	◯	◯	◯	◯	◯
When driving with the system you feel calm -> restless	◯	◯	◯	◯	◯
When driving with the system you feel relaxed -> strenuous	◯	◯	◯	◯	◯
Driving with the system is easy -> hard	◯	◯	◯	◯	◯
Driving with the system is not tiring -> tiring	◯	◯	◯	◯	◯
Because of the system my fuel consumption has decreased -> increased	◯	◯	◯	◯	◯
Because of the system my drives are shorter -> longer	◯	◯	◯	◯	◯
Because of the system when I drive I feel less hurried -> more hurried	◯	◯	◯	◯	◯

6. Do you ever drive under time pressure?

◯ hardly ever ◯ sometimes ◯ often

7. Do you drive faster or do you feel more hurried because of time pressure?

◯ no, not at all ◯ yes, somewhat ◯ yes, a lot

8. Do you drive faster or do you feel more hurried if you have lost time due to traffic jams?

◯ no, not at all ◯ yes, somewhat ◯ yes, a lot

9. How do you like driving? I find driving ...

- ◯ very unpleasant
- ◯ somewhat unpleasant
- ◯ not pleasant nor unpleasant
- ◯ somewhat pleasant
- ◯ very pleasant

10. How would you characterize your driving style? (check the circle between two terms that mostly reflects your driving style)

	1	2	3	4	5
relaxed -> tense	◯	◯	◯	◯	◯
calm -> restless	◯	◯	◯	◯	◯
slow -> fast	◯	◯	◯	◯	◯
attentive -> inattentive	◯	◯	◯	◯	◯
safe -> unsafe	◯	◯	◯	◯	◯
courteous -> aggressive	◯	◯	◯	◯	◯

11. Do you honk your horn or flash your high beams when others drive too slowly?

◯ usually ◯ sometimes ◯ never

12. Do you find driving tiring?

◯ most of the time ◯ sometimes ◯ hardly ever

13. As a driver, do you get annoyed with other drivers? (you can check as many answers as you wish)

- [ ] no, I never get annoyed with other drivers
- [ ] yes, I get annoyed with drivers that stay in the left lane of the highway for too long
- [ ] yes, I get annoyed with drivers that drive too slow on a 80km-road
- [ ] yes, I get annoyed with drivers that drive too fast
- [ ] yes, I get annoyed with drivers that merge too slowly onto the highway
- [ ] yes, I get annoyed with drivers that tailgate
- [ ] yes, I get annoyed with drivers that pass on the right
- [ ] yes, I get annoyed with drivers that flash their lights
- [ ] yes, I get annoyed with trucks that pass each other while going only marginally faster
- [ ] yes, I get annoyed with trucks that move to the left lane to pass without checking
- [ ] yes, I get annoyed with motorcyclists

Yes, I get annoyed with ...

14. On average, how often do you check the SafeMiles display?

- ○ once or a few times per minute
- ○ once or a few times every fifteen minutes
- ○ once or a few times per hour
- ○ once or a few times per day
- ○ once or a few times per week
- ○ once or a few times per month
- ○ never or hardly ever

15. How much does each of the following influence your driving behaviour (check the circle between 1= "a little" to 5= "a lot" that most closely reflects your opinion)

	1	2	3	4	5
the feedback on the display during the drive	○	○	○	○	○
the points on the display after the drive	○	○	○	○	○
the reward points on the website	○	○	○	○	○

16. Has your own driving behaviour changed lately compared with the first weeks that the SafeMiles system was working?

- ○ I've started to pay more attention to the display
- ○ I pay as much attention to the display as in the beginning
- ○ I've started to pay less attention to the display

2. Speed

The following questions refer to the driving speed.

17. Are you under the impression that the SafeMiles system identifies the correct speed limits (as they are posted)?

○ always ○ mostly ○ sometimes ○ hardly ever

18. When do you look at the SafeMiles display to see if you are speeding? (you can check several answers)

- ☐ if I suspect that I am speeding
- ☐ if I think there could be a police check (surveillance)
- ☐ it just happens when I look at the dashboard
- ☐ I check without having a special reason
- ☐ I see the display constantly from the corner of my eye

Other (please specify)

19. Has the number of times you check the SafeMiles display to see whether you are speeding changed since the start of the SafeMiles trial?

- ◯ yes, I have started to check the display more often
- ◯ yes, I have started to check the display less often
- ◯ no, I check the display just as often

20. Do you reduce your speed if the SafeMiles display indicates that you are speeding?

- ◯ yes, almost always
- ◯ yes, often
- ◯ yes, sometimes
- ◯ no, almost never
- ◯ it hardly ever/never happens that the display indicates that I am speeding
- ◯ it hardly ever/never happens that I check my speed on the display

21. For you personally, what are the most important reasons to reduce your driving speed if the SafeMiles display indicates that you are speeding? (you can check several answers)

- ☐ because I think it is safer to drive the speed limit
- ☐ because I think it's a challenge or a game to drive the speed limit
- ☐ to limit the chance of getting a fine for speeding
- ☐ because the yellow light irritates me
- ☐ because my passenger(s) think it's important

Other (please specify)

____

22. At what speed do you usually drive on the highway (with a speed limit of 100 km/hr), on a clear day and when there is no traffic on the road?

____

23. At what speed do you usually drive on a two-lane 80km/hr-highway, on a clear day and when there is no traffic on the road?

____

24. For you personally, what are the most important reasons to NOT reduce your driving speed if the SafeMiles display indicates that you are speeding? (you can check several answers)

- ☐ because I'm in a hurry/want to arrive on time
- ☐ because I think my speed is still safe
- ☐ because I don't care for collecting points
- ☐ because I don’t want to be a follower in traffic
- ☐ because then I get negative reactions from other drivers
- ☐ because driving the speed the SafeMiles display indicates, is not 'comfortable' (for instance because I must brake more often or have to change lanes more often)
- ☐ because I think the speed the SafeMiles display advises is less safe than the speed I usually go
- ☐ because I do not care for the SafeMiles system (I do not like being told at what speed to drive)

Other (please specify)

25. Do you increase your speed if the SafeMiles display indicates that you are not speeding?

- ○ yes, almost always
- ○ yes, often
- ○ yes, sometimes
- ○ no, almost never
- ○ it hardly ever happens that the SafeMiles display indicates that I am not speeding
- ○ it hardly ever happens that I check my speed on the SafeMiles display

26. Do you think you drive within the speed limit more often than before you had the SafeMiles display in your vehicle?

- ○ yes, more often
- ○ yes, somewhat more often
- ○ no, I always go the speed limit
- ○ no, I don't stick to the speed limit as much

27. For you personally, is it a problem if drivers drive faster than the speed limit?

- ◯ a big problem
- ◯ somewhat of a problem
- ◯ no problem

28. Do you think it is a problem for society as a whole if drivers drive faster than the speed limit?

- ◯ a big problem
- ◯ somewhat of a problem
- ◯ no problem

3. Following Distance

These questions relate to the following distance.

29. What do you think of the indication of the following distance on the SafeMiles display?

- ◯ very correct
- ◯ somewhat correct
- ◯ somewhat incorrect
- ◯ very incorrect

30. When do you check the SafeMiles display to see if there is sufficient distance between you and the vehicle in front of you? (you can check several answers)

- ☐ if I suspect that I am following too closely
- ☐ if I think there (might) be a police check
- ☐ it just happens when I look at the dashboard
- ☐ I check for no special reason
- ☐ I can see the display constantly from the corner of my eye

Other (please specify)

31. Has the number of times you check the SafeMiles display to see if you are following too closely changed since the beginning of the SafeMiles trial?

- ◯ yes, I am checking the display more often
- ◯ yes, I am checking the display less often
- ◯ no, I check the display just as often

32. What do you think of the following distance the SafeMiles display likes you to keep?

- ◯ much too big
- ◯ somewhat too big
- ◯ exactly right
- ◯ somewhat too small
- ◯ much too small

33. In your opinion, what headway or car following time triggers the "too close" signal?

- ◯ a following time of less than 1 second
- ◯ a following time of 1.0 seconds
- ◯ a following time of 1.2 seconds
- ◯ a following time of 1.8 seconds
- ◯ a following time of 2.0 seconds
- ◯ a following time of more than 2 seconds
- ◯ I have no idea

34. In your opinion, what are the most important reasons to increase your following distance if the SafeMiles display indicates that you are following the vehicle in front of you too closely? (you can check several answers)

- [ ] to collect points
- [ ] because I think it's safer to keep the suggested following distance
- [ ] because I think it's a challenge or a game to keep the suggested following distance
- [ ] to limit the chances to get a fine for following too closely
- [ ] because the yellow light irritates me
- [ ] because my passenger(s) think it's important

Other (please specify)

35. For you personally, what are the most important reasons to NOT increase the distance to the car in front of you, when the SafeMiles display indicates that you are following too closely? (you can check several answers)

- [ ] because I follow closely for a reason, for instance to indicate to the car in front of me that I want to pass
- [ ] because I think that my following distance is safe
- [ ] if I keep enough distance other cars will cut in, and then I will follow those cars too closely
- [ ] because I do not care for collecting points
- [ ] because I do not care for the SafeMiles system (I do not like being told what following distance to drive)

Other (please specify)

36. Do you increase the distance to the car in front of you if the SafeMiles display indicates that you are following too closely?

- ○ yes, almost always
- ○ yes, often
- ○ yes, sometimes
- ○ no, almost never
- ○ it hardly ever/never happens that the SafeMiles display indicates that I follow the car in front of me too closely
- ○ I hardly ever/never check my following distance on the SafeMiles display

37. Has the number of times that you changed your following distance based on the information from the SafeMiles display changed since the beginning of the SafeMiles trial?

- ◯ yes, I am changing my following distance more often
- ◯ yes, I am changing my following distance less often
- ◯ no, I change my following distance as often as I used to
- ◯ no, almost never
- ◯ it hardly ever/never happens that the SafeMiles display indicates that the distance to the car in front of me is sufficient
- ◯ I hardly ever/never check my following distance on the SafeMiles display

38. Do you think, now that you have the SafeMiles system in your car, that you keep a better distance to the vehicles in front of you than before you had the SafeMiles display?

- ◯ yes, much better
- ◯ yes, somewhat better
- ◯ no, I maintain an adequate headway anyway
- ◯ no, I like a close headway

39. For you personally, is it a problem if drivers follow the vehicles in front of them too closely?

- ◯ a big problem
- ◯ somewhat of a problem
- ◯ no problem

40. Do you think it is a problem for society as a whole if drivers follow the vehicles in front of them too closely?

- ◯ a big problem
- ◯ somewhat of a problem
- ◯ no problem

4. Points and rewards

The following questions are in respect to points and rewards.

41. How often do you check the SafeMiles display to see how many points you have earned?

- ◯ several times per trip
- ◯ before and/or after every trip
- ◯ about once a day
- ◯ about once a week
- ◯ about once a month
- ◯ never or hardly ever

42. How often do you check the website www.SafeMiles.net to see how many points you have earned?

- ◯ about once a day
- ◯ about once a week
- ◯ about once a month
- ◯ never or hardly ever

43. How hard was it to earn the points?

- ◯ extremely hard
- ◯ very hard
- ◯ somewhat hard
- ◯ not hard at all

44. During the test, did it get easier for you to earn points?

- ◯ yes, earning points was harder at the beginning
- ◯ no, earning points was equally hard for the duration of the test
- ◯ no, earning points was harder at the end

45. With which of the following statements do you agree? (you can check several answers)

- ☐ if I am already speeding, I don't care about my following distance anymore
- ☐ if I am already following too closely I don't care about my speed anymore
- ☐ none of the above

46. In your opinion, what is the relation between the effort needed to collect points and the size of the reward? unfavourable -> favourable

◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5

47. Do you have any other remarks on the SafeMiles program? All your experiences and suggestions are welcome.

Thank you for your participation and your time and effort in completing this questionnaire.

7. How would you characterize your driving style? (between 1 and 5 check the box that mostly reflects your driving style)

	1	2	3	4	5
relaxed -> tense	○	○	○	○	○
calm -> restless	○	○	○	○	○
slow -> fast	○	○	○	○	○
attentive -> inattentive	○	○	○	○	○
safe -> unsafe	○	○	○	○	○
courteous -> aggressive	○	○	○	○	○

8. Has your driving style changed because of your experience with the SafeMiles trial, compared to the period prior to the trial?

○ my driving style has changed greatly due to SafeMiles

○ my driving style has changed somewhat due to SafeMiles

○ my driving style has not changed due to SafeMiles

9. Do you flash your high beam when others drive too slow?

○ never ○ sometimes ○ always

10. Do you find driving tiring?

○ most of the time ○ sometimes ○ hardly ever

11. As a driver, do you get annoyed with other drivers? (you can check as many answers as you wish)

- ☐ yes, I get annoyed with drivers that stay in the left lane of the highway for too long
- ☐ yes, I get annoyed with drivers that drive too slow on a 80km-road
- ☐ yes, I get annoyed with drivers that drive too fast
- ☐ yes, I get annoyed with drivers that merge too slowly onto the highway
- ☐ yes, I get annoyed with drivers that tailgate
- ☐ yes, I get annoyed with drivers that pass on the right
- ☐ yes, I get annoyed with drivers that flash their lights
- ☐ yes, I get annoyed with trucks that pass each other while going only marginally faster
- ☐ yes, I get annoyed with trucks that move to the left lane to pass without checking
- ☐ yes, I get annoyed with motorcyclists
- ☐ no, I never get annoyed in traffic

yes, I get annoyed with ...

12. At what speed do you usually drive on the highway (with a speed limit of 100 km/hr), on a clear day and when there is no traffic on the road?

13. At what speed do you usually drive on a two-lane 80km/hr highway, on a clear day and when there is no traffic on the road?

14. Do you find that you stick to the speed limit more, during the SafeMiles trial compared to before the trial?

- ○ yes, much better
- ○ yes, somewhat better
- ○ no, I stick to the speed limit anyway
- ○ no, it did not change the speed at which I usually drive

3. Your Experiences With The Trial

15. Do you find that you have increased your following distance since the SafeMiles trial compared with before the trial?

- ◯ yes, much more
- ◯ yes, somewhat more
- ◯ no, I keep the same following distance
- ◯ no, I've decreased my following distance

16. How do you like driving without the speed limit information given by the SafeMiles display?

- ◯ I very much miss the speed limit information
- ◯ I somewhat miss the speed limit information
- ◯ I don't miss the speed limit information

17. How do you like driving without the following distance information given by the SafeMiles display?

- ◯ I very much miss the following distance information
- ◯ I somewhat miss the following distance information
- ◯ I don't miss the following distance information

18. How do you like driving and not collecting points and rewards with the SafeMiles system?

- ◯ I very much miss the points and rewards
- ◯ I somewhat miss the points and rewards
- ◯ I don't miss the points and rewards

19. Would you appreciate being rewarded for good driving behaviour?

- ◯ yes, I would appreciate that
- ◯ it would not make much difference to me
- ◯ no, I would not appreciate that

20. If you were to be rewarded for good driving behaviour, which rewards would you appreciate the most? (you can check several answers)

- ☐ free extra accessories for my car
- ☐ presents (such as reinforcements)
- ☐ discounts on my insurance premium
- ☐ discounts on fuel purchases
- ☐ discounts on store purchases
- ☐ collecting points (for instance Aeroplan)
- ☐ money deposited in my bank account
- ☐ an minor reward (for instance appreciation from the employer or the possibility to win a contest)

Other (please specify)

21. Would you like to have a display in your car that indicates whether you are speeding or following too closely while you are driving?

- ○ yes, but I would only appreciate information on speeding
- ○ yes, but I would only appreciate information on following too closely
- ○ yes, I would appreciate information on speeding as well as following too closely
- ○ it doesn't really matter to me
- ○ no, I would not appreciate that, because …

22. Do you think manufacturers should have to equip their vehicles with such an information display?

- ○ Yes, I think it is a good idea
- ○ No, I do not think it is a good idea

4. Thanks!

This completes the questionnaire survey portion of the trial. If you have any other questions, opinions or ideas regarding the trial or road safety in general please use the space below to provide them to us.

Thanks again for your participation from the project team.

GW Taylor Consulting

Persen Technologies
Centre for Sustainable Transportation

23. Comments or Ideas