Effects of a Feedback-Reward System on Headway Time

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Abstract

Rear-end crashes constitute approximately 30% of all crashes and drivers who maintain inappropriately short time headways are at a higher risk for this type of crash. One approach to help drivers maintain appropriate headway times is to use technology to monitor headway and provide drivers with feedback. This paper investigates the effects of a feedback-reward system on headway time. Data utilized in this research 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 safe headway maintenance (≥1.2 seconds) and speed limit compliance. 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. Results indicate that the intervention increased safe headway compliance rates by 10%. Further, during instances when the drivers were not within the safe headway time, headway time was larger in the intervention period compared to the baseline. Thus, intervention had a positive effect even when the drivers were not compliant. To a large degree, these benefits appeared to not persist in the post-intervention phase.

Résumé

Les collisions par l’arrière représentent environ 30% des collisions et les conducteurs qui maintiennent un espace insuffisant avec les autres risquent davantage d’être impliqués dans ce type de collision. Une façon pour les conducteurs de maintenir une distance appropriée avec les autres véhicules est d’utiliser des technologies qui mesurent et surveillent ces distances et les signalent au conducteur au besoin. Le présent document examine les effets engendrés par un système qui donne de la rétroaction et qui récompense en fonction de l’écart entre les véhicules. Les données utilisées aux fins de cette recherche ont été recueillies auprès de 37 participants (âgés de 20 à 70 ans) lors d’un essai sur le terrain commandé par Transports Canada. Dans cet essai de terrain, on a examiné un système de rétroaction-récompense qui donne de la rétroaction et qui récompense les conducteurs lorsque ceux-ci maintiennent un écart sécuritaire entre les véhicules (≥ 1,2 seconde) et respectent la limite de vitesse établie. L’essai comportait trois volets : la phase de référence (deux semaines), de l’intervention (douze semaines) et la phase postérieure à l’intervention (deux semaines). Pendant la phase d’intervention, une rétroaction en temps réel était donnée par un dispositif d’affichage de bord. Les participants accumulaient également des points en récompense et pouvaient visionner des renseignements connexes sur un site Web spécial. Les résultats indiquent que l’intervention a amené une augmentation de 10% du taux de respect de l’écart sécuritaire. De plus, lorsque les conducteurs ne respectaient pas un écart sécuritaire entre les véhicules, la moyenne de cet écart était plus grande pendant la phase de l’intervention que pendant celle de référence. Ainsi, l’intervention a eu un effet positif même lorsque les conducteurs n’étaient pas en conformité. Dans une large mesure, ces avantages ne semblent pas s’être répercutés lors de la phase postérieure à l’intervention.

INTRODUCTION

Rear-end crashes constitute approximately 30% of all crashes [1]. In Canada, 25% of all crashes reported in 2008 were rear-end crashes [2]. Drivers who maintain inappropriately short time headways are at a higher risk for this type of crash [3, 4]. According to Evans [5], drivers tend to maintain unsafe headways 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. Another potential reason for adopting an unsafe headway is the inability of drivers to correctly estimate their distance to the vehicle ahead. In fact, previous research has shown that drivers tend to greatly overestimate headway times, in particular for higher speeds [6, 7]. Given that maintaining short time headways is a risk factor for rear-end crashes and that drivers are unable to correctly estimate headway times, technological devices which provide feedback to the drivers based on unsafe headway times can potentially help reduce rear-end crashes.

Another approach to enhancing driver behaviour, or in the context of this paper, car following behaviour, is to utilize incentives. Incentives can significantly influence behaviour [8, 9], and rewarding desirable behaviours is usually more effective than penalizing undesirable behaviours [10]. For example, Elman and Killebrew [11] showed that seat belt use increased by approximately 25% when drivers were given the possibility of receiving a monetary reward. Similarly, Hultkranz and Lindberg [12] showed that the number of speeding violations would decrease if drivers are rewarded based on their speed behaviour.

To investigate the effects of rewards in combination with feedback, a feedback-reward system was evaluated in the Netherlands, via a quasi-controlled on-road experiment, the Belonitor Trial [13]. This feedback-reward system aimed to promote safe following distances and enhance speed limit compliance. A similar field trial, SafeMiles, commissioned by Transport Canada, was conducted in Winnipeg, MB, in 2009 [14, 15]. Both of these field trials employed three phases: baseline, intervention, and post-intervention. Overall, percentage of kilometres covered at a safe distance from the car in front improved during the intervention stage compared to the baseline, however this increase did not sustain during the post-intervention stage [13, 14]. The threshold safe headway time used in the Belonitor Trial was 1.3 seconds, 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.

The current paper utilizes data collected in the SafeMiles Trial to investigate if the feedback-reward system assists the drivers in maintaining safe headway times and if positive effects sustain after feedback-reward removal. Although descriptive statistics on headway compliance rates were reported previously for both the Belonitor and SafeMiles Trials, no formal statistical analysis were reported. Further, the actual values of headway time adopted by drivers during different phases of the trials were also not reported previously. In this paper, headway compliance rates and the actual values of headway time observed in the SafeMiles Trial are compared across the three study phases: baseline, intervention, and post-intervention. Further, weekly effects are also investigated.

METHOD

Data utilized in this paper were collected through a field operational trial, commissioned by Transport Canada and conducted by G.W. Taylor Consulting, in Winnipeg, MB, over a four-month period between mid-August and mid-November 2009. The following sections present relevant information on the SafeMiles Trial design and procedures. Further details on this trial can be found in Taylor [15].

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. Forty-one drivers were 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.

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 some 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.

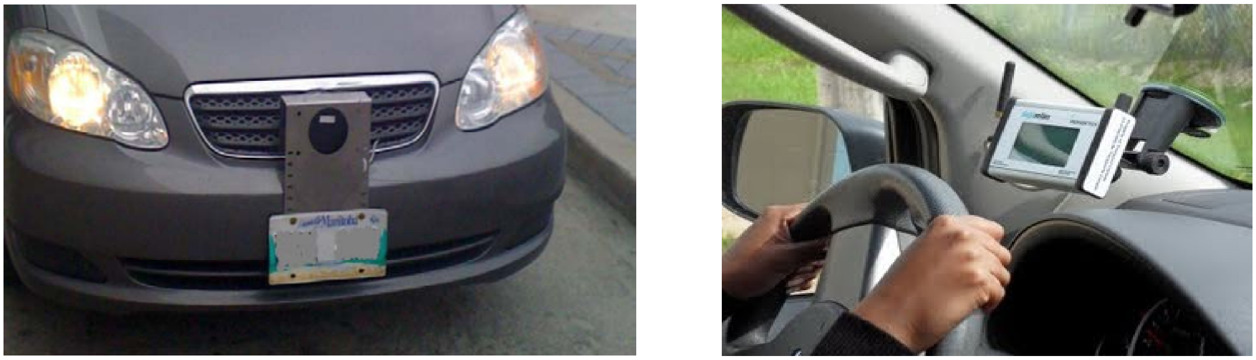
(a) (b)

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

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). These 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 metres), 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. The rewards could be claimed as gift cards for a variety of goods and services such as consumer electronics and resort packages. The average value of reward per participant was $307, ranging from $25 to $935.

The experiment was conducted in three phases: a two-week baseline, a 12-week intervention phase, and a two-week post-intervention phase. The baseline phase involved collecting baseline data with no feedback-reward. Following this phase, feedback-reward system and the website were initialized for the intervention phase. During the post-intervention phase, feedback-reward system and the website were disabled and participants did not earn any points, however, monitoring of data continued.

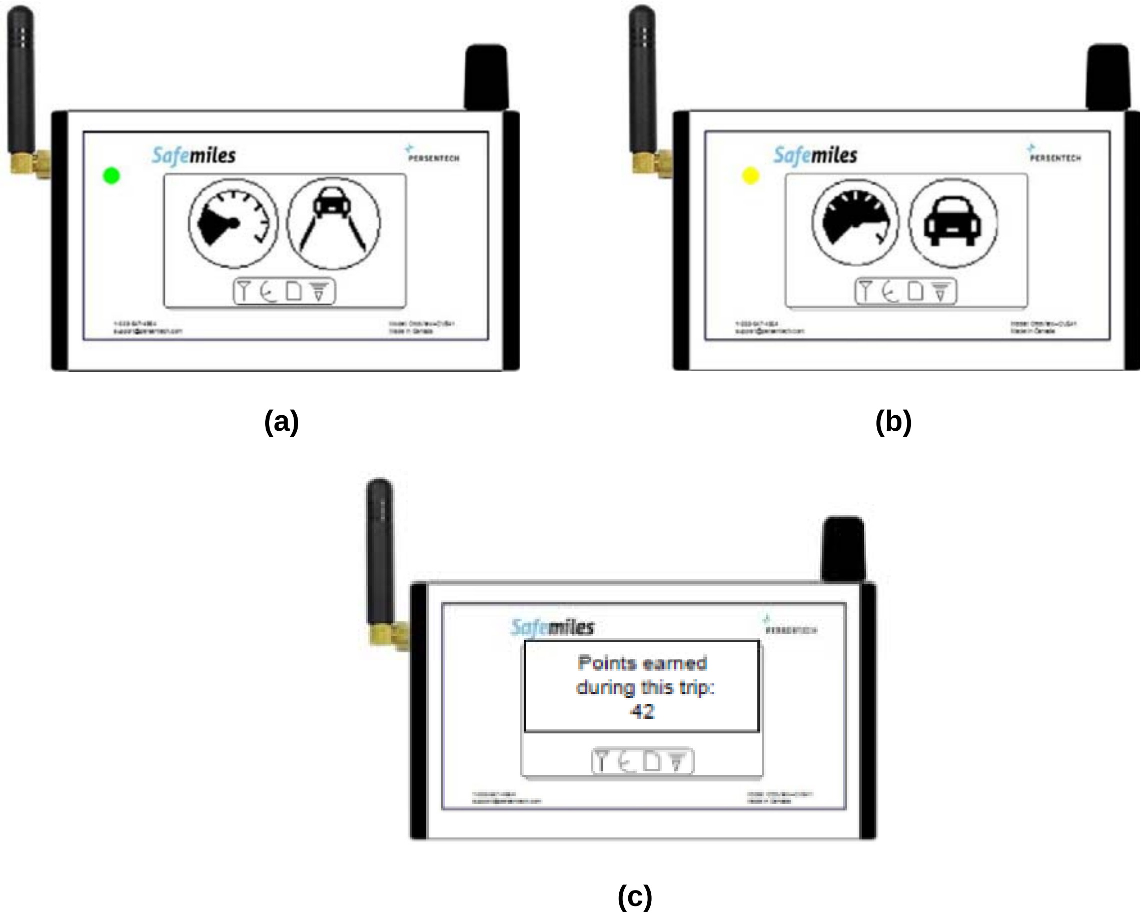

Figure 2- In-vehicle display: (a) the green light (top left corner) indicated a total compliant status, (b) the yellow light (top left corner) indicated that at least one of the criteria was not met, (c) the points displayed at the end of trip

RESULTS

The current paper focuses on driver behaviour in the presence of a lead vehicle, operationalized as headway compliance rates and average headway time, compared across age, gender, and posted speed limit (50, 60, 70, 80, 90, 100 km/h) for the three study phases previously discussed (baseline, intervention, and post-intervention). Further, driving time within each experimental phase and speed limit 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.

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). However, some drivers were not observed to drive in certain speed limit-phase combinations, resulting in 634 observations used in the analysis. 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, mixed linear models (PROC MIXED statement in SAS 9.1) were built, and the appropriate variance covariance structures were selected based on the Bayesian Information Criterion (BIC) [16]. Data for the 30 km/h speed limit zones were excluded from all analysis due to insufficient number of observations within this speed limit zone.

Headway Time Compliance

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)=10.85, p<.0001), speed limit (F(5, 165)=5.72, p=.0001), and gender (F(1,32)=6.81, p=.01). The interaction between speed limit and driver's age was also significant (F(15,165)=2.38, p=.004). In the baseline phase, drivers were compliant on average 81.0% of the time. During the intervention phase, this rate increased to 91.2% (t(72)=3.78, p=.0003), and after feedback-reward removal, it dropped to 84.3% which was not significantly different than the baseline phase (t(72)=1.05, p=.3) (Figure 3).

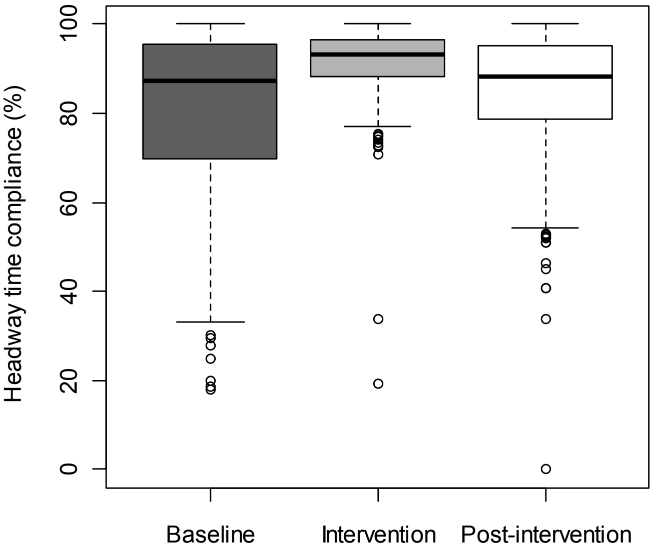

Figure 3- Headway time compliance (%) across three experimental phases (boxplots with range, 1st quartile, median, 3rd quartile, and potential outliers)

In general, females were significantly more headway compliant than males: 88% versus 83% (t(32)=2.61, p=.01). As for the speed limit – driver age interaction, the 20s and 30s age groups had higher compliance rates than the 50+ age group in high speed limits, namely 90 km/h (20s vs. 50+ t(165)=3.36, p=.001; 30s vs. 50+: t(165)=3.61, p=.0004) and 100 km/h speed limit zones (20s vs. 50+: t(165)=2.24, p=.03; 30s vs. 50+: t(165)=2.58, p=.01). Moreover, drivers appeared to be more headway compliant in 50 km/h speed limit zones then they did in higher speed limit zones (Figure 4).

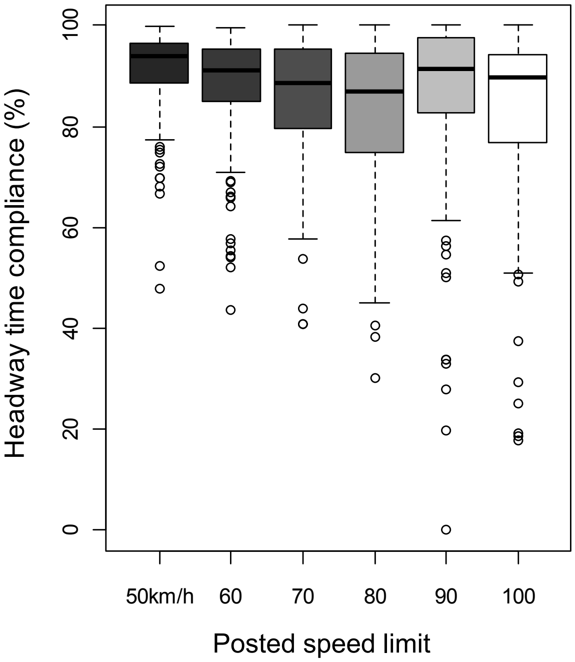

Figure 4- Headway time compliance (%) across speed limits

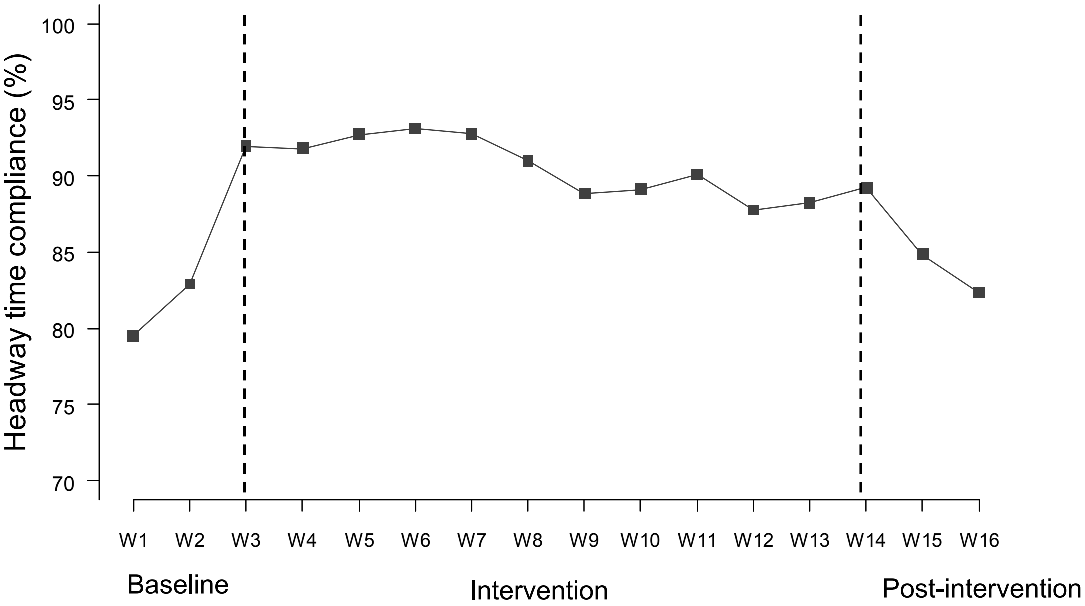

Figure 5- Headway time compliance (%) across sixteen weeks of the experiment averaged across all drivers

Figure 5 presents weekly headway time compliance rates. These 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 increased from 82.7% to 92.1%, and after six weeks there was a drop to 88.5%. Formal statistical analysis revealed that the headway compliance rate was 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.

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). The average headway time was 2.61 sec in the intervention phase compared to 2.46 sec in the baseline. However, this positive trend was not statistically significant (intervention vs. baseline: t(72)=1.69, p=.09). 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)=-5.2, p<.0001) (Figure 6).

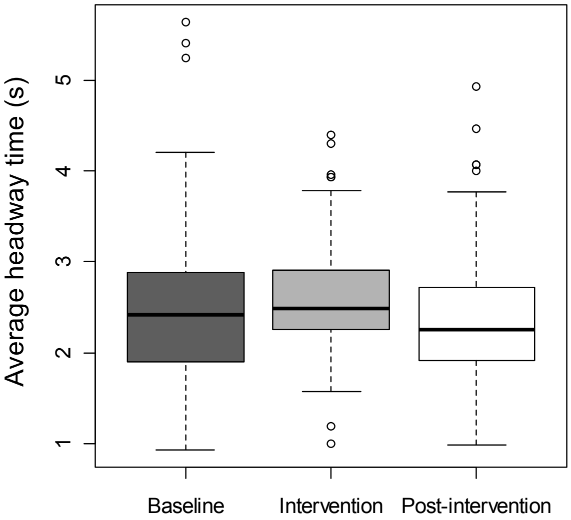

Figure 6- Average headway time across three experimental phases

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 7). 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.

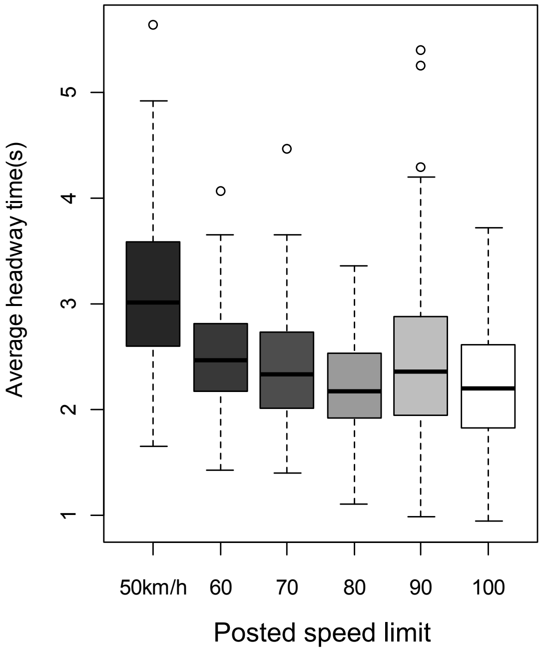

Figure 7- Average headway time across speed limits

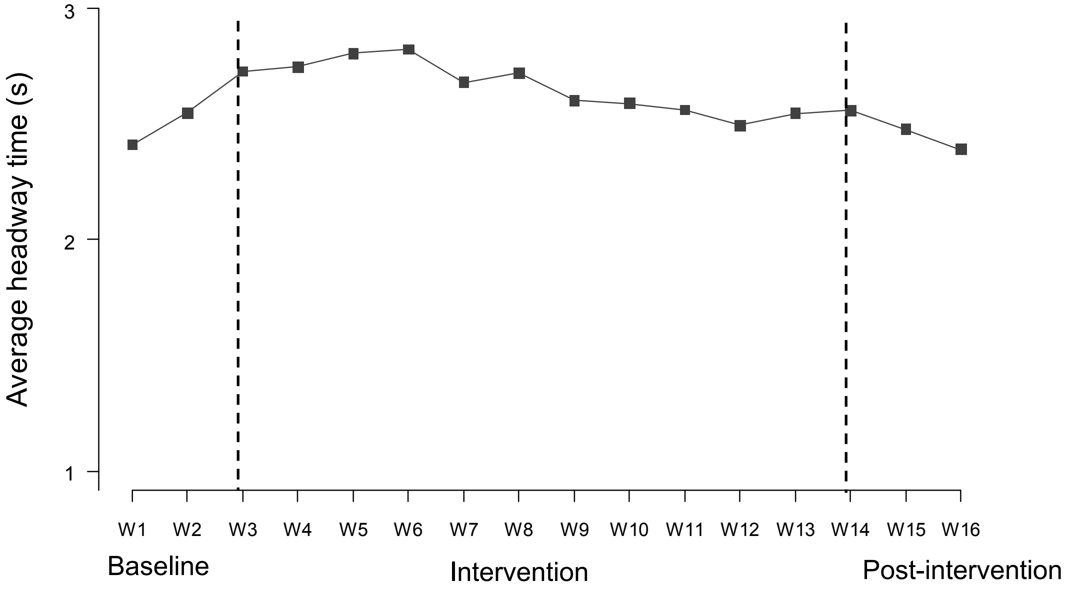

Figure 8- Average headway time across sixteen weeks of the experiment averaged across all drivers

Figure 8 presents weekly average headway times, which were calculated by averaging headway times within each week and speed limit combination. The average headway time was significantly higher in the first half of the intervention phase 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). 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)=.06, p=.35) phases.

Average Headway Time During Noncompliance

The average headway time during instances when the drivers were not within the safe headway time (noncompliant) 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=.025). In the intervention phase, average headway time significantly increased for both females (intervention vs. baseline: t(70)=3.24, p=.002) and males (intervention vs. baseline: t(70)=6.74, p<.0001). However after feedback-reward removal this positive effect only sustained for males (post-intervention vs. intervention: t(70)=4.61, p<.0001) (Figure 9).

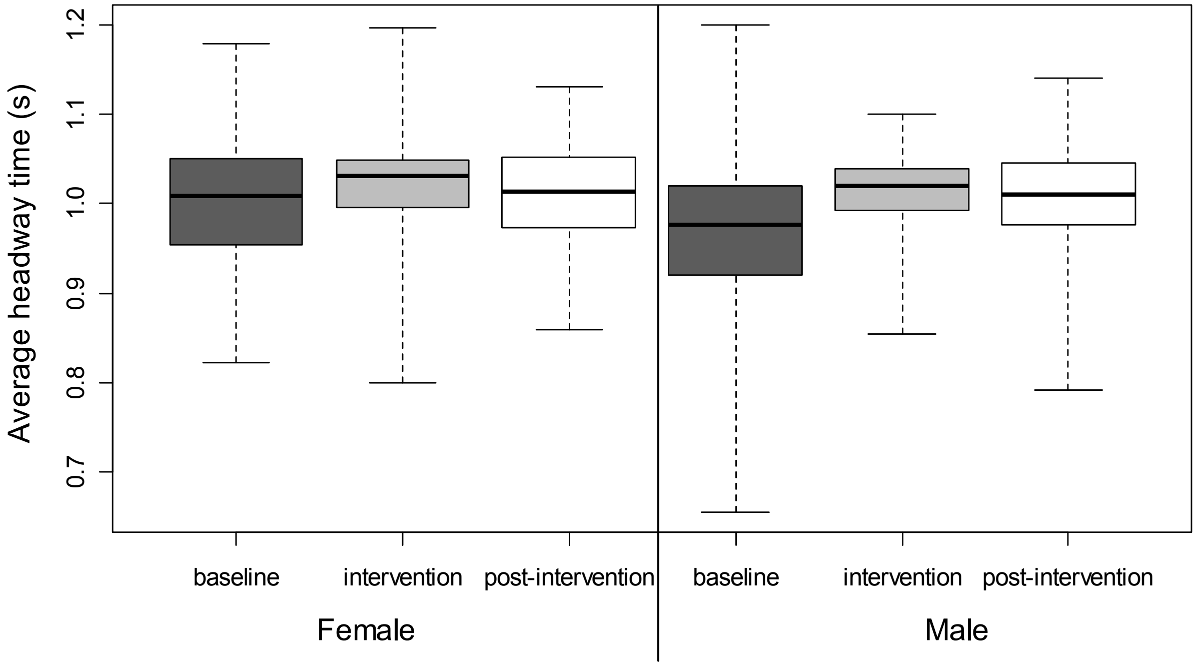

Figure 9- Average headway time for noncompliant cases across gender and experimental phases

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 10). 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).

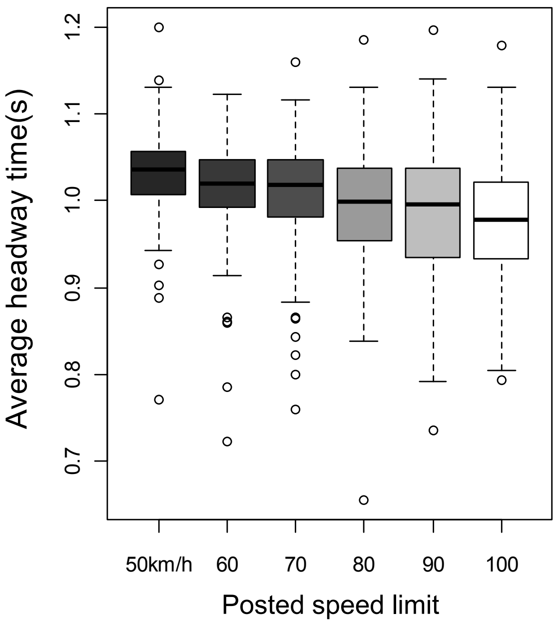

Figure 10- Average headway time for noncompliant cases across speed limits

Further, the average headway time when noncompliant was lower in the second half of the intervention phase compared to the first half (t(108)=-3.45, p=.0008). However, average headway time when noncompliant was still higher in the second half of the intervention phase compared to the baseline (t(108)=7.41, p<.0001). There were no statistical differences between the first and second weeks for the baseline (t(31)=.65, p=.52) and post-intervention (t(35)=.32, p=.75) phases.

CONCLUSIONS

This paper presents headway time compliance results obtained through a quasi-controlled on-road experiment conducted in Winnipeg, MB, commissioned by Transport Canada. 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 real-time feedback on their headway maintenance as well as their speed compliance and were also rewarded.

Findings on speed limit compliance have been reported previously in Merrikhpour, Donmez, and Battista [17]. In general results showed that intervention increased speed limit compliance, and this positive effect, although dampened, was still apparent even after feedback-reward removal. In particular, the positive effects persisted for high speed limit zones (70, 80, 90 and 100 km/h). Further, when the drivers were noncompliant, the degree of speeding was reduced by the intervention. The current results on headway time compliance are in line with previously published speed limit compliance results, with the intervention having a positive effect on compliance. In particular, the headway time compliance rate significantly increased from 81.0% in the baseline to 91.2% 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 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 [13], and another recent study by Young, et al. [18].

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. It appears that longer exposure to the intervention may not necessarily result in a sustained benefit. Future research should explore longer term adaptation to such systems. 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 suggests 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 [19] also found that feedback generated a significant increase in average headway times as well as compliance rates. The feedback in [19] 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 our study). It should be noted that there appears to be differences between the Israeli drivers investigated in [19] 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 [19] (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 density, and roadway structure.

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 overestimate headway times, and the error in estimation is larger for higher speeds [7]. This differential error in headway time estimation can potentially explain why drivers in our study maintained lower headway times in higher speeds.

In the SafeMiles Trial, questionnaires were administered to participants to assess their attitudes towards safe driving in general, as well as towards the feedback-reward system. The ultimate goal of this research is to provide a lasting behavioural change which will enhance safety. Future research will incorporate the questionnaire data to identify if and how driver attitudes interact with feedback to guide a behavioural shift. Clustering drivers based on their propensity to exhibit non-compliant behaviours can also provide further details into how higher risk drivers respond to feedback. Moreover, the speed compliance data will be jointly analysed with headway compliance data to identify if the headway compliant drivers also tend to maintain safer speeds. Although this field trial revealed promising results for the feedback-reward system tested, future investigations should attempt to isolate the contribution of the feedback and reward components of the system. Further, the optimal modality of feedback and the risk of inducing driver distraction by such feedback should be investigated.

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