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Effects of a Feedback/Reward System on Speed Compliance Rates and the Degree of Speeding during Noncompliance

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ABSTRACT

Speeding is known to contribute to crash risks and severities. One approach to inhibit speeding is to use technology to monitor driver speed and provide drivers with feedback. This paper investigates the effects of a feedback/reward system on speed limit compliance rates as well as the degree of speeding during noncompliance. 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 speed limit compliance and safe headway maintenance. The trial consisted of three phases: baseline (two weeks), feedback (twelve weeks), and post feedback (two weeks). Real-time feedback was provided on an in-vehicle display. During the feedback phase, participants also accumulated reward points and could view related information on a special website. Results suggest that feedback increased speed limit compliance, and this positive effect, although dampened, was still apparent even after feedback removal. Moreover, when considering cases with no lead vehicle ahead, the positive effects persisted for high speed limit zones (70, 80, 90 and 100 km/h). In general, when the drivers were noncompliant, the degree of speeding was reduced by the presence of feedback.

INTRODUCTION

Human error is estimated to be the sole cause in 57% of all traffic crashes and a contributing factor in over 90% of them (*1*). Inappropriate speed choice, gap acceptance decisions, close following distances, and improper visual scanning behaviours have been identified to increase crash risks (*2-7*). 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 appropriately due to factors such as inexperience or perceptual/cognitive saturation. Consequently, modifying driver attitudes and encouraging safer behaviour can have a positive effect on road safety. Similarly, aiding drivers to assess roadway demands can also have a positive effect on driver behaviour. One approach to enhance driving behaviour is to use technologies to monitor driver actions and provide drivers with feedback (*8*).

A particular human behaviour of concern is speeding as it has been shown to contribute to crash risks. Kloeden et al. (*3*) estimated that in a 60 km/h speed limit zone, the risk of involvement in a fatal crash doubles with each 5 km/h increase in travelling speed above 60 km/h. Speeding was reported as a contributing factor in about 31% of all fatal crashes in 2007 (*9*), and it has been found to be a significant factor affecting crash injury severities. It is reported that an above speed limit crash is associated with more severe injuries (*10, 11*) than a below speed limit crash.

A wide range of speeding countermeasures are in effect such as law enforcement, radar speed display signs, variable message signs, educational messages, supervising drivers, and driving instructors. Each medium or person provides some feedback on what the driver should be doing, or has already done in the hopes that they will correct their behaviour on future drives. However, such feedback is dependent on the environment, is not tailored to the behaviour of the individual, and may be absent in some situations. Therefore, such feedback may have little influence on drivers' behaviour. Emerging technology can circumvent the limits of current feedback and may provide an effective means by which to alert the driver to inappropriate behaviours.

An example on immediate effects of speed-related feedback was observed in a study by Wrapson, Harre, and Murrell (*12*), which 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 (*13*). These studies indicate the importance of understanding whether the immediate effects of feedback will persist when the feedback is no longer available.

A feedback/reward system aimed to enhance speed compliance and promote safe following distances was designed and evaluated in the Netherlands, via a quasi-controlled on-road experiment, the Belonitor Trial (*14*). The Belonitor Trial started in 2005. A similar field trial, SafeMiles, commissioned by Transport Canada, was conducted in Winnipeg, MB (*15, 16*). These field trials employed three phases: baseline, feedback, post feedback. Overall, speed compliance rates improved during the feedback stage compared to the baseline. The Canadian study (*15, 16*) also revealed that speed compliance rates during the post-feedback stage were higher than they were in the baseline, suggesting a persistent effect of feedback, which appeared to be smaller than the effect observed when feedback was actually present. In the Netherlands trial, most drivers did not maintain the improvement when feedback was removed (*14*).

Previous publications from these two trials (Belonitor and SafeMiles) considered speed compliance as a dichotomous variable. Moreover, the presence of a lead vehicle was not accounted for in the analysis. The current paper utilizes the data collected in the Transport Canada (SafeMiles) trial to investigate speed compliance rates and the degree of speeding during noncompliant episodes both for the entire dataset as well as for data with no lead vehicle present.

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, in 2009. The following sections present relevant information on the SafeMiles trial design and procedures. Further details on this trial can be found in (*16*).

Participants

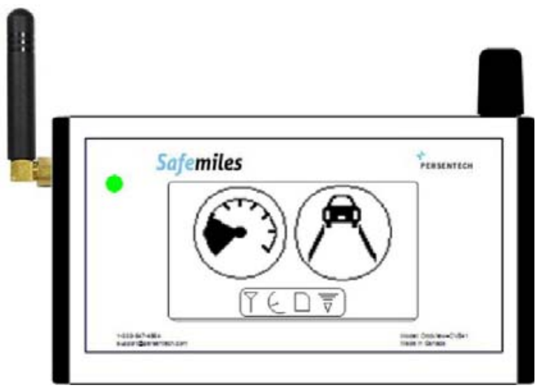
Thirty-seven participants (20 males and 17 females) across four age groups 20-29 (n= 9), 30-39 (n=7), 40-49 (n= 9), and 50+ (n= 12) completed the study. Participants were recruited through direct marketing, media announcement, and the Center for Sustainable Transportation website. They had to be at least 20-years old, hold a valid class five driver's license (i.e., fully licensed), and consider themselves as the primary driver of their vehicle. 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

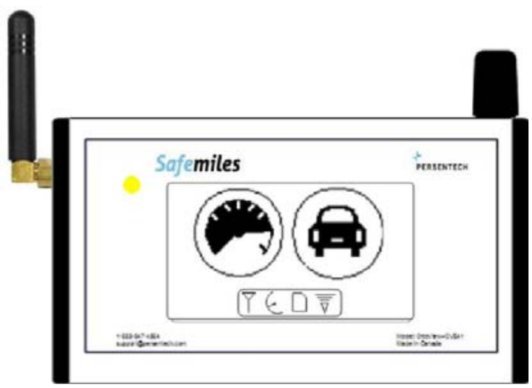
Participant vehicles were instrumented with an in-vehicle device, a forward-looking radar unit, a radio link using a GSM (a wireless data system) – GPRS (General Packet Radio System) network, a TCP/IP connection to a remote host PC-web server, and a client connection to the remote host PC-web server to access data and manage the system's parameters. The in-vehicle device included an integrated display, an on-board diagnostics interface (OBDII), and an internal GPS device that included posted speed limit (PSL) 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 (Figure 1) included symbols for compliance in speed, compliance in headway distance, compliance in both (total compliance), and some operational status information on GPS signal lock, GSM-GPRS network availability, radar unit, and memory card.

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 ≤ PSL + 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 1a), which turned to yellow when the drivers were not compliant in either speed or headway or both (Figure 1b). A speedometer symbol was used to indicate speed compliance: there were two realizations of this symbol as demonstrated in Figures 1a (compliant) and 1b (noncompliant). Similarly, there were two realizations of the headway compliance symbol: a distant lead vehicle icon for compliance (Figure 1a) and a closer lead vehicle icon for noncompliance (Figure 1b). A compliance point was obtained when both speed and headway were compliant for 15 s, which translated to reward points earned by the participant. Information on points accumulated was provided to the participants on a website.



(a)



(b)

FIGURE 1 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.

The experiment was conducted in three phases consisting of a two-week baseline, a 12-week feedback phase, and a two-week post-feedback 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 feedback phase. During the post-feedback phase, feedback system and the website were disabled and participants did not earn any points, however, monitoring of data continued.

Data Analysis

The current paper focuses on speeding behaviour, operationalized as speed limit compliance rates and the degree of speeding when noncompliant. The effects of feedback/reward system, driver age, driver gender, and speed limit zone were investigated for the entire dataset as well as for the subset of the data with no lead vehicle presence. No lead vehicle presence is defined as the radar not detecting a lead vehicle in less than 120 m ahead.

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

The analyses were conducted in two parts. In the first part, speed limit compliance rate (GPS based speed ≤ PSL + 2 km/h) was considered as a response variable. It was calculated as the ratio of the compliant time over the total time spent in each experimental phase and speed limit combination. In the second part, we considered the cases when the driver was noncompliant and analyzed the maximum deviation from the posted speed limit (GPS-based speed – PSL). The maximum deviations from PSL were averaged for each driver across the three phases and the six speed limit zones. In order to control for the traffic flow effect, analyses were applied on both the entire dataset and the data points for which a lead vehicle was not present.

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) (*17*). When needed, transformations were applied to correct problems of non-normality and heteroskedasticity.

RESULTS

Speed Limit Compliance

Speed limit compliance was compared across age, gender, and posted speed limit for the three study phases previously discussed (baseline, feedback, and post-feedback). 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. A logarithmic transformation was applied to correct problems of non-normality and heteroskedasticity.

The analysis of the entire dataset revealed that speed compliance rate was significantly associated with phase ($F(2, 72)=27.41$, $p<.0001$) and speed limit ($F(5, 159)=4.53$, $p=.0007$). Gender, driving time, and their interactions with other predictor variables were not significant ($p>.05$). In particular, participants complied with posted speed limit significantly more in the feedback phase than they did in the baseline ($t(72)=7.30$, $p<.0001$). This positive effect, although dampened (post-feedback vs. feedback: $t(72)=-2.51$, $p=.01$), sustained after feedback removal (post-feedback vs. baseline: $t(72)=4.05$, $p=.0001$) (Figure 2).

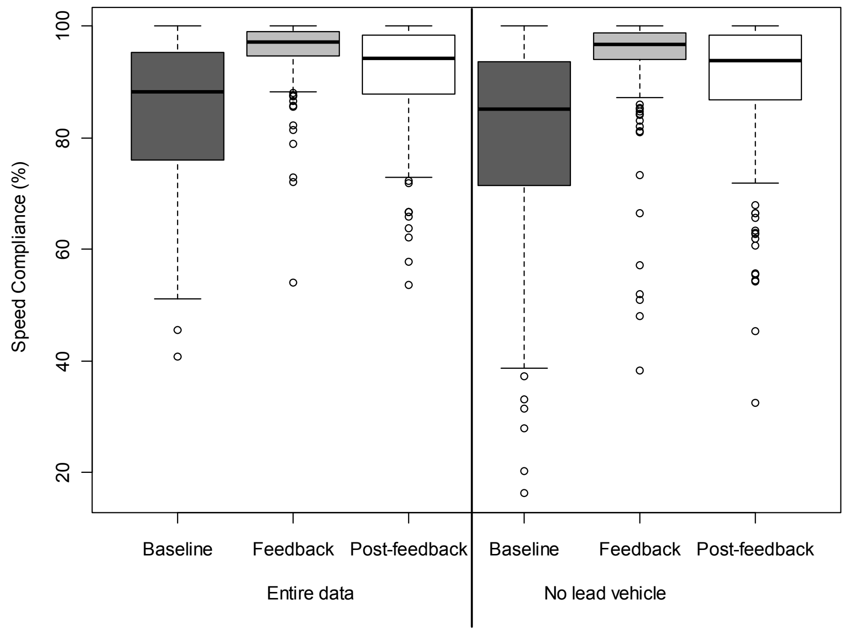


FIGURE 2 Speed compliance (%) across three experimental phases for the entire data as well as for cases during which there was no lead vehicle.

The interaction between driver's age and speed limit was also significant (F(15,159)=2.07, p=.01). The 40s age group drove significantly less speed compliant than all other age groups in 90 km/h speed limit zones (40s vs. 20s: t(159)=-3.77, p=.0002; 40s vs. 30s: t(159)=-3.73, p=.0003; 40s vs. 50+s: t(159)=-4.30, p<.0001) (Figure 3).

It should be noted that the analysis involving the complete 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 data for which a lead vehicle was not present. Main effects of phase (F(2, 72)=25.35, p<.0001), speed limit (F(5,165)=7.53, p<.0001), and their interaction (F(10,328)=4.05, p<.0001) were all significant. Figure 4 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 feedback phase than they did in the baseline period (50 km/h limit: t(328)=2.6, p=.009; 60 km/h limit: t(328)=3.00, p=.003; 70 km/h limit: t(328)=3.47, p=.0006; 80 km/h limit: t(328)=3.17, p=.002; 90 km/h limit: t(328)=2.55, p=.01; 100 km/h limit: t(328)=8.56, p<.0001). The difference between the baseline and the post-feedback periods was also significant for 70 km/h (t(328)= 2.12, p=0.03), 80 km/h (t(328)=2.03, p=0.04), 90 km/h (t(328)=2.82, p=.005) and 100 km/h (t(328)=6.25, p<.0001) speed limit zones, for which the positive effects of feedback sustained. 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 5).

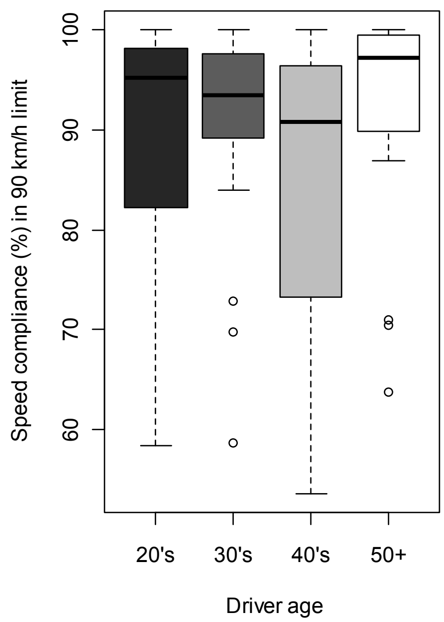


FIGURE 3 Speed compliance (%) across four age groups in 90 km/h speed limit zones.

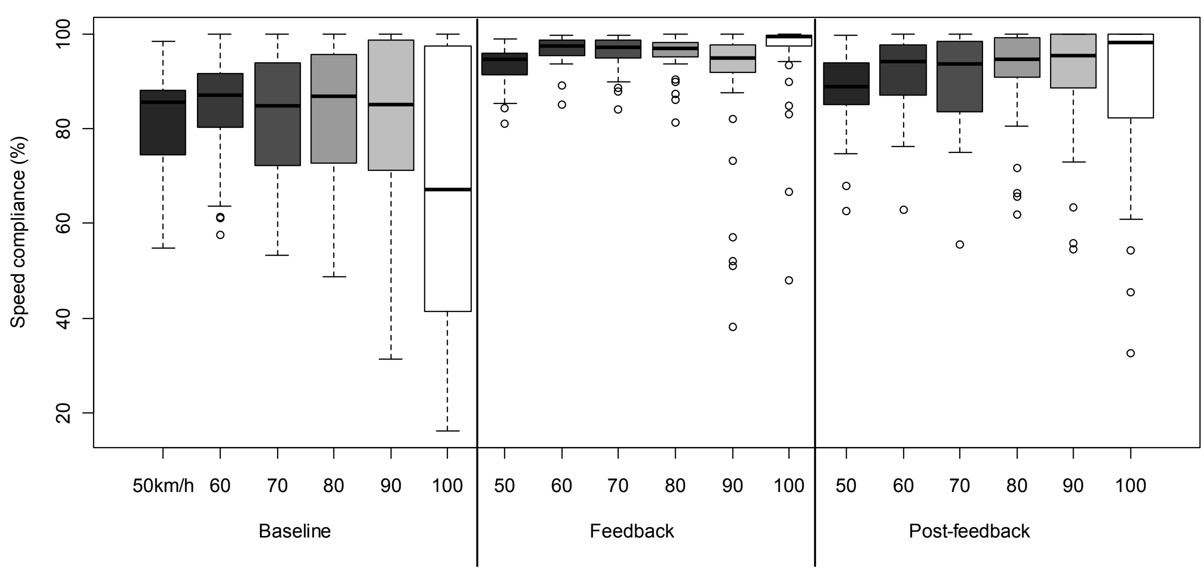


FIGURE 4 Speed compliance (%) for no lead vehicle data across experimental phases and speed limits.

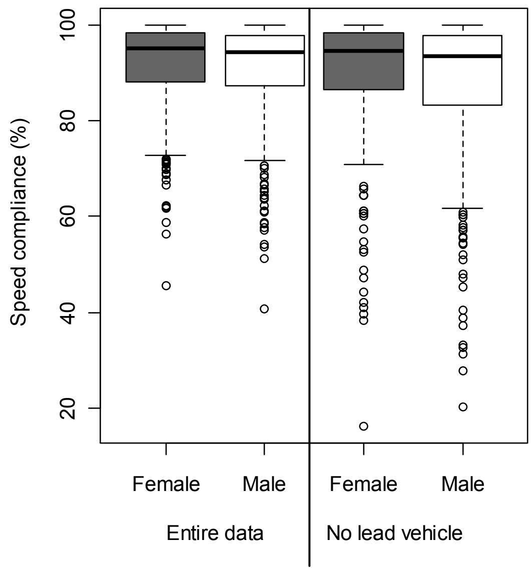


FIGURE 5 Speed compliance (%) across gender for the entire data as well as for cases during which there was no lead vehicle.

Maximum Deviation from Posted Speed Limit when Noncompliant

Maximum deviation from PSL for noncompliant cases 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.

In the entire data, the main effect of experimental phase was significant ($F(2,72)=5.61$, $p=.005$) (Figure 6); maximum deviation from PSL was significantly lower in the feedback phase in comparison to the baseline phase ($t(72)=-3.33$, $p=.001$). No significant difference between feedback and post-feedback phases was observed, and the positive effect sustained after feedback was removed (post-feedback vs. baseline: $t(72)=-2.01$, $p=.04$)).

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 also 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 7). Moreover, males reached higher speed values than females in 70 km/h speed limit zones when noncompliant ($t(157)=-2.06$, $p=.04$) (Figure 8).

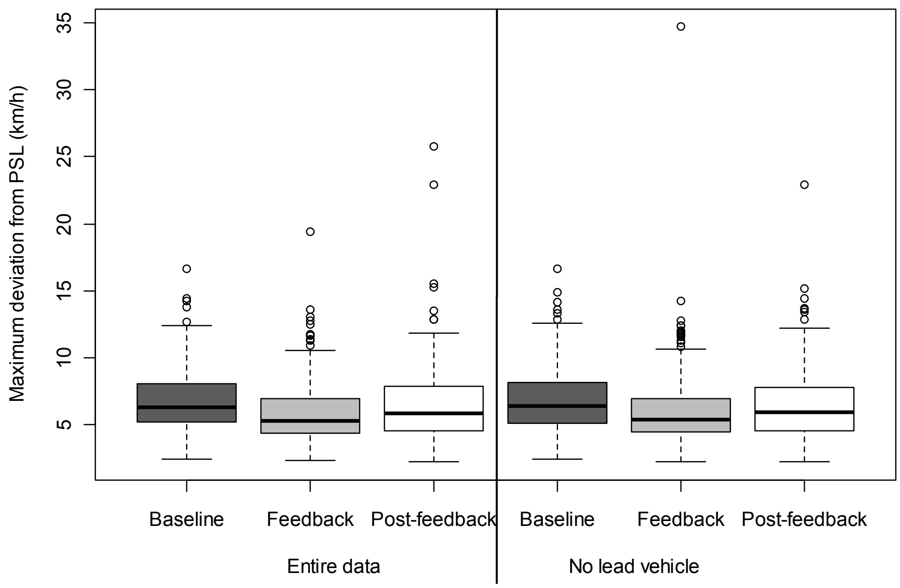


FIGURE 6 Maximum deviation from PSL (km/h) across three experimental phases for the entire data as well as for cases during which there was no lead vehicle.

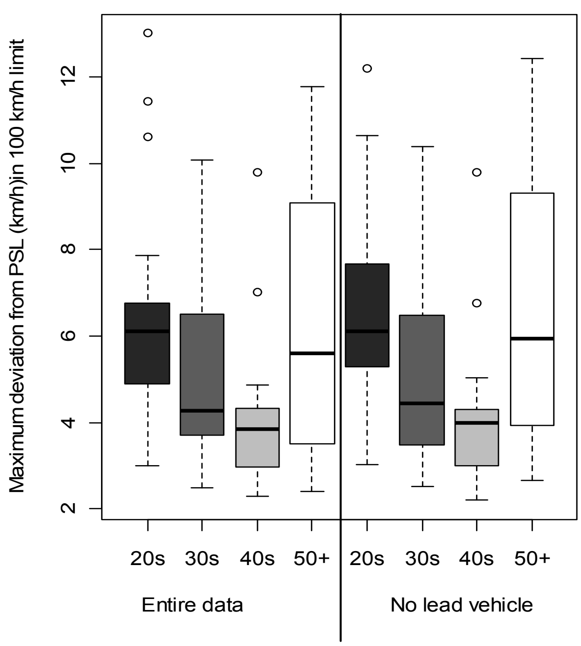


FIGURE 7 Maximum deviation from PSL (km/h) across four age groups in 100 km/h speed limit zones.

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 6); maximum deviations from PSL in feedback ($t(70)=-2.80$, $p=0.007$) and post-feedback ($t(70)=-2.06$, $p=0.04$) phases were significantly lower than they were in the baseline phase.

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 ($F(5,156)=2.86$, $p=.017$) were also significant. In 100 km/h speed limit zones, the 40s age group had the lowest maximum deviation from PSL (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 7). Further, maximum deviation from PSL 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 9). As can be seen in Figures 6-9, the entire dataset and the no lead vehicle data have almost the same distributions, suggesting that the highest speed values during noncompliant states were most likely reached when there was no lead vehicle ahead.

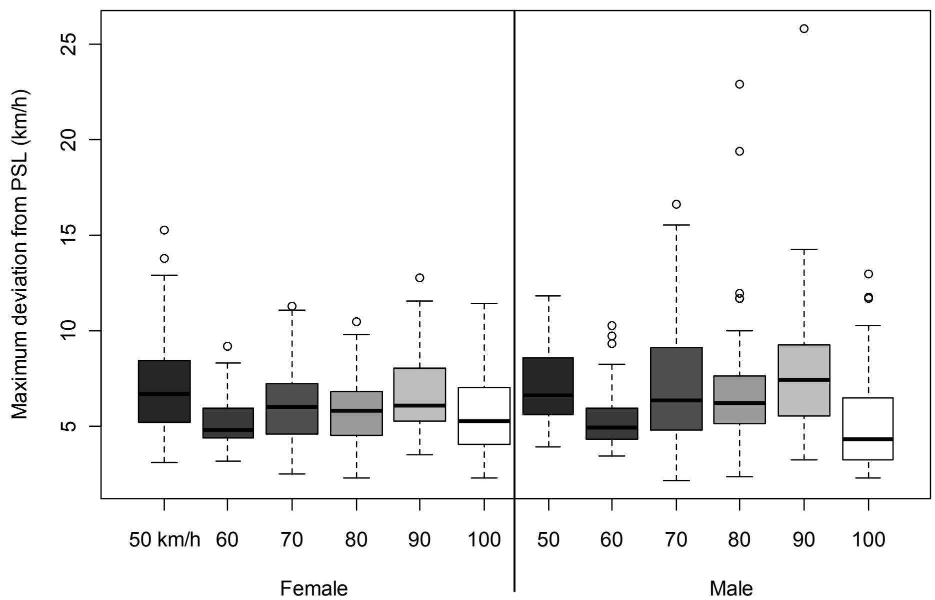


FIGURE 8 Maximum deviation from PSL (km/h) for entire data across gender and speed limits.

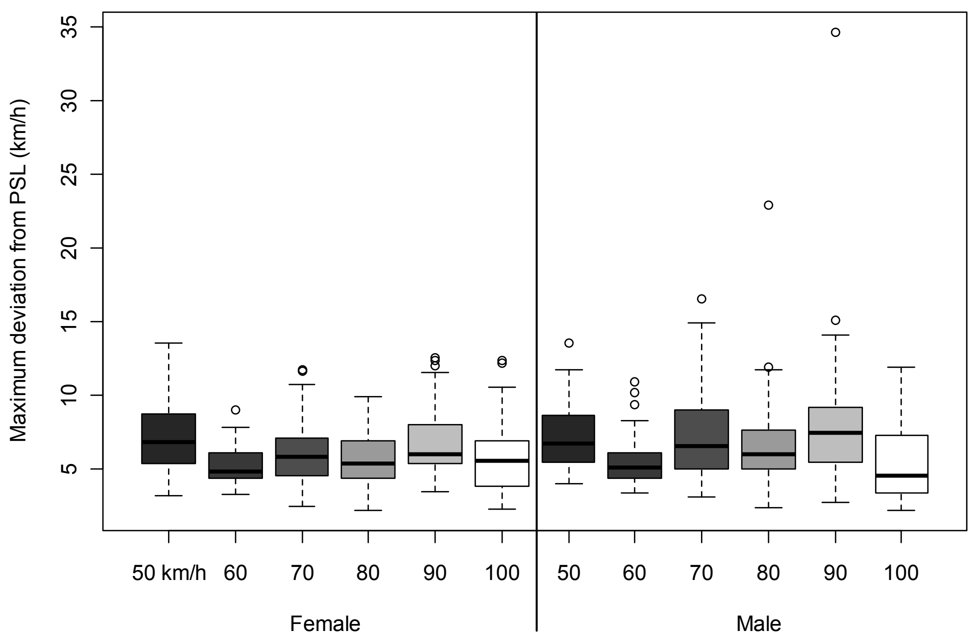


FIGURE 9 Maximum deviation from PSL (km/h) for no lead vehicle data across gender and speed limits.

CONCLUSIONS

This paper presents the speed limit compliance results obtained through a quasi-controlled on-road experiment conducted in Winnipeg, MB and 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, feedback, and post feedback. During the feedback phase, the participants were provided with real-time feedback on their speed limit compliance as well as headway maintenance and were also rewarded.

Results show that feedback increased speed compliance as reported in previous results published from the SafeMiles Trial (*15*) as well as in Belonitor Trial conducted in the Netherlands (*14*). The positive benefits observed with feedback sustained even after feedback was removed. However, there was a decline in the amount of compliance from the feedback to the post-feedback phase. 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 feedback effect was the same. However, when feedback 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 shorter reaction time windows and high crash severities due to transfer of kinetic energy during a collision (*18*).

When the drivers were noncompliant, a significant main effect of feedback was observed on the degree of speeding measured through the maximum deviation from the posted speed limit, and this positive effect sustained in post-feedback phase. Further, in 70km/h speed limit zones, noncompliant males appeared to reach higher speed values than noncompliant females. 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 (*19, 20*), 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. Lack of statistical power may also be a factor.

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. Future research will incorporate the questionnaire data to identify if and how driver attitudes interact with feedback to guide a behavioural shift. Moreover, the headway compliance data will be jointly analysed with speed compliance data to identify if the speed compliant drivers also tend to maintain safer headway times. 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.

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