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The Effects of External Motivation and Real-Time Automated Feedback on Speeding Behavior in a Naturalistic Setting

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Objective: In this field experiment, the authors tested an alerting system and a monetary incentive system with the objective of reducing speeding more than 5 mph faster than the posted speed limit.

Background: Speeding is a factor in a significant number of traffic fatalities. The systems tested in this project have been evaluated outside but not within the United States. These studies indicated that similar systems led to reductions in speeding.

Method: For this study, eight vehicles were instrumented such that vehicle speed and speed limits were linked in real time. A total of 50 participants drove assigned vehicles for 4 weeks. Week 1 was a baseline period; during Week 2 or Week 3, 40 participants experienced the alerting system that issued auditory and visual advisory signals when drivers exceeded the limit by 5 mph or more. Of these 40 individuals, 20 experienced the monetary incentive system during Weeks 2 and 3; Week 4 was a return-to-baseline period. A control group of 10 drivers experienced neither system during the study.

Results: Results indicated that the incentive system resulted in significant reductions in driving faster than the posted limit, and the feedback system led to modest changes in speeding. In the condition in which drivers experienced the feedback and incentive, reductions in speeding were similar to those found during the incentive-only condition.

Conclusion: The technology tested in this study has potential to benefit traffic safety by reducing the incidence of driving faster than the posted limit, which should lead to a reduction in speed-related crashes.

Application: Insurers provide incentive-based discounts on premiums. Combining this technology with such a discount program may improve traffic safety significantly.

Keywords: accidents, safety, and human error, driver behavior, highway and vehicle design

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INTRODUCTION

Speeding is a serious threat to traffic safety. In the United States in 2008, 31% of fatal crashes were related to speeding. This percentage means that in 2008, nearly 12,000 people were killed in the United States in speeding-related crashes (National Highway Traffic Safety Administration [NHTSA], 2009). Elvik, Christensen, and Amundsen (2004) provided clear evidence that increasing mean speed increases crash rates. The authors completed a meta-analysis that assessed the effects of speed changes and then generated numerical estimates for expected changes in the number of injuries and crashes associated with changes in mean speeds. They reported that in 95% of studies of reduced speeds, speed reduction resulted in reduced injuries and crashes; in contrast, more than 70% of studies of increased mean speeds resulted in increased injuries and crashes. The set of estimates that the authors developed accounted for change in mean speed as well as crash severity (e.g., fatal, serious, slight). Elvik et al. concluded that higher speeds increased stopping distances and exponential crash forces.

Several countermeasures exist to reduce speeding-related crashes. This article documents a field experiment that assessed a technology-based speeding countermeasure. The technology, commonly referred to as “intelligent speed adaptation” (ISA), links vehicle speed with speed limits of the roads on which the vehicle is traveling. With this linkage, it is possible to prevent speeding by constraining the throttle, to make speeding more difficult by requiring drivers to override a counterforce to accelerator pedals, or to present advisory alerts to drivers. A less intrusive option to reduce speeding with ISA technology is to incentivize drivers with external motivation. Past research showed that each level of ISA automation resulted in decreases in driving faster than posted limits (see Biding & Lind, 2002; Brookhuis & de Waard, 1999; Carsten, 2002; Carsten & Tate, 2005; Harms et al., 2007; Hultkrantz & Lindberg, 2003; Regan et al., 2005).

The current project was the first evaluation of a GPS-based ISA system in the United States in a naturalistic experimental setting. We tested separate and combined effects of an automated advisory and a monetary incentive (MI) on speeding behavior, mental workload, and driver trust and acceptance of the systems. Because of the magnitude of the effort, this article focuses on the effects of the advisory and incentive systems on observed speeding. The writing of a second manuscript devoted to mental workload and driver trust and acceptance is in progress.

Alerting Drivers When They Speed

The purpose of an advisory ISA is to alert drivers when they exceed the limit so they can reduce their speed manually. Advisory systems are the lowest level of ISA automation: Drivers can choose to allocate the speed-monitoring task to the system. Such a system could be beneficial in situations when drivers are speeding unintentionally. For example, drivers in free-flow conditions may forget to scan the speedometer and match speed with vehicles traveling faster than the limit, or they may be in an unfamiliar area and not know the speed limit. Blincoe, Jones, Sauerzapf, and Haynes (2006) surveyed several hundred drivers about reasons they were convicted for speeding, and a significant portion of the sample indicated that poor signage prefaced their citation.

A third source of unintended speeding stems from perceptual speed adaptation, which occurs when individuals adapt to a set speed, for example, 45 mph, and suddenly change to a new constant velocity, for example, 25 or 65 mph. The adaptation causes perceived speed to differ from true speed and from what drivers would have perceived (Denton, 1966; Matthews, 1978; Schmidt & Tiffin, 1969). For example, Schmidt and Tiffin's (1969) participants could accurately estimate when their vehicle reached 40 mph when accelerating from a complete stop. However, when drivers adapted to 70 mph and were asked to slow to 40 mph, they reduced speed on average to 50 mph.

Field Operational Tests of Advisory ISA

In a proof-of-concept study, Brookhuis and de Waard (1999) demonstrated the potential benefit of an early advisory ISA system by having drivers complete baseline and ISA drives on a fixed 35-min route with five speed limits. The system provided graded visual and vocal feedback to drivers when they exceeded the limit. The gradations of visual feedback were green to denote adherence to the speed, yellow to indicate intermediate violations, and red to signal violations greater than 10 km/h. The vocal feedback coincided with the red visual display. The researchers showed a significant reduction in the time that drivers exceeded the limit by 10% when driving with the ISA system. An obvious limitation of this study was the contrived nature of the drives: Participants drove the same route and there was no basis to assess the effect of the system over time.

However, with advancements in GPS technology have come long-term field operational tests (FOTs) of ISA systems in more naturalistic settings. To date, the most comprehensive ISA FOT occurred in Sweden between 1999 and 2002 (Biding & Lind, 2002). Biding and Lind (2002) report the results of their large-scale test of four systems in four urban areas across a 2-year period. Two systems tested were exclusively advisory-level ISA. In two of the four sites, experimenters recorded baseline driving measures during the 1st month of the trial then activated the ISA systems and continued data recording for approximately 2 years. The analyses compared the pre-ISA activation period with two ISA activation periods of 1 month each. Overall, Biding and Lind reported reductions in speeding that ranged from 10 to 20 percentage points across sites and speed limits when the ISA system was active. The authors noted that the reduction in speed violations was attenuated during the second post-ISA period although still significantly lower than the baseline period.

External Motivation and Advisory ISA

Given that advisory ISA leaves the decision of setting vehicle speed to the driver, some individuals may choose to ignore the system to continue violating the speed limit (Biding & Lind, 2002). An alternative to deploying a higher-level

ISA automation is to provide additional motivation for drivers to adhere to speed limits.

Two studies, both completed in Europe, involved economic incentives coupled with advisory ISA to reduce speeding (Harms et al., 2007; Hultkrantz & Lindberg, 2003). Both field experiments were completed in naturalistic settings, with trials lasting for several months, and each tested delayed incentives coupled with partial disincentives. Drivers received the full incentive amount if they fully complied with the constraints set by the experimenters and would lose small portions of the incentive if they chose to violate the limit (e.g., $0.15 per minute for driving 20% faster than the limit). According to behavior theorists, such quality-dependent reward structures are very effective agents for behavior change (Eisenberger & Cameron, 1996). The researchers found that economic incentives coupled with advisory ISA led to the greatest reductions in the percentage of time spent driving faster than the speed limit. Interestingly, Harms et al. (2007) reported that participants who could earn the incentive but did not receive advisory alerts had greater speed violations than did drivers who drove with advisory ISA but were not in the incentive condition.

Two additional studies, completed in Canada and the Netherlands, also demonstrated that economic incentives can effectively alter driver behavior (Mazurek & van Hattem, 2006). However, rather than focusing on speeding, both studies' incentive schedules were based on maintaining safe following distance and speed. Thus, it is problematic to know the extent to which the behavior change observed during the FOTs' treatment phases was affected by the separate or combined effects of the two systems.

Driver Trust of the ISA System

As the presence of technological aids in automobile cockpits increases, one of the more important aspects of driver behavior has become trust in automation. Cell phones, navigation aids, and onboard diagnostic systems all have the potential to issue audible signals. As noted earlier, some proposed implementations for speeding control have included automated alerting systems to inform drivers when they have exceeded safe or tolerable speed limits. However, as is evident from research by Lee and See (2004), it is important for designers to consider many aspects when implementing signaling systems in the automobile cockpit. If such implementation is done improperly, drivers may demonstrate overreliance on the technology, particularly in times of distraction (Lees & Lee, 2007).

Bliss and Acton (2003) found that historical reliability of alerting systems has a clear effect on drivers when they react to collision avoidance signals. In their study, driving reactions improved as a function of the reliability of the collision alerting system. As noted by Lee and See (2004), trust in the signaling system mediates reactions to alerts; such trust is affected by perceptions of reliability as well as knowledge of the underlying causes for generated signals. A particularly important consideration for any implemented alert in the driving environment is timing. It is very possible that driver trust and behavior may change depending on the temporal relationship of the signal and the impending consequences (Abe & Richardson, 2005). Because of the importance of trust, we were careful to query users concerning their trust in the speeding alert system.

Cultural Differences in Speeding

An extensive body of literature indicates that social norms affect within-group behavior and vary widely from one culture to another. Research indicates that these between-group differences include traffic safety culture, specifically, attitudes about speeding (Warner, Ozkan, & Lajunen, 2009). Warner et al. (2009) reported that Swedish drivers consider speeding to be a significantly greater safety threat than do Turkish drivers and that these attitudes predict national crash rates in the two countries. Media sources in the United States indicate that speeding is accepted and even desirable (see Harsha & Hedlund, 2007). Further support for the existence of significant cultural differences comes from the U.S. Department of State (2011), which advises drivers traveling to the Netherlands that speeding is stringently enforced, with tickets frequently issued for exceeding the limit by 1.25 to 2.4 mph (2 to 4 km/h).

TABLE 1: Experimental Design

	Week 1	Week 2 (AF On or Off[a])	Week 3 (AF On or Off[a])	Week 4
Incentive (*n* = 20)	Baseline	Advisory on or off	Advisory on or off	Reversal
No incentive (*n* = 20)	Baseline	Advisory on or off	Advisory on or off	Reversal
Control (*n* = 10)	Control	Control	Control	Control

Note. AF = automated feedback.
[a]Within the monetary incentive (MI) and no-MI groups, the advisory was counterbalanced between Weeks 2 and 3.

These figures contrast sharply with data obtained from officials in state highway safety offices throughout the United States, who report that law enforcement agencies give drivers considerable cushions before issuing speeding tickets (Governors' Highway Safety Association [GHSA], 2005). The most common response (22 of 45) to the GHSA survey indicated that the speed tolerance provided to drivers was 9 mph or more past the limit. A comparison of expected fines by country further underscores the cultural differences. In the United States, drivers receive warnings for speeding 1 to 5 mph faster than the limit; comparable speed violators in Canada, Denmark, the Netherlands, and Sweden are fined between €30 and €106 (approximately US$35 to US$123), depending on country and speed limit. Thus, the United States appears to have a much more liberal definition of speeding than do the three countries that completed FOTs of incentive-based advisory ISA systems.

METHOD

Hypotheses and Experimental Design

Hypotheses. On the basis of previous ISA research (e.g., Biding & Lind, 2002; Harms et al., 2007; Jamson, Carsten, Chorlton, & Fowkes, 2006) and on principles of behavior theory (Eisenberger & Cameron, 1996), we predicted that the combination of MI and automated feedback (AF) would result in the greatest reductions in exceeding the speed limit compared with either MI or AF alone and with baseline and control conditions. We also predicted significant reductions in speeding as a function of individual effects of AF and MI compared with baseline and control conditions.

Experimental design. We assigned 50 drivers randomly to three MI groups. Of these drivers, 10 acted as a baseline group, driving for 4 weeks with no AF or MI. Another 20 drivers received no MI but received AF during either Week 2 or Week 3 (counterbalanced). The remaining 20 drivers received MI during Weeks 2 and 3 and received AF during either Week 2 or Week 3 (counterbalanced) (see Table 1). Weeks 1 and 4 served as baseline and reversal periods for the 40 experimental participants, respectively.

This design builds on the work of Battista, Burns, and Taylor (2010), Harms et al. (2007), Hultkrantz and Lindberg (2003), and Mazureck and van Hattem (2006) by including a control group and a reversal (return-to-baseline) period. In contrast, Battista et al. and Mazureck and van Hattem used an ABA design with no control group, and Harms et al. and Hultkrantz and Linberg used an AB design with control group. In addition, the current project and the research completed by Harms et al. were the only designs to isolate the effects of the advisory speed information. Additionally, the design of the advisory system was a graded alert, and this design feature was based on participant feedback from Biding and Lind (2002), wherein participants indicated that an alert that distinguished between different levels of speeding violations was preferable to a binary alert.

Participants

Participants were a convenience sample of 50 licensed drivers (26 males and 24 females) with at least 5 years of driving experience who lived and worked in the Kalamazoo, Michigan, area. Table 2 presents the number of males and females and average age for the sample. Drivers convicted of impaired or reckless driving or

TABLE 2: Males and Females and Average Age by Experimental Group

Group	Males	Females	Average Age (*SD*)
Control	5	5	27.7 (4.22)
Incentive	10	10	27.8 (3.43)
No incentive	11	9	28.0 (4.90)

who had their license suspended were prevented from participating.

Researchers followed a multistage recruitment process. Potential participants signed an initial informed-consent document and provided self-report information about driving habits and driver license numbers. Drivers who met safety and driving exposure criteria signed a second informed-consent document. Drivers received compensation for their participation in the field study. The test vehicles received a full tank of gas on Day 1 of the experimental trial, and participants received $80 for completing experimental activities.

Materials

Vehicles. Project staff instrumented eight vehicles for use during the field study. NHTSA provided a 2002 Oldsmobile Intrigue, a 2001 Saturn L 200, a 1998 Chevrolet Malibu, a 2000 Ford Taurus, a 2005 Cadillac STS, a 1999 Toyota Camry, a 2003 Toyota Corolla, and a 2004 Toyota Sienna.

Speed map. Researchers obtained blueprints of the study areas and associated speed limits from the local governments. The area mapped included portions of Kalamazoo County, which is 573 square miles and has 1,263 miles of roads as well as the major arterials that flow into and out of Kalamazoo and Portage cities. Approximately 730 miles of roads were mapped for this study, and approximately 80% of the driving that participants completed during the experiment was on the mapped roads. With regard to mapping speed transition points, researchers noted the distance between a transition point and the nearest intersection and then transposed this information to the color-coded map so that the transition point in the database was accurate within 50 feet of the speed limit sign. Persentech, Inc., integrated the speed limit information into an existing Automate™ GPS device. The project's software engineer designed the microprocessor to receive GPS and speed limit information from the GPS device and vehicle speed information from the antilock brake sensors or vehicle speed sensors. The engineer filtered out instances of zero speed during the data reduction process. From this input, the microprocessor recorded driving data and activated the incentive and feedback systems.

MI system. The MI condition was structured as a bonus system with a delayed incentive and an immediate disincentive. Individuals in the MI condition began Weeks 2 and 3 with $25.00. In a manner similar to Harms et al. (2007), the bonus declined by 3 cents every 6-s period that the driver remained 5 to 8 mph faster than the limit. The penalty increased to 6 cents if the driver was 9 mph or more faster than the limit during any segment of the 6-s period. A visual display, analogous to a meter in a taxicab, provided updated bonus amounts but displayed the information only when the ignition was turned on or off.

Advisory display. The display box that presented the updates about the incentive also displayed the visual speed alert and housed the speaker that annunciated the auditory component of the alert. The auditory alert included two 400-Hz tone stimuli to advise drivers during the AF conditions. The research assistant ensured that the alerts were audible from the driver's seat in the presence of the ambient noise of popular music playing at a level deemed to be "loud."

The temporal pattern of the auditory alert varied as a function of the magnitude of speed violation (Alert A for 5 to 8 mph past the limit and Alert B for 9 or more mph past the limit). The graded alert builds on and stems from previous ISA FOT results (Biding & Lind, 2002). Specifically, Biding and Lind's (2002) participants stated that the binary alerts they experienced could be improved by presenting alerts that differentiated between levels of speeding. Each alert in the current study lasted for 3 s. Alert A consisted of four bursts with two pulses per burst; Alert B consisted of four bursts with three pulses per burst. Research indicates that increased pulse rate increases perceived urgency (Edworthy, Loxley, & Dennis, 1991), and the research team and pilot participants agreed that Alert B was distinct from and more urgent than Alert A. To reduce annoyance, alerts terminated after three consecutive presentations without a change in speed. However, if drivers drove at 79 mph or faster, Alert B would continue to sound. In contrast to the auditory signal, the visual alert displayed at 6-s intervals as long as the driver exceeded either speed violation threshold. The display flashed the speed limit that the driver violated at the same time that the auditory alert sounded.

Procedure

Pilot testing. Throughout the development of the instrumentation and prior to full-scale data collection, we pilot tested components of the ISA system and microprocessor to ensure the functional reliability of each, to measure and improve the validity of the speed limit database, and to assess the combined effects of MI and AF on 3 pilot participants who were naive to the study. These iterative procedures included working with the GPS manufacturer to change speed limit and latitude and longitude values when we noted inaccuracies during field test drives. We adjusted the AF and MI parameters on the basis of daily and weekly traffic flow conditions on the primary, secondary, and arterial roads in the test area as well as previous research (GHSA, 2005; Harsha & Hedlund, 2007).

While on these drives, the research team noted the speeds of the prevailing traffic and whether and to what extent drivers had the opportunity to speed. Additionally, the research assistant drove for 1-week increments assuming the behavior of a driver who would drive the speed of a platoon of vehicles and otherwise moderately exceed the speed limit when the opportunity existed. We computed dependent variables (DVs) from the raw data files and tested reliability with the summary data files (all r values > .99). The effects of the AF and MI on the pilot test participants were encouraging.

Week 1. Participants received the vehicle at the beginning of Week 1. At that time, the experimenter informed drivers that the study was testing an emerging traffic safety system and that the vehicles had systems that recorded distance traveled, speed, seatbelt use, GPS, and time of day.

Participants provided a second informed consent and answered self-report questions. The experimenter provided participants an overview of their assigned vehicle and instructed participants that during the trial, they should drive as they would during normal, everyday driving. Participants were aware that a number of safety-related driving behaviors were recorded but were not specifically told that the target behavior in the study was speeding.

Weeks 2 and 3. After Week 1, participants who met distance and speeding exposure criteria continued to Week 2. The distance criterion was to drive approximately 100 miles during Week 1. To ensure that participants represented habitual speeders, the speeding criterion was based on the bonus structure used for MI participants. Therefore, only participants who would have lost approximately 35% of the bonus amount ($8.00) during the baseline week were allowed to continue. We established these criteria because the primary focus of the study was to assess whether the treatments affected speeding. The experimenter met with participants who satisfied the criteria to provide further instructions and had participants fill out self-report questions about sensation seeking and automation use and complete the NASA–Task Load Index (NASA-TLX) for Week 1. To aid in their completion of the NASA-TLX, the researcher asked participants to consider mental workload demand associated with the overall driving task. Instructions for Weeks 2 and 3 included explanations of the AF and MI systems, depending on group assignment.

The 40 participants in the MI and no-MI groups drove for 1 week, either Week 2 or Week 3, with the AF system in active mode. The researcher used stratified random assignment for this condition to ensure that 10 participants in each MI condition experienced active AF during Week 2 and that the remaining 10 per group drove with AF active during Week 3. For participants experiencing MI or AF, the researcher used a street map to show where the roads were mapped and explained that the system would "hibernate" if they ventured outside the area. Participants completed ratings of trust and acceptance of the MI and AF systems at the end of any week they drove with the systems. At the end of Weeks 2 and 3, the participants in the MI condition provided trust and acceptance ratings on the MI system. The full sample of 50 participants completed the NASA-TLX at the end of Weeks 2 and 3.

Week 4. During the final measurement period, Week 4, participants drove their assigned vehicles with AF and MI systems deactivated, as in Week 1. At the end of Week 4, participants provided subjective workload ratings via the NASA-TLX and then completed a debriefing interview.

RESULTS

Time Speeding by and Across Speed Limit Zone

Statistical approach. We inspected DVs for outliers using the following approach recommended by Tabachnik and Fidell (2001): z scores were generated for each DV; outliers were defined as having an absolute z score greater than 3.3; outlying observed scores were changed to one unit greater than the next largest score. This process resulted in the identification and changing of 44 of approximately 11,200 (.004%) values of the dependent measures.

A series of 3 × 4 mixed factorial ANCOVAs tested for the effects of MI and AF. The covariates included to control for driving exposure were measures of miles driven across the 4-week trials respective of the speed limit zone(s) in the analysis. To analyze the percentage of time driving in certain speed ranges, there were eight series of analyses, with four ANCOVAs in each series. AF activation period was counterbalanced during Weeks 2 and 3 for the no-MI and MI groups. For ease of interpretation, all analyses present the AF activation period as having occurred during Week 2.

Following recommendations by Tabachnik and Fidell (2001), normality was assumed when error degrees of freedom was greater than 20. The only analyses in which normality was violated were those for 55-mph roads. We computed Levene's tests to assess homogeneity of variance. In the current project, we set the alpha criterion at $p < .01$ for all analyses to satisfy instances when the Levene's test indicated heterogeneity of variance and to establish a more conservative threshold, given the number of analyses. If the assumption of sphericity was violated, then the Greenhouse-Geisser statistic was reported. Trend analyses were used as follow-up tests for significant effects. For analyses with significant interactions and main effects, only interactions are interpreted (Tabachnik & Fidell, 2001).

Percentage of time driving at or slower than the speed limit. The covariate included for this analysis was the total number of miles driven across the 4-week trial period. The ANCOVA indicated that the covariate was significant, $F(1, 46) = 4.62$, $p < .05$, partial $\eta^2 = .56$. The analysis also indicated a significant main effect for incentive group, $F(2, 46) = 5.32$, $p < .01$. The interaction between AF period and incentive group was also significant, $F(6, 138) = 8.78$, $p < .001$, partial $\eta^2 = .28$, observed power = 1.00. Trend analyses indicated a significant quadratic trend for the interaction, $F(2, 47) = 18.23$, $p < .001$, partial $\eta^2 = .44$, observed power = 1.00. Drivers in the MI group significantly increased the percentage of time spent driving at or slower than all speed limits during Weeks 2 (M = 83.05%) and 3 (M = 81.85%) relative to Weeks 1 (M = 68.90%) and 4 (M = 70.95%) and to the control group and no-MI group at each week of driving. In contrast, the amount of time spent driving at or slower than the speed limit did not vary reliably within or between the control and no-MI groups across the four measurement periods (see Figure 1).

Percentage of time driving 1 to 4 mph faster than 35-mph speed limits. The covariate for this analysis was the total miles driven in 35-mph zones summed across the 4 weeks. The ANCOVA indicated that the covariate was significant: $F(1, 45) = 10.43$, $p < .01$, partial $\eta^2 = .19$. The main effects of week and incentive group were not significant, $F(2.18, 98.18) = 4.17$, *ns*, and $F(2, 45) = 1.67$, *ns*, respectively. The interaction between week and incentive group was significant, $F(4.36, 98.18) = 4.60$, $p < .01$, partial $\eta^2 = .17$. Trend analysis indicated a significant quadratic trend for the interaction, $F(2, 46) = 6.67$, $p < .01$, partial $\eta^2 = .23$. Figure 2 shows the interaction between incentive group

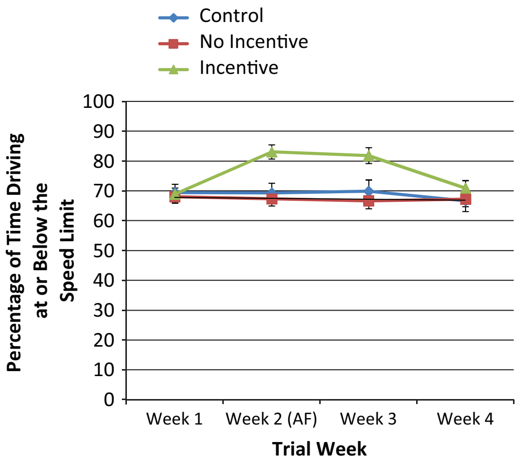

Figure 1. Percentage of time driving at or slower than the speed limit as a function of monetary incentive and advisory feedback. Error bars indicate the standard errors of the means.

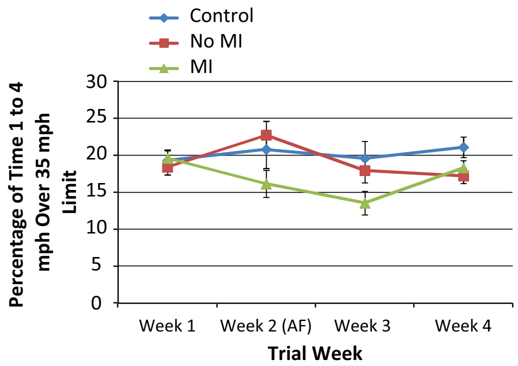

Figure 2. The effect of monetary incentive and automated feedback on the percentage of time driving 1 to 4 mph faster than 35 mph.

and week, with the no-MI group increasing and the MI group decreasing the time spent driving 1 to 4 mph faster than the limit during Week 2 relative to Week 1 for both groups and Weeks 3 and 4 for the no-MI group.

Percentage of time driving at or slower than 70-mph limits. The covariate for this analysis was the total miles driven in 70-mph zones summed across the 4-week trial period. The ANCOVA indicated that the covariate was significant: $F(1, 23) = 10.18$, $p < .01$, partial $\eta^2 = .31$. The main effect of week was not significant, $F(3, 69) = 1.96$, *ns*. The main effect of incentive group was not significant given the reduced alpha criterion: $F(2, 23) = 4.69$, $p = .02$, partial $\eta^2 = .29$. The mean percentages of time at or slower than 70 mph by the incentive, no-incentive, and control groups were 70.40%, 54.83%, and 48.78%, respectively. The interaction between incentive group and week was not significant, $F(6, 69) = 1.40$, *ns*.

Mean speed on 25-mph roads. The covariate for this analysis was the total miles driven in 25-mph zones summed across the 4-week trial period. The ANCOVA indicated that the covariate was significant: $F(1, 46) = 9.53$, $p < .01$, partial $\eta^2 = .17$. The main effects of incentive group and week were not significant, $F(2, 46) = 4.24$, *ns*, and $F(3, 138) = 1.50$, *ns*, respectively. The interaction between week and experimental group was significant $F(6, 138) = 4.51$, $p < .001$, partial $\eta^2 = .16$. Trend analysis indicated a significant quadratic trend for this interaction, $F(2, 47) = 19.29$, $p < .001$, partial $\eta^2 = .28$. Drivers in the MI group significantly reduced their mean speed during Weeks 2 and 3 ($M = 14.80$ mph) relative to Weeks 1 ($M = 16.60$ mph) and 4 ($M = 16.40$ mph). The MI group's mean speed during Weeks 2 and 3 was slower than the mean speeds of the control group and no-MI group at each measurement period. The mean speed of the no-MI group during Week 4 ($M = 18.2$ mph) was also significantly higher than the MI group's mean speed at Week 1 ($M = 16.6$ mph) and Week 4 ($M = 16.4$ mph). Mean speed of the control and no-MI groups did not differ significantly from week to week (see Figure 3).

Miles Driven per Week

An ANOVA assessed whether miles driven by each incentive group varied from week to week. The test of sphericity was not violated, but the Levene's test for homogeneity of variance was significant. The effect of week was significant, $F(3, 141) = 6.16$, $p < .01$, partial $\eta^2 = .12$, observed power = .96. The Bonferroni post hoc test indicated that drivers drove significantly more miles during Week 1 ($M = 167.91$) than

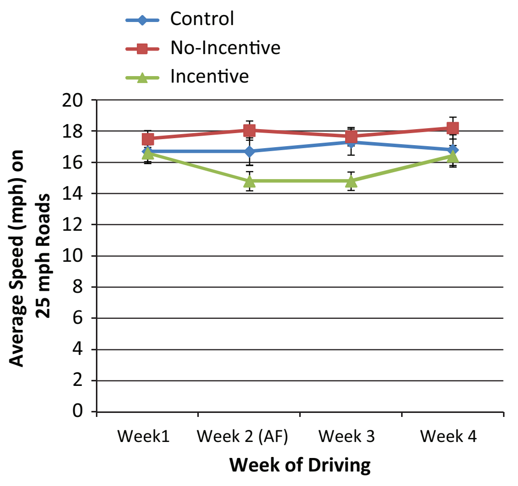

Figure 3. Average speed on 25-mph roads as a function of monetary incentive and advisory feedback.

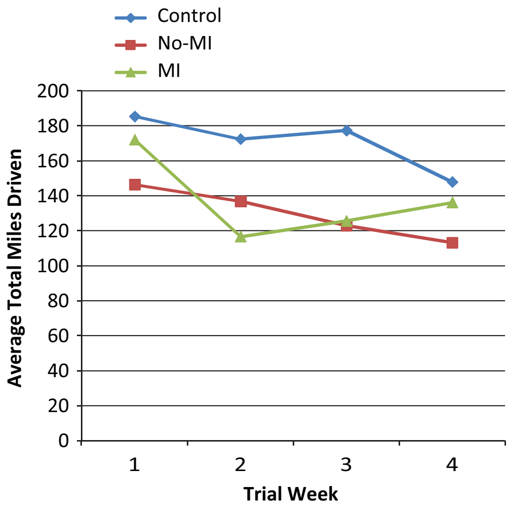

Figure 4. Average total miles driven per week by incentive group.

during Week 2 (M = 141.90), Week 3 (M = 141.92), and Week 4 (M = 132.37). The interaction between incentive group and week was not significant, $F(6, 141) = 1.83$, *ns*. The effect of incentive group was not significant, $F(2, 47) = 1.17$, *ns* (see Figure 4).

Trust in AF System

After experiencing the AF system, drivers rated the statement, "The speed warning system was trustworthy." The ratings were made on a scale of 1 to 10, with 1 indicating complete disagreement and 10 indicating complete agreement. The means for the MI and no-MI groups were 6.80 and 8.40, respectively. An independent-samples t test indicated a marginal (given the reduced alpha criterion) difference between the two groups: $t(33) = 2.44$, $p = .02$.

DISCUSSION

This field experiment combined a technology-based system that provided real-time feedback to drivers with principles of behavior theory in an effort to reduce observed speeding faster than posted limits. The results indicated large effects for the interaction between week and incentive group after we controlled for the mileage driven by each driver within each speed limit zone as well as total mileage collapsed across zones. However, the effects were, with one exception, different from the predicted interaction. Drivers in the incentive group significantly reduced their speeding behavior during Weeks 2 and 3 when MI was active, relative to Week 1 and to the control group's during all 4 weeks of driving and, typically, relative to the no-MI group's measures at all 4 weeks.

The reduction in speeding behavior during these 2 weeks was manifested by several measures. Drivers in the MI group consistently increased the percentage of time driving at or slower than the speed limit and reduced the percentage of time driving 5 mph of more faster than the posted speed limit. The pattern of results was consistent whether we analyzed different speed limits or collapsed across all speed limits. Drivers in the MI group also significantly reduced their average speeds in several speed limit zones when they received the incentive. The floor effect in the MI group appears to have eliminated the potential to differentiate between the MI-only and the MI-plus-AF conditions.

Applied human factors research is frequently guided by and benefits from theoretical perspectives. In many cases, the research focus requires consideration of principles rooted in cognitive psychology. For example, the bulk of mental workload studies requires that researchers embrace models of information processing and attention. Usable computer software menus are based on theories of working and short-term memory. Designers improve signage on the basis of scientific principles drawn from visual perception. In the current study, the primary goal was to affect behavior change, and as such, the inclusion of the incentive condition and the design of the contingency and display in the experimental design stemmed directly from behavior theory. As stated by Eisenberger and Cameron (1996), "any learnable category of performance, including original thinking, can be effectively strengthened by reward" (p. 1164). Thus, the hypothesized effects of the incentive on observed speeding were straightforward.

However, the obtained results for the incentive alone were larger than expected given two European studies that paired advisory ISA with economic incentives (Harms et al., 2007; Hultkrantz & Lindberg, 2003). An explanation for this floor effect may be the inclusion of the in-vehicle incentive display on which drivers saw running totals of their reward remaining at the start and end of each trip. The display may have provided sufficient feedback and extra motivation to the drivers to keep their speed at levels that would maintain their bonus. In retrospect, Harms et al. (2007) and Hultkrantz and Lindberg (2003) did not provide any in-vehicle feedback about the incentive, which may explain why Harms et al. reported that the effect of the incentive alone resulted in more modest reductions in speeding compared with the incentive plus ISA and no incentive plus ISA.

The patterns of results in the current study were similar to Battista et al. (2010) and Mazureck and van Hattem (2006). Specifically, these researchers reported large effects on speeding and following distance associated with the pairing of incentives and in-vehicle feedback. These two research efforts also indicated that drivers reverted to baseline measures following the removal of the intervention, which also occurred during the current project. Together, the current results combined with previous incentive-based advisory ISA systems have clear implications for future research about the effect of in-vehicle incentive displays as well as the need to continue to provide the external motivation to maintain behavior change. At the end of the study, some participants in the MI condition noted that they treated the incentive condition as a "game" in which they were trying to "win," and this comment provides some indication that for these participants, the condition became associated with internal motivation. Follow-up research could assess the extent to which such drivers differed from those who did not report creating this internal motivation.

In contrast to the incentive, the advisory system had moderate effects on speeding behavior. There were analyses that indicated that drivers in the AF condition significantly reduced their speeding 5 or more mph faster than the limit. In addition, drivers in the no-MI group increased the percentage of time driving 1 to 4 mph faster than the limit during the week they received the AF compared with baseline weeks. However, these results were less than expected given the results of European researchers (see Harms et al., 2007). This lack of correspondence between the current project and Harms and colleagues (2007) underscores the importance of not assuming that empirical results will transfer from culture to culture.

Warner et al. (2009) provide another example of significant cultural differences regarding traffic safety behavior. Warner et al. compared differences between Turkish and Swedish drivers' attitudes about speeding and self-reported speeding behavior. Drivers in Sweden reported a greater degree of compliance with speed limits and favorable attitudes toward their country's speed limits than did drivers in Turkey. Warner et al. suggested that a primary reason for the difference is the relative importance of traffic safety in each country. Sweden has spent a significant effort on traffic safety initiatives, which is evidenced by a lower fatality rate. Warner et al. suggest that an additional result of Sweden's effort is a perception among Swedish drivers that it is normal to obey traffic laws, including speed limits. In contrast, Turkey has a much higher fatality rate than Sweden, and the authors indicate that this fatality rate is reflected in the attitudes of Turkish drivers, who perceive the norm to be to violate speed limits.

A similar difference in attitudes about speeding may exist between drivers in the United States and Sweden, the country in which Biding and Lind (2002) completed the large-scale evaluation of ISA, and between the United States and Denmark, where Harms et al. (2007) completed their field test of advisory ISA and incentives. Specifically, if Danish and Swedish drivers' attitudes are more favorable toward obeying the speed limit than those of drivers in the United States, then Danish and Swedish drivers may have been more likely to reduce their speeds when alerted by the advisory ISA. Shinar, Schechtman, and Compton (1999) reported that drivers in the United States rated speeding as less of a threat to their safety than they rated driving unbelted or driving impaired. This finding further supports the notion of meaningful cultural differences in attitudes about traffic safety behaviors.

As mentioned earlier in this article, the variable of user trust is of particular importance when considering whether and how to implement additional signaling systems in the driving cockpit. In the current study, we noted one marginal difference in self-reported trust among experimental groups, whereby participants in the MI group provided lower ratings for the AF system "trustworthiness" than did the no-MI group. This rating, combined with the comparatively stronger effect of MI for speeding control indicates that the participants in the MI group may not have fully allocated the task of speed limit maintenance to the AF system. However, despite this marginal difference, both groups' mean ratings indicated relatively high levels of trust. We consider this a positive finding, suggesting that our design and implementation of the auditory alerting signal did not lead to negative group ratings of trust. In fact, the collective results suggest that participants in the MI group were more concerned about monetary consequences than about whether the auditory signal was or was not trustworthy. It is also possible, given the relative simplicity of the signal (nontext, repetitive auditory bursts), that participants lacked information to form a qualitative judgment about signal trust.

In summary, this project tested the effects of MI and AF on speeding behavior of habitual speeders, and the results indicate that the participants who received an MI to drive within 4 mph of the speed limit significantly reduced their speeding behavior. Moderate reductions in speeding resulted from the AF system, although the participants' relative familiarity of the test area, the habitual manner of speeding, and the 1-week exposure period may have affected these results. In addition to the effect on speeding 5 mph faster than the limit, drivers indicated a high degree of acceptance for the MI system. Other results associated with trust and acceptance as well as perceived mental workload suggest that future research is needed to maximize acceptability of the advisory ISA system and to reduce workload associated with the MI system.

If further research demonstrates that small MIs affect behavior for longer periods than the 2-week span used in this study, then this approach may be a feasible and effective technology-based countermeasure. Determining the extent of such persistent behavior change with or after the removal of an incentive is important because other non-incentive-based ISA research (Biding & Lind, 2002) indicates some attenuation of system effects on speeding. Additional ISA research should also more completely account for the opportunity to speed. In the current study, we limited this effort to filtering zero speeds from analysis. Including video cameras or radar in the instrumentation suite would address this limitation. Despite these issues, the results of the current project were encouraging; drivers in a naturalistic setting reduced speeding when they received a modest incentive, and changing this behavior in the real world is noted to be a difficult endeavor (Harsha & Hedlund, 2007).

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KEY POINTS

- Application of principals of behavioral psychology with developing technology applications resulted in a large significant reduction in speeding 5 mph or more faster than the speed limit in a naturalistic setting.
- The alerting system that provided auditory and visual alerts to drivers had modest effects on speeding behavior.
- The findings have implications for the use of intelligent speed adaptation systems in conjunction with insurance premiums to significantly improve traffic safety.

REFERENCES

Abe, G., & Richardson, J. (2005). The influence of alarm timing on braking response and driver trust in low speed driving. *Safety Science, 43*, 639–654.

Adell, E., & Varhelyi, A. (2008). Driver comprehension and acceptance of the active accelerator pedal after long-term use. *Transportation Research Part F, 11*, 33–51.

Battista, V., Burns, P., & Taylor, G. (2010, June). *Using rewards to influence driving behaviour: A field operational trial*. Paper presented at the 2010 Canadian Multidisciplinary Road Safety Conference, Niagara Falls.

Biding, T., & Lind, G. (2002) Intelligent speed adaptation (ISA): Results of large-scale trials in Borlänge, Lidköping, Lund and Umeå during the period 1999–2002 (Publication 2002:89 E). Borlänge: Swedish National Road Administration.

Blincoe, K. M., Jones, A. P., Sauerzapf, V., & Haynes, R. (2006). Speeding drivers' attitudes and perceptions of speed cameras in rural England. *Accident Analysis & Prevention, 38*, 371–378.

Bliss, J. P., & Acton, S. A. (2003). Alarm mistrust in automobiles: How collision alarm reliability affects driving. *Applied Ergonomics, 34*, 499–509.

Brookhuis, K., & de Waard, D. (1999). Limiting speed: Towards an intelligent speed adapter (ISA). *Transportation Research Part F, 2*, 81–90.

Carsten, O. (2002). European research on ISA: Where are we now and what remains to be done. In *Proceedings of the ICTCT Workshop*, Retrieved from http://www.ictct.org/workshop.php?workshop_nr=16

Carsten, O. M. J., & Tate, F. N. (2005). Intelligent speed adaptation: Accident savings and cost–benefit analysis. *Accident Analysis & Prevention, 37*, 407–416.

Denton, G. G. (1966). A subjective scale of speed when driving in a motor vehicle. *Ergonomics, 9*, 203–210.

Edworthy, J., Loxley, S., & Dennis, I. (1991). Improving auditory warning design: Relationship between warning sound parameters and perceived urgency. *Human Factors, 33*, 205–231.

Eisenberger, R., & Cameron, J. (1996). Detrimental effects of reward. Reality or myth? *American Psychologist, 56*, 1153–1166.

Elvik, R., Christensen, P., & Amundsen, A. (2004). *Speed and road accidents* (TOI Report 740/2004). Oslo, Norway: Institute of Transport Economics.

Governors' Highway Safety Association. (2005). *Survey of the states: Speeding*. Retrieved from http://www.ghsa.org/html/publications/survey/pdf/speeding/surveystates_speeding.pdf

Harms, L., Klarborg, B., Lahrmann, H., Agerholm, N., Jensen, E., & Tradisauskas, N. (2007, June). *Effects of ISA on the driving speed of young volunteers: A controlled study of the impact information and incentives on speed*. Proposal for paper at the 6th European Congress on Intelligent Transport Systems and Services, Aalborg, Denmark.

Harsha, B., & Hedlund, J. (2007). *Changing America's culture of speed on the roads*. Washington, DC: AAA Foundation for Traffic Safety. Retrieved from http://tinyurl.com/38mktm

Hultkrantz, L., & Lindberg, G. (2003, August). *Intelligent economic speed adaptation*. Paper presented at the 10th International Conference on Travel Behaviour Research, Lucerne, Switzerland.

Jamson, S., Carsten, O., Chorlton, K., & Fowkes, M. (2006). Intelligent speed adaptation: Literature review and scoping study. *Review: Literature and Arts of the Americas, 37*, 407–416.

Lee, J. D., & See, K. A. (2004). Trust in technology: Designing for appropriate reliance. *Human Factors, 46*, 50–80.

Lees, M. N., & Lee, J. D. (2007). The influence of distraction and driving context on driver response to imperfect collision warning systems. *Ergonomics, 50*, 1264–1286.

Matthews, M. L. (1978). A field study of the effects of drivers' adaptation to automobile velocity. *Human Factors, 20*, 709–716.

Mazureck, U., & van Hattem, J. (2006). Rewards for safe driving behaviour. *Transportation Research Record, 1980*, 31–38.

National Highway Traffic Safety Administration. (2009). *Traffic safety facts (2008 data): Speeding* (DOT HS 811 166). Washington, DC: Author.

Regan, M. A., Young, K., Triggs, T., Tomasevic, N., Mitsopoulos, E., Tierney, P. . . Tingvall, C. (2005). *Effects on driving performance of in-vehicle intelligent transport systems: Final results of the Australian TAC SafeCar Project* (Vol. 1, Final Report No. 253). Wellington: Australasian Road Safety Research, Policing and Education Conference.

Schmidt, F., & Tiffin, J. (1969). Distortion of drivers' estimates of automobile speed as a function of speed adaptation. *Journal of Applied Psychology, 53*, 536–539.

Shinar, D., Schechtman, E., & Compton, R. P. (1999). Trends in safe driving behaviors and in relations to trends in health maintenance behaviors in the U.S.A.: 1985–1995. *Accident Analysis & Prevention, 31*, 497–503.

Tabachnick, B. G., & Fidell, L. S. (2001). *Computer-assisted research design and analysis*. Boston, MA: Allyn & Bacon.

U.S. Department of State. (2011). *Netherlands, the: Country specific information*. Retrieved from http://travel.state.gov/travel/cis_pa_tw/cis/cis_982.html

Warner, H. W., Ozkan, T., & Lajunen, T. (2009). Cross-cultural differences in drivers' speed choice. *Accident Analysis & Prevention, 41*, 816–819.

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