Threshold Effects of Speed-Monitoring Devices on the Speeding Behavior of Drivers

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This paper summarizes an evaluation of a speed-monitoring system that provides speed warning feedback to drivers enrolled in a voluntary program. The field study aimed to determine the effects of immediate feedback on drivers, especially chronic speeders. Drivers with at least three speeding violations in the past 3 years were recruited through the Maryland Motor Vehicle Administration. After a 2-week baseline period, the alert system was activated, and driving behavior was monitored for any changes for approximately 4 weeks. Subjects were monitored (silently) for a follow-up phase of 2 weeks. During the treatment phase, drivers received alerts when their speeds exceeded the posted speed limit by more than 8 mph. The findings are encouraging and suggest that verbal alerts are successful in producing short-term changes in driving behavior. Overall, the average proportion of speeding above the alert threshold declined significantly during the treatment phase, an indication that the alerts did have a deterring effect on speeding behavior. Once the alerts were silenced, there was evidence suggesting a sustained change in driving behavior for some participants. Although the proportion of speeding above the threshold was higher during the 2-week follow-up period than during the treatment phase, for some participants the follow-up speeds were lower than those recorded during the baseline phase. Although speeding was reduced during the treatment phase at speeds over the feedback threshold, much of this speeding appeared to have shifted down to just below the threshold. This finding raises an important question regarding optimal levels for setting thresholds for feedback on speeding behavior.

Speeding behavior is pervasive in the United States and is commonly accepted within the driving culture (1). Approximately three-quarters of all drivers in the 2002 NHTSA national survey reported exceeding the posted speed limit (2). In addition, excessive speed is a contributing factor in a high proportion of severe and fatal crashes (3) and was associated with the loss of 9,944 lives (30% of all highway fatalities) in 2011 (4).

Despite decades of efforts in high-visibility enforcement, traffic engineering, driver training, and public education, speeding is a behavior that remains resistant to change. Although traditional approaches (e.g., expanded regular patrols or designated patrols) and more recent innovations (e.g., automated enforcement) certainly help mitigate the problem, these approaches have limitations in terms of their effectiveness, cost, implementation time, and practicality of coverage. High-visibility enforcement programs are costly and can take up to 4 to 6 months to plan, publicize, and implement. Their effectiveness is often site-specific, they are restricted to locations (roadways) that have been targeted for enforcement because of an increased number of speed-related crashes, and drivers other than the general speeding population are often affected by these countermeasures. The impact of automated enforcement programs is delayed because drivers are often unaware for several weeks that they have committed a violation, because speeding citations are not mailed to drivers until after law enforcement personnel have reviewed the evidence. In addition, automated speed enforcement programs are often viewed as intrusive on individual privacy or as a revenue generator rather than a means of improving safety.

One new approach for solving the speeding problem is through the use of a vehicle-based monitoring and feedback system. This particular countermeasure is less affected by the limitations described above, largely because it is paired with an individual driver. The device constantly monitors a given driver, allowing feedback to be immediate and relevant in time. There are currently a variety of commercial and experimental systems that can be installed in an individual’s vehicle to monitor various aspects of driving behavior and vehicle control. These systems frequently include the monitoring of speed and other indices of severe maneuvers, such as hard deceleration.

Recent evaluations of driver monitoring programs are promising and often reporting substantial decreases in risky behaviors, including speeding (5). Unverified reports from fleet owners (i.e., owners or managers of many vehicles such as moving trucks or rental cars) claim that the presence of a monitoring device in their vehicles has led to precipitous decreases in violations and crash rates. Several recent studies have found that equipping teens’ vehicles with in-vehicle monitoring devices helped reduce risky driving behavior by giving feedback about driving behavior to teenagers and their parents (6). In addition, insurance companies are actively pursuing and commercially employing these technologies.

Although the studies are promising, there are reasons for caution as well. In the studies, driver participation was not fully voluntary, with the driver under the influence of a third party who often shared the feedback, such as a parent (for teens), employer (7), or insurer. The tested systems often included more extensive feedback than just speed warnings and it is not known what aspects contributed to


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effectiveness. The findings of benefits in these studies have not been uniformly substantial or sustained.

The current report summarizes a naturalistic driving study that used a viable commercial device (inthinc’s TiwiPRO), which provides speed warning feedback to drivers enrolled in a voluntary program, with emphasis on chronic speeders.

FIELD DATA COLLECTION THROUGH AN IN-VEHICLE NATURALISTIC DRIVING STUDY

The procedures and design of the in-vehicle study were based on previous research, evaluations of commercial speed-monitoring devices, and major themes and issues identified during a focus group with chronic speeders. The in-vehicle study allowed for a careful examination of the driving behavior of chronic speeders in the presence and absence of a speed-monitoring and warning device. In addition, certain subjective data were gathered during device removal, to access participants’ experiences with the device and their overall acceptance of the system.

Study Design

The study used a mixed factorial design, with the treatment phase as a within-subjects factor and age (21–30 years and 30 years or older) and gender as between-subjects factors. Although location (urban, suburban, rural) may play a role in speeding, as would a variety of other factors (e.g., vehicle characteristics, other demographic characteristics, commuting patterns, fuel prices, local enforcement practices, roadway network characteristics), adding additional variables to the study design would have necessitated an increased sample size to maintain similar statistical power. Therefore, for this pilot study, other variables were not included in the research design.

The within-subjects factor of the treatment phase had three levels: baseline, treatment, and follow-up. The pilot study was not intended to quantify fully the magnitude and temporal aspects of the treatment. However, to avoid mistaking gradual effects for the absence of treatment effects, the study design employed an 8-week data collection period for each participant; this included a 2-week baseline period, a 4-week treatment period, and a 2-week follow-up. Although this design would be too limited for a full-scale assessment, it was considered to be adequate to meet the requirements of this pilot.

Participant Recruitment and Characteristics

All participants were recruited in the greater Washington, D.C., area of Maryland. Recruitment efforts targeted individuals of ages 21 years and older who had a valid driver’s license and drove a passenger vehicle at least 100 mi per week on a regular basis. All participants had received at least three speeding violations in the past 3 years (this did not include automated speed enforcement violations, which are not reflected on drivers’ records in Maryland).

The research team developed a cooperative agreement with Maryland’s Motor Vehicle Administration (MVA) to provide a mechanism for identifying a pool of qualified drivers. The MVA contacted sampled drivers by mail and requested that they contact the research team to discuss participation in a research study. This method preserved the anonymity of the drivers until they elected to participate in the survey. When interested drivers contacted the research team, they were screened to identify and recruit qualified study participants. On the basis of the MVA driver records, 9,304 licensed drivers residing in six Maryland counties met the speeding violation and age criteria. The Maryland MVA sent recruitment letters to 6,361 individuals. Of those, 271 individuals contacted the research team and 183 agreed to complete a screener.

A total of 101 participants were enrolled in the study and had TiwiPRO units installed in their vehicles. However, data from 18 participants were compromised and had to be replaced. Issues leading to replacement included traveling out of state for work (not using their own vehicle), driving status change (license revocation), vehicle flooding, tampering with the device, and a crash shortly after the participant entered the treatment phase (which the participant reported as unrelated to the warning system). Seventy-eight participants provided usable data (38 women and 40 men).

All the participants were the sole driver of their vehicle, drove their vehicle almost every day, and drove at least 100 mi in an average week. Maryland’s graduated licensing program made it virtually impossible to find teens meeting the study criteria, so the research team elected not to include them in this study.

Data Collection Procedures

Device Installation

The device installation was simple and took approximately 15–20 min. The system was connected to the on-board diagnostics connector in the vehicle and attached to the lower-left corner of the windshield. Once the device was physically attached to the vehicle, the technician calibrated and activated it for data collection. Before leaving the installation appointment, participants were familiarized with the operation of the device, the kinds of warnings they should expect, and whom to contact in the event of an emergency.

Data Collection

Once installed, the device automatically transmitted data to inthinc servers. The research team monitored the data routinely to confirm that devices were operational, vehicles were being driven regularly, and data did not appear aberrant. During the baseline phase, which lasted approximately 2 weeks, the device collected baseline data without providing speeding feedback to the drivers.

During the study, inthinc provided bread crumb data from the TiwiPRO. This was a continuous stream of travel and speed data that included events such as speeding violations. Data were delivered to an FTP server, appended to a SAS data set, and joined with demographic data collected when the participant was screened and enrolled in the study. Each record in the data set was marked with the participant ID, date and time, location (latitude and longitude), speed, speed limit, incremental time, incremental distance, and event type.

When the driver was above the threshold for speeding in any posted speed limit category, an indication of Speeding was listed on his or her record. This allowed the research team to calculate the proportion of miles the participant traveled while speeding relative to the total miles he or she traveled for each trip. For other records, the event type was identified as Speed Coaching, indicating that verbal
feedback was being delivered to the driver. Speed Coaching occurred only during the treatment phase of the study.

Data were monitored daily to identify any anomalies or suspicious driving behavior. Approximately 2 weeks after device installation, the treatment phase was activated for each participant. During the treatment phase, a verbal alert was triggered if the participant’s speed was in excess of 8 mph over the posted speed limit for a given roadway. The audio alert was a computerized voice that repeated the phrase Speeding Violation until the driver’s speed dropped below the trigger threshold speed. Participants were informed in advance of the date of the feedback mode (i.e., treatment phase) changes. The research team adopted this strategy to avoid startling the participants and inadvertently causing a reaction that might have resulted in an injury or crash. Participants experienced the treatment phase for 4 weeks.

The research team wanted to limit the number of false alarms experienced by a participant. During the treatment phase, participants were instructed to contact the research team if they noticed that the verbal alert was triggered when they were not actually traveling over the posted speed limit. Two participants reported a discrepancy to the research team and the information was confirmed, reported, to in-hinc, and corrected. These notifications occurred only twice and the steps to rectify them were accomplished immediately to minimize any data impact. Although some database records might possibly have been affected by these erroneous speed limits, the quantity and impact of these discrepancies were likely very limited.

Following the treatment phase, the verbal alerts were remotely silenced for the duration of the study (2 weeks). Participants were notified when this occurred.

**Device Removal and Debriefing**

At the completion of data collection, each participant was scheduled for device removal and a debriefing. The removal of the device took approximately five minutes. The debriefing covered topics such as effectiveness of the device, acceptability, motivation, perceived changes in behavior, and so forth. On completion of the study, participants received $150 for their participation.

**Data Cleaning**

During the course of the study, data cleaning involved value transformations, variable derivations, exclusion of erroneous data, elimination of useless records, and identification of tampering situations.

Individual trips were defined for each participant. The beginning of a trip was identified by either the first reported record or a record with the description Ignition On. The end of a trip was identified by a record with the description Ignition Off. Once trips were identified, trip distances, times, and numbers of records comprising a trip were calculated.

Occasionally, faulty GPS data were identified. Sometimes latitude or longitude froze, resulting in adjacent records with identical values for one, the other, or both variables. If more than five consecutive records with faulty GPS data were identified, those records were excluded (<1% of the data set). In addition, some records (<1%) did not have high-quality position information and were also removed from the data set. In some locations, the GPS information was always poor.

The device periodically collected data on vehicle location and speed. Although this information was usually reported every few seconds, the periods were not of a consistent temporal or distance interval. As such, treating them as uniform during the data analysis was impossible. Instead, the distances had to be summed (the primary unit of measure for computing rates of behavior). The analysis reported here examines, in each of the study phases, the sum of distance traveled while speeding per trip relative to total distance traveled per trip. The lack of uniformity in data collection intervals complicated the analysis somewhat, requiring the use of a mixed-model analysis rather than a simple ANOVA or MANOVA, but this approach nonetheless allowed a closer examination of the mile-by-mile behavior of drivers as they made various types of trips on various types of roads.

Several variables were created to characterize the data and to assist with the subsequent analysis. At-speed (@Speed) records were defined as a subset of the overall data set; these represented intervals where the driver was traveling above a threshold set 15 mph below the posted speed limit (see Figure 1). These records were assumed to represent situations where participants were traveling close to the posted speed limit and may have had the opportunity to reach or exceed it. However, without information on the surrounding traffic stream, there was no way to confirm this assumption. This approach also allowed the analysis team to ignore the low-speed or stopped traffic conditions associated with intersections, congestion, and so forth.

Because trips had been identified using raw data records, it was possible to use only the @Speed records for a given trip to calculate within-trip statistics of speeding incidence. All the statistics presented in this report were created from this subset of the overall data set.

![FIGURE 1 At-speed driving.](Image)
RESULTS

The intention of this study was to explore the ability of a speed-monitoring and warning system to monitor and reduce speeding behavior among adults with a history of speeding violations. The intention was not to examine the effects of such a system on speeding that was related to specific speed zones or speed limits.

One measure of the effectiveness of a warning system is the percentage of travel occurring at a given level above the posted speed when alerts are activated relative to when alerts are silenced. The following sections describe the overall effects of a speed-monitoring and warning system on two types of speeding behavior:

- Driving up to 8 mph over the posted speed limit. This behavior includes events when participants were driving above the posted speed limit but below the threshold set for receiving alerts during the treatment phase.
- Driving above 8 mph over the speed limit. This behavior includes events when participants were driving above the speed threshold set for receiving alerts during the treatment phase.

The data used in this analysis were distance based rather than time based, that is, the proportion of trip distance traveled over a posted speed limit in relation to the total trip distance. The use of time-based data was considered but would have complicated the analysis when vehicle speed was very slow (e.g., congestion) or 0 (e.g., idling).

Instead of the traditional repeated-measures ANOVA approach, the analysis team implemented a mixed-model approach with SAS PROC MIXED. SAS PROC MIXED was more appropriate for the data structure and questions of interest, in addition to having advantages over traditional repeated-measures approaches. The dependent variables of interest were subjected to a logit transform, instead of the more common arcsin transform approach.

SAS PROC MIXED was used for the repeated-measures analyses on the logit transform of each variable (i.e., the average proportions of events involving travel up to 8 mph above the speed limit and events involving travel over 8 mph above the posted speed limit), with an ante-dependence covariance structure. All dependent variables discussed below were analyzed as logit transforms of the original dependent variable. In addition, the p values reported for contrast comparisons with t-tests were Sidak adjusted.

Because this was an exploration of speeding behavior, the analyses focused only on cases where there was an opportunity to speed; that is, when the driver was traveling at a speed within at least 15 mph of the posted speed limit (@Speed). Drivers were separated into two broad age categories: 21–30 and 30 years or older. Because there were no main effects or interactions with gender, it was not included in the analytical models in an effort to increase statistical power.

Speeding Behavior

Driving Up to 8 mph Above the Posted Speed Limit

If the alert was effective at modifying the participant’s behavior, the average proportion of speeding over 8 mph above the posted speed limit should have dropped off during the treatment phase. Conversely, the average proportion of speeding up to 8 mph above the posted speed limit may have escalated as drivers slowed to avoid the alert. This section analyzes the mean proportion of each trip that a participant was speeding up to, but not exceeding, 8 mph over the speed limit in each of the study phases.

A robust effect was seen for the treatment phase ($F = 12.17$, $p < .0001$). There was an increased proportion ($X$) of speeding up to 8 mph over the posted speed limit for each trip during the treatment phase ($X = .29$) compared with the baseline or follow-up phase ($X = .27$ and $X = .28$, respectively) (see Figure 2). The proportion of speeding up to 8 mph over the posted speed limit was significantly higher during the treatment phase than during the baseline phase ($t = -3.72$, $p < .005$) or the follow-up phase ($t = 3.80$, $p < .001$). These findings suggest that, during the treatment phase, there was a downward shift in behavior from driving at higher speeds to electing to drive at a speed below the threshold for alerts (8 mph above the posted speed limit). Although the participant was still driving over the speed limit, no verbal feedback was provided during the treatment phase unless the participant’s speed exceeded the alert threshold. There was no statistical difference between the baseline and follow-up phases with regard to proportion of speeding up to

![FIGURE 2 Mean proportion of speeding up to 8 mph over the posted speed limit by phase.](image-url)
8 mph above the posted speed limit \((t < 1)\) and no significant difference between the two age groups \((F < 1)\) (see Figure 3) or the interaction of age and treatment phase \((F = 1.13)\).

**Driving More Than 8 mph Above the Posted Speed Limit**

If the alert received during the treatment phase was effective at modifying the participant’s behavior, the participant’s average proportion of speeding over 8 mph above the posted speed limit should have decreased.

There was a main effect of the treatment phase \((F = 37.84, p < .005)\). The proportion of speeding over 8 mph was significantly lower during the treatment phase \((X = .13)\) than during the baseline phase \((X = .18; t = 7.90, p < .0001)\) or the follow-up phase \((X = .16; t = −5.89, p < .0001)\). Figure 4 shows that speeding behavior decreased dramatically during the treatment phase; this result suggests that the alerts do have an influence on suppressing speeding behavior.

A significant difference was also seen when the baseline and follow-up conditions were examined \((t = 3.18, p < .01)\). The proportion of speeding over 8 mph was lower during the follow-up phase than the baseline phase, suggesting that participants’ speeding behavior may begin to increase during the 2-week follow-up phase but does not return to baseline levels immediately.

There was a significant main effect of age \((F = 8.71, p < .01)\), with drivers in the 21–29 years age group more often speeding by more than 8 mph above the speed limit compared with those in the 30 years or older age group in all three phases (see Figure 5).

**Habitual Versus Nonhabitual Speeders**

For the purposes of this study, habitual speeders were defined as individuals who drove at least 30% of their total miles speeding over 8 mph above the posted speed limit during the baseline phase. The degree of speeding above this threshold suggested that this subgroup may have been more willing to risk receiving a speeding
violation and therefore more resistant to the deterring effects of the alerts during the treatment phase. Highlighting this group is another way to infer a conservative estimate of the alert’s effectiveness. With this definition, 35 of the 78 participants were classified as habitual speeders and the remainder was categorized as nonhabitual speeders. Twenty-one of the habitual speeders were between the ages of 21 and 29, and 14 were 30 or older. As in the previous comparisons, gender differences were not significant; therefore, data were collapsed for subsequent analyses of habitual speeders. Similarly, age was not significant throughout the analyses of habitual speeders, so age data were collapsed to increase statistical power.

Habitual Versus Nonhabitual Speeders Driving Up to 8 mph Above the Posted Speed Limit

There was a strong main effect of the treatment phase ($F = 13.30, p < .001$) (Figure 6). During that phase ($X = .29$), there was an increased proportion of speeding up to 8 mph over the speed limit relative to the baseline phase ($X = .27; t = -3.99, p < .001$) or the follow-up phase ($X = .28; t = 3.96, p < .001$). There was no statistically significant difference between the baseline and follow-up phases ($t = -0.36, p > .05$). The alert seemed to modify the participants’ behavior, with the average proportion of speeding up to 8 mph above the posted speed limit escalating as drivers slowed to avoid the alert.

There was also a robust significant effect of habitual speeding as a category ($F = 6.05, p < .05$). Habitual speeders had a much lower proportion of speeding up to 8 mph over the speed limit compared with nonhabitual speeders in all three phases (see Figure 7).

Habitual Versus Nonhabitual Speeders Driving over 8 mph Above the Posted Speed Limit

The analysis of the percentage of speeding over 8 mph above the speed limit showed a strong main effect of the treatment phase...
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\((F = 37.90, p < .0001)\) (Figure 8). This effect was driven by the lower proportion of speeding over 8 mph above the speed limit for each trip during the treatment phase \((X = .13)\) relative to the baseline or follow-up phase \((X = .18\) and \(X = .16\), respectively). The proportion of speeding was significantly lower in the treatment phase than in either the baseline phase \((t = 7.94, p < .0001)\) or the follow-up phase \((t = -5.86, p < .0001)\). The proportion of speeding was also lower in the follow-up phase than in the baseline phase \((t = 3.19, p < .01)\), an indication that speeding behavior remained less frequent after treatment subsided. Figure 9 shows that speeding behavior decreased dramatically during the treatment phase; this result suggests that the alerts did have an influence on suppressing speeding behavior over 8 mph above the posted speed limit.

Habitual speeding as a category was highly significant \((F = 80.04, p < .0001)\). The proportion of speeding over 8 mph above the posted speed limit was much higher among habitual speeders than among nonhabitual speeders (see Figure 9).

**CONCLUSIONS AND DISCUSSION**

This study aimed to determine the impact of long-term exposure to a speed-monitoring and warning system on drivers’ speeding behavior. The purpose of such a system is to discourage the driver from speeding by continuously comparing the vehicle speed to the posted speed limit and alerting the driver when the vehicle speed surpasses a given threshold. Although the cost and benefits of traditional countermeasures have been investigated over the years, the influence of in-vehicle technologies as a deterrent to speeding behavior is only beginning to be considered. If this technology is effective and efficient in suppressing speeding behavior, speed-monitoring and warning systems might be useful in supplementing more traditional countermeasures.

This study’s findings are encouraging and suggest that the verbal alerts provided by the system produced short-term changes in speeding behavior. The true measure of system effectiveness is the change in the average proportion of each trip that the driver speeded over...
8 mph above the posted speed limit, the threshold for the alert in the current study. Overall, this proportion declined significantly during the treatment phase, indicating that audio alerts do have a deterring effect on speeding behavior. In addition, once the treatment was lifted, the evidence suggested a sustained change in driving behavior for some participants. Although the proportion of each trip that drivers speeded above the threshold was higher during the 2-week follow-up phase than during the treatment phase, both were significantly lower than the proportion of speeding recorded during the baseline phase.

The effects seemed to be similar for habitual speeders, where a decline in the proportion of speeding above the threshold was seen during the treatment phase; however, the speeding behavior resumed once the alerts were removed. This group of drivers, on average, drove at speeds greater than 8 mph over the speed limit for at least 30% of their baseline trips and may be more willing to risk receiving a speeding citation. Thus, from a safety perspective, they might benefit the most from using a speed-monitoring and warning system.

During the treatment phase, the alert threshold actually appeared to increase the proportion of speeding in the range above the posted speed limit but below the speed required to trigger the audio alert. Although speeding over the feedback threshold was reduced during the treatment phase, much of this speeding appears to have shifted to just below the threshold. This raises an important question regarding optimal thresholds for feedback on speeding behavior. Variation in threshold levels for triggering audio alerts is an area that warrants further study.

Because the current study lasted only 8 weeks for each driver, testing the prolonged effects of the alerts on driving behavior was not possible. Further research with longer treatment and follow-up periods may be necessary for understanding the true, lasting effects of this type of system on driving behavior.

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REFERENCES


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