The effects of persistent audible seat belt reminders and a speed-limiting interlock on the seat belt use of drivers who do not always use a seat belt

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ABSTRACT

INTRODUCTION: Vehicle technologies that increase seat belt use can potentially save thousands of lives each year. Kidd et al. (2018) found that a gearshift interlock was more effective for increasing seat belt use than an intermittent 7-second audible reminder, but interlocks may not be more effective than persistent audible reminders lasting at least 90 seconds.

METHOD: Forty-nine part-time belt users who had a recent seat belt citation and reported not always using a seat belt drove two vehicles for 1 week each. Thirty-three drove a Chevrolet with three intermittent 7-second audible reminders followed by either a BMW with a 90-second audible reminder (n=17) or a Subaru with an indefinite audible reminder (n=16). The other 16 participants experienced the BMW audible reminder followed by a speed-limiting interlock that limited speed to 15 mph during unbelted driving. These data were combined with data from 32 part-time belt users in Kidd et al. (2018) who experienced the intermittent reminder for 2 weeks or the intermittent reminder for 1 week and a gearshift interlock the next.

RESULTS: Relative to the intermittent reminder, seat belt use was significantly increased 30% by the BMW reminder, 34% by the Subaru reminder, and 33% by the speed-limiting interlock. Belt use was increased 16% by the gearshift interlock, but this change was not significant. More participants circumvented the speed-limiting interlock to drive unbelted than the audible reminders. Response to a poststudy survey indicated that interlocks were less acceptable than reminders.

CONCLUSIONS: Audible reminders lasting at least 90 seconds and a speed-limiting interlock were significantly more effective for increasing seat belt use than an intermittent audible reminder, but reminders were found more acceptable.

PRACTICAL APPLICATIONS: Strengthening existing U.S. safety standards to require audible reminders lasting at least 90 seconds for front-row occupants could save up to 1,489 lives annually.

Keywords: seat belt use; seat belt reminder; enhanced reminder; seat belt interlock; part-time seat belt user

INTRODUCTION

Seat belts reduce the fatality risk of front-row passenger vehicle occupants involved in a crash by 45% (Kahane, 2000). About 90% of front-row occupants observed at controlled intersections during the day time in the United States were using a seat belt in 2017 (Li & Pickrell, 2018), but only slightly more than half of front-row occupants fatally injured in a crash where belt use was known were using a seat belt (National Center for Statistics and Analysis, 2018). Based on 2016 data from the Fatality Analysis Reporting System, increasing seat belt use to 100% can potentially save an additional 2,456 lives each year (National Center for Statistics and Analysis, 2017). Most occupants who do not routinely use seat belts say they are not opposed to seat belts but frequently forget, are in a rush, or are driving a short distance (Boyle & Lampkin, 2007; Kidd, McCartt, & Oesch, 2014). Vehicle technology can address these issues by reminding forgetful occupants to use a seat belt using auditory chimes and visual prompts, or coercing occupants to buckle up by limiting vehicle use or restricting vehicle functions. Past approaches for increasing belt use using vehicle technology have not always been acceptable to the public (Transportation Research Board, 2003). Therefore, it is critical to not only identify the most effective vehicle technology for increasing seat belt use but to also identify one that is acceptable to consumers.

Federal Motor Vehicle Safety Standard (FMVSS) 208 requires every passenger vehicle to be equipped with a seat belt reminder system that provides a continuous or intermittent auditory signal lasting at least 4 seconds but not more than 8 seconds and some continuous or flashing visual display when a driver is not using a seat belt at ignition (Office of the Federal Register, 1974). Past research has shown that seat belt reminder systems meeting FMVSS 208 are not effective for increasing seat belt use (Cohen & Brown, 1973; Robertson & Haddon, 1974; Westefeld & Phillips, 1976). Many automakers have voluntarily equipped vehicles with enhanced seat belt reminder systems that have auditory chimes that go beyond the 4–8 second period required by FMVSS 208. Previous research has found that enhanced reminders with auditory signals occurring more than 8 seconds after ignition increase seat belt use up to 6 percentage points relative to vehicles without an enhanced reminder (Ferguson, Wells, & Kirley, 2007; Freedman, Levi, Zador, Lopdell, & Bergeron, 2007; Williams, Wells, & Farmer, 2002).

Although many automakers equip vehicles with enhanced reminders for the driver, the design of these systems vary and, consequently, so do their effects on seat belt use. Persistent enhanced reminders with longer-lasting or more frequent auditory chimes have been found to be more effective for increasing seat belt use (Lerner, Singer, Huey, & Jenness, 2007). The European New Car Assessment Programme (Euro NCAP) encourages more

persistent enhanced reminders by giving credit to vehicles with a seat belt reminder system that has a "final audible signal" at least 90 seconds in duration with no gaps in the signal greater than 10 seconds (Euro NCAP, 2017). The requirements previously allowed gaps up to 25 seconds (Euro NCAP, 2015). Part-time belt users who experienced various enhanced reminders during a simulated drive perceived enhanced reminders that met the previous Euro NCAP's design requirement to be more effective for increasing belt use than a reminder that did not meet the requirement (Kidd 2012). Krafft, Kullgren, Lie, and Tingvall (2006) observed drivers in five Swedish cities and found that driver belt use was 6 percentage points higher in vehicles with an enhanced reminder that met the prior Euro NCAP design requirement compared with drivers in vehicles with an enhanced reminder that did not meet the requirements, and was 17 percentage points higher than drivers in vehicles without a seat belt reminder system.

Seat belt interlocks restrict the use of a vehicle feature if an occupant is not using a seat belt to motivate belt use, and may be more effective for increasing seat belt use than enhanced reminders. Van Houten, Hilton, Schulman, and Reagan (2011) recorded seat belt use among a small sample of commercial vehicle drivers who operated a vehicle with a system that increased accelerator pedal resistance when the driver was unbelted. The system increased belt use from under 70% to 100%. Kidd, Singer, Huey, and Kerfoot (2018) examined the effectiveness of a gearshift interlock that delayed an unbelted driver from shifting into gear for 30 seconds for increasing the seat belt use of drivers who received a seat belt citation and self-reported not routinely using a seat belt. The gearshift interlock increased the average amount of time the driver belt was in use during a trip by 16% relative to the vehicle's enhanced reminder system.

The enhanced reminder evaluated in Kidd et al.'s (2018) study issued five auditory chimes in a 7-second period immediately after ignition, 105 seconds after ignition, and 360 seconds after ignition when the driver was unbelted, and did not meet Euro NCAP's design requirements for the final audible signal. A persistent enhanced reminder meeting Euro NCAP's design requirements for the duration of an auditory signal may be more effective for increasing seat belt use, but the effectiveness relative to a gearshift interlock or other types of seat belt interlocks is unknown. This study measured the effectiveness of two persistent enhanced reminders that provided an auditory signal lasting at least 90 seconds in duration and a speed-limiting interlock system that restricted the vehicle's speed to 15 mph for increasing the seat belt use of drivers who do not always use a seat belt. The data from this study were combined with data from Kidd et al. (2018) to compare these technologies with a gearshift interlock and an enhanced reminder that did not meet Euro NCAP's design requirements. Based on previous research (Krafft,

Kullgren, Lie, & Tingvall, 2016), it was hypothesized that the persistent enhanced reminders meeting Euro NCAP's design requirements would be significantly more effective for increasing belt use than an enhanced reminder that did not meet these requirements. Based on Kidd et al.'s (2018) findings, the speed-limiting interlock and gearshift interlock were expected to be more effective for increasing seat belt use than all of the enhanced reminders.

Acceptance is critical to the viability of using vehicle technologies to increase belt use, so a second objective of this study was to evaluate driver acceptance of persistent reminders and the speed-limiting interlock system. More persistent enhanced reminders are perceived to be more annoying (Kidd, 2012; Lerner et al., 2007), but may still be more favorable than seat belt interlocks. A national survey conducted by Kidd et al. (2014) suggests that there is far less public support for using seat belt interlocks to increase seat belt use than using enhanced reminders. Therefore, it was hypothesized that participants would be less accepting of using a speed-limiting interlock for increasing seat belt use compared with a persistent enhanced reminder.

METHOD

Kidd et al. (2018) measured the effect of a gearshift interlock on the belt use of part-time belt users by comparing the change in seat belt use for part-time belt users who drove a Chevrolet vehicle with an enhanced reminder for 1 week followed by a similar Chevrolet vehicle with a gearshift interlock for 1 week to the weekly change in belt use of part-time belt users who only drove Chevrolet vehicles with an enhanced reminder for 2 weeks. The latter group of participants provided a baseline reference for measuring the effects of two persistent enhanced reminders and a speed-limiting interlock on the seat belt use of part-time belt users. Accordingly, this study followed the methods used in Kidd et al.'s 2018 study, so that data from this study could be combined with data from part-time seat belt users in Kidd et al.'s study to make these comparisons and address the main research question. The methodology is summarized here, and a detailed description can be found in Kidd et al (2018).

Recruitment

Records provided by the Maryland Judiciary System were used to identify people who received a seat belt citation between 2013 and 2018. Flyers were mailed to 32,945 potential participants that invited them to participate in a study evaluating new vehicles; 1,650 people responded to the flyer. Of those who responded, 1,365 completed a screener survey over the phone to determine eligibility. In the screener survey, respondents had to self-report using a seat belt rarely or some of the time as a driver to be eligible for participation. Respondents who reported using a seat belt most of the time as a driver also had to report using a seat belt in eight or fewer of their last 10 trips to be

eligible. Kidd et al. (2018) required respondents who reported using a belt most of the time while driving to report not using a seat belt in seven or fewer of their last 10 trips to be eligible. Individuals who reported never using a seat belt were not eligible. Participants in this study met the same eligibility requirements for driving history, medical history, and vehicle insurance used in Kidd et al (2018).

Participants

One hundred and ten people were eligible to participate in this study and 62 were enrolled. Thirteen of the 62 participants were excluded from the final sample; 12 due to a data collection equipment failure and one who did not complete the first study week. The final sample in this study included 49 participants (31 men, 18 women) ages 25–59 years (*M*=38.7, *SD*=10.3). Data from the final sample in this study were combined with data from the 32 part-time belt users in Kidd et al. for the main analysis. The combined sample included 81 part-time belt users (54 men, 27 women) that were 25–59 years old (*M* = 38.0, *SD* = 10.1).

Vehicles and instrumentation

Eight vehicles were used in this study: two 2015 Chevrolet Cruzes, a 2017 Subaru Impreza, and five 2014 BMW X5s. Every vehicle was equipped with an enhanced seat belt reminder for the driver and right front passenger, but only the driver enhanced reminder was evaluated. The Chevrolet enhanced reminder included three reminder cycles that occurred at ignition, 105 seconds after ignition, and 360 seconds after ignition. Each reminder cycle was 20 seconds in duration and included five audible tones during a 7-second period. At the beginning of the reminder cycle, a red seat belt "telltale" icon in the tachometer flashed for 20 seconds and remained illuminated afterwards (Figure 1a).

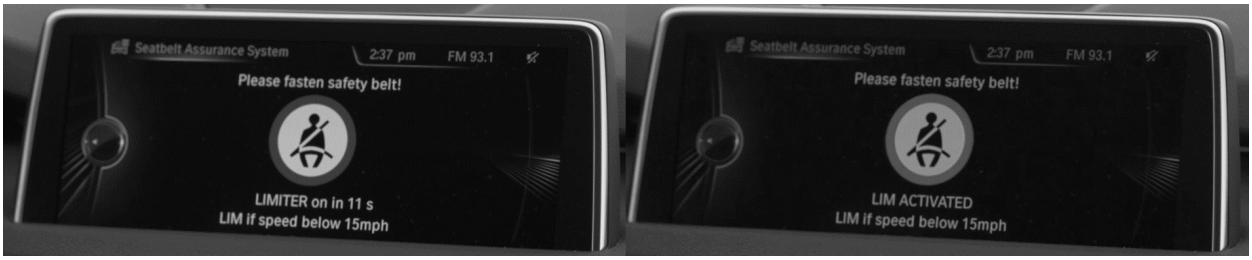
(a) **(b)** **(c)**

Figure 1. Red seat belt telltale icon in the (a) Chevrolet, (b) BMW, and (c) Subaru.

The BMW enhanced reminder consisted of an audible tone, visual icon, and a text display that began soon after ignition. The audible tone occurred almost every second for 100 seconds. During this period, a red seat belt telltale icon was shown in the instrument cluster (Figure 1b). The seat belt telltale icon remained illuminated after 100 seconds elapsed. The message "Please fasten safety belt" was displayed in the central information display until the driver used a seat belt.

The Subaru enhanced reminder also began shortly after ignition and included an audible tone and visual icon that was presented until the driver seat belt was buckled. The audible tone occurred every second and increased in volume if the driver was continuously unbuckled for 15 seconds. A red seat belt telltale icon above the speedometer flashed every second for 15 seconds and then was static for 15 seconds (Figure 1c). This 30-second cycle continued until the driver seat belt was buckled.

Three BMW vehicles were equipped with a prototype speed-limiting interlock system in addition to the enhanced reminder system. The speed-limiting interlock restricted the vehicle speed to 15 mph if the driver or right front passenger (if detected) was not using a seat belt. The system restricted speed immediately if the driver or right front-passenger seat belt was not in use at ignition, the gear selector was set to "Drive," and the vehicle speed was less than or equal to 15 mph. A 13-second visual countdown was presented on a display above the center console prior to restricting the vehicle's speed if the driver or right front-passenger seat belt was in use at ignition and later unbuckled and the vehicle speed was greater than 15 mph (Figure 2a). The message "Please fasten safety belt!" was shown during the countdown. After the countdown expired, the message "Please fasten safety belt!" was displayed along with the message "LIM ACTIVATED" to indicate that the speed-limiting interlock was active (Figure 2b). The audible tone and visual signal from the BMW driver enhanced reminder were presented when the driver seat belt was unbuckled.



(a) **(b)**

Figure 2. BMW speed-limiting interlock (a) 13-second visual countdown display that precedes the (b) activation display.

Prior to data collection, sound-level readings were taken to measure the ambient road noise and audible tone sound level in each vehicle. Three readings were taken when traveling at 10, 25, and 35 mph in each vehicle. On average, the ambient road noise was 57 dB in each vehicle. The sound level with the audible tone from the enhanced reminder system in the Chevrolet was 68 dB and was 71 dB in the BMW. The sound level of the audible tone from the Subaru reminder was 61 dB when it began and 69 dB when the tone increased in volume.

Each vehicle was equipped with the same data acquisition system used in Kidd et al. (2018) to record vehicle controller area network (CAN) bus data, global positioning system (GPS) information, time, video, and photography. Data were logged at 1 Hz. A camera mounted on the ceiling inside the vehicle captured images and video of front-row occupant seat belt use (Figure 3). Video recordings began when the driver's door was first opened and continued for 2 minutes after vehicle ignition. A photo was captured every 30 seconds for the duration of the trip. The camera used infrared to record videos and photos at night.

Figure 3. Photograph of the vehicle interior.

Study design

Like Kidd et al. (2018), this study employed a mixed-factorial design with two independent variables: vehicle technology condition and study week. Participants were randomly assigned to the Subaru enhanced reminder, BMW enhanced reminder, or BMW speed-limiting interlock vehicle technology condition. Sixteen

participants were assigned to the Subaru enhanced reminder and BMW speed-limiting interlock conditions. An extra participant assigned to the BMW enhanced reminder condition resulted in 17 participants.

Participants in each condition drove two vehicles for 1 week each. Table 1 summarizes the vehicles driven by part-time belt users in this study and Kidd et al.'s (2018) study each study week. Participants in the Subaru enhanced reminder and BMW enhanced reminder conditions drove a Chevrolet Cruze with an enhanced reminder the first study week and then either a Subaru with an enhanced reminder or a BMW with an enhanced reminder the second study week depending on their vehicle technology condition. This design allowed the change in seat belt use associated with the Subaru or BMW enhanced reminder to be measured relative to the change in seat belt use associated with the Chevrolet enhanced reminder condition from Kidd et al.'s study.

Table 1. Vehicles assigned to participants in each vehicle technology condition by study week.

Vehicle technology condition	Vehicle	
	Study week 1	Study week 2
Chevrolet enhanced reminder [a]	Chevrolet Cruze with enhanced reminder	Chevrolet Cruze with enhanced reminder
Chevrolet gearshift interlock [a]	Chevrolet Cruze with enhanced reminder	Chevrolet Cruze with gearshift interlock
Subaru enhanced reminder [b]	Chevrolet Cruze with enhanced reminder	Subaru Impreza with enhanced reminder
BMW enhanced reminder [b]	Chevrolet Cruze with enhanced reminder	BMW X5 with enhanced reminder
BMW speed-limiting interlock [b]	BMW X5 with enhanced reminder	BMW X5 with speed-limiting interlock

Notes. [a] Participants in Kidd et al. (2018). [b] Participants in this study.

Part-time belt users in the speed-limiting interlock condition drove a BMW X5 with an enhanced reminder in the first study week and a BMW X5 with a speed-limiting interlock in the second study week. Similar to the gearshift interlock condition in Kidd et al.'s (2018) study, this condition was designed to isolate the effect of the BMW speed-limiting interlock on seat belt use from the enhanced reminder in the same vehicle. However, in this study, the first study vehicle in the BMW speed-limiting interlock condition was not the same as the first study vehicle in the other vehicle technology conditions (Table 1). Still, the design permitted the effect of the BMW speed-limiting interlock to be measured relative to the Chevrolet enhanced reminder condition by combining the week-to-week change in belt use observed in the BMW speed-limiting interlock condition with that of the BMW enhanced reminder condition.

Procedure

Participants completed an informed consent form, a vehicle use agreement, an indemnity agreement, and had their driving history reviewed before the first study vehicle was scheduled for delivery. A research assistant provided a short overview of vehicle features (e.g., entertainment system, engine size, drive train) when introducing participants to the first study vehicle. Participants were encouraged to consult the vehicle owner manual for more vehicle information. A demographic questionnaire was administered when participants took possession of the first vehicle.

After driving the first study vehicle for 1 week, a research assistant returned to pick up the vehicle and deliver the second vehicle. Participants were given the same vehicle evaluation survey used in Kidd et al. (2018) to provide feedback about the first study vehicle. The survey also was used to convince participants that the purpose of the study was to evaluate new vehicles and not to examine seat belt use. The research assistant provided a short overview of the second vehicle's features before giving the vehicle to participants.

Participants drove the second study vehicle for 1week. A research assistant picked up the second study vehicle and instructed participants to complete a vehicle evaluation survey for the second study vehicle and a poststudy survey. The poststudy survey was similar to the one used in Kidd et al.'s (2018) study. It asked participants about their interactions with and opinions of the vehicle technology they experienced in the second study vehicle. All participants were asked whether they sought ways to get around the vehicle technology to operate the vehicle without using a seat belt, would support or oppose different in-vehicle technologies designed to increase belt use, and thought the reminder or interlock technology in the second study vehicle increased their seat belt use and was acceptable. All survey instructions stressed that the survey was voluntary and individual questions could be skipped.

Data were collected between July 2017 and August 2018. Participants were compensated $300 for volunteering. The study protocol was approved by Westat's Institutional Review Board.

Image coding

Photographs from every trip in both study weeks were reviewed to identify instances where participants circumvented the enhanced reminder or speed-limiting interlock. A research assistant reviewed 169,110 images and noted those where the driver was sitting on the seat belt or where the seat belt webbing was routed behind the

driver's back or behind the driver's seat. The first author independently reviewed 50,254 images to double code images from study weeks where circumvention was identified and to verify coding consistency.

Dependent measures

Information from the vehicle CAN was used to measure the total amount of time that the driver seat belt was in use during travel. Travel time was defined as the number of hours from when the vehicle was first placed into gear until the transmission was last placed into park during an ignition cycle. Seat belt use was defined as the number of hours that the driver seat belt was in use during travel time. Note that measuring seat belt use based on information from the vehicle CAN cannot distinguish between appropriate and inappropriate use.

Data analysis

Data from this study were combined with data from Kidd et al. (2018) for the main analysis that compared the effects of two persistent enhanced reminders, a speed-limiting interlock, and a gearshift interlock on the seat belt use of part-time belt users. Seat belt use data from Kidd et al. came from 16 part-time belt users who drove a Chevrolet with an enhanced reminder each study week, and 16 part-time belt users who drove a Chevrolet with an enhanced reminder in the first study week and a Chevrolet with a gearshift interlock in the second study week. The Chevrolet gearshift interlock prevented the vehicle from being shifted into gear for 30 seconds after ignition if the driver or front right passenger (if present) was not using a seat belt.

The goal of the main analysis was to determine whether seat belt interlocks and enhanced reminders with more persistent auditory warnings like those in the BMW and Subaru were more effective for increasing seat belt use than a less persistent enhanced reminder like the one in the Chevrolet, and if the relative changes in belt use associated with the different technologies were different from one another. Poisson regression was used to compare the week-to-week changes in the rate of seat belt use between part-time belt users in each vehicle technology condition. Hours of belt use during a trip was modeled with vehicle technology condition (Chevrolet enhanced reminder, Chevrolet gearshift interlock, Subaru enhanced reminder, BMW enhanced reminder, BMW speed-limiting interlock), study week (1, 2), and the two-way interaction between these variables. The natural logarithm of travel time was computed for every trip and included as an offset variable to model the rate of belt use per hour, which accounts for variation in travel time across trips.

The interaction between vehicle technology and study week was the effect of interest and quantified the difference in the change in rate of belt use across study weeks between a specific vehicle technology condition and

the Chevrolet enhanced reminder condition. These parameter estimates were appropriate when the first study vehicle was a Chevrolet with an enhanced reminder, which was the case in every vehicle technology condition except the BMW speed-limiting interlock condition.

The following steps were used to derive an estimate for the difference in the change in belt use across study weeks between the BMW speed-limiting interlock condition and the Chevrolet enhanced reminder condition. First, the parameter estimate for the main effect of study week that quantified the change in belt use across study weeks for the Chevrolet enhanced reminder condition was added to the two-way interaction estimated for the BMW speed-limiting interlock condition. The resulting estimate quantified the change in belt use across study weeks for only the BMW speed-limiting interlock condition. Next, this estimate was added to the two-way interaction estimated for the BMW enhanced reminder condition. The resulting estimate quantified the difference between the change in belt use across study weeks for the BMW speed-limiting interlock condition and the Chevrolet enhanced reminder condition. The standard error for this effect estimate was estimated as the square root of the sum of the squared standard errors for the main effect of study week, the two-way interaction for the BMW speed-limiting interlock condition, and the two-way interaction for the BMW enhanced reminder condition. The standard error estimate was multiplied by 1.96 and the product was added to and subtracted from the effect estimate to compute a 95% confidence interval.

Poisson models were fitted using the GENMOD procedure in SAS 9.4. A generalized estimating equation that included participant as a random effect was used to account for the correlation among trips taken by each participant in each study week. An exchangeable correlation structure was assumed. Parameter estimates were considered statistically significant if the associated Wald statistical test indicated it was significantly different from 0 at the 0.05 level. The percentage change in the rate of belt use during travel time in a trip for every one-unit increase in a parameter, β, was computed as $[\exp(\beta) - 1] \times 100$. The lower and upper 95% confidence bounds for each estimate were transformed into percentage change values using the same approach. A parameter can be considered statistically significant if the 95% confidence interval does not include zero. Percentage change values greater than zero indicate that the parameter was associated with an increase in the rate of belt use. Values less than zero indicate that the parameter is associated with a decrease in the rate of belt use.

Responses to the vehicle evaluation survey and poststudy survey were only analyzed for participants in this study. Rated level of agreement with statements in the vehicle evaluation survey and statements related to the acceptance of the speed-limiting interlock in the poststudy survey were classified as positive (agree, strongly agree)

or not positive (neutral, disagree, strongly disagree). The number of participants in the BMW enhanced reminder, Subaru enhanced reminder, and BMW speed-limiting interlock conditions that responded positively to each statement about acceptance was compared using Fisher's exact tests. Fisher's exact tests also were used to analyze responses to the final post-survey question that asked respondents if they would support or oppose different vehicle technologies for increasing belt use. Cases with missing responses were excluded from the statistical tests.

RESULTS

The demographic characteristics of the combined sample are shown in Table 2. Participants in the combined sample were 38 years old on average, and 67% were male. Among part-time belt users who provided detailed demographic information, most (79%) had received at least some college education, the majority (62%) lived in a household earning less than $75,000 per year, and about half (52%) reported their race as black or African-American.

Table 2. Distribution of demographic characteristics of the combined sample overall and by vehicle technology condition.

	Vehicle technology condition					
	Chevrolet enhanced reminder[a] (n=16)	Chevrolet gearshift interlock[a] (n=16)	Subaru enhanced reminder[b] (n=16)	BMW enhanced reminder[b] (n=17)	BMW speed-limiting interlock[b] (n=16)	Combined sample (n=81)
Age						
Mean	38.9	35.0	43.0	37.7	35.4	38.0
SD	11.3	8.2	10.1	9.8	10.2	10.1
Range	26–59	25–53	27–59	25–59	25–57	25–59
Gender						
Male (n)	9	14	9	12	10	54
Female (n)	7	2	7	5	6	27
Education						
High school or less (n)	2	4	4	2	3	15
Some college or more (n)	14	12	10	11	11	58
No response (n)	0	0	2	4	2	8
Race						
White (n)	6	4	2	4	1	17
Black/African-American (n)	9	7	6	6	9	37
Hispanic/Latino (n)	1	2	4	1	2	10
Other (n)	0	3	1	1	2	7
No response (n)	0	0	3	5	2	10
Household income						
Less than $75,000 (n)	10	10	8	9	8	45
$75,000 or more (n)	6	6	6	4	5	27
No response (n)	0	0	2	4	3	9

Notes. [a] Participants in Kidd et al. (2018). [b] Participants in this study.

Participants in the combined sample took 6,974 trips (Table 3); 4,346 were by part-time belt users in this study and 2,628 by part-time belt users in Kidd et al.'s (2018) study. Trips shorter than 100 meters in distance, that were shorter than 60 s or longer than 10 hours in duration, or where the vehicle's speed did not exceed 5 mph were excluded. In total, 817 trips (11.7% of all trips) were removed, leaving 6,157 trips available for analysis. The trips included in the analysis were 1–585 min in duration with an average duration of 23.9 min and a median duration of 15.8 min.

Table 3. Characteristics of trips taken by all participants in the combined sample and by vehicle technology condition.

			Trips available for analysis			
Vehicle technology condition	Total trips taken	Trips excluded	n	Mean (SD) duration (min)	Median duration (min)	Duration range (min)
Chevrolet enhanced reminder [a] (n=16)	1,319	150	1,169	20.0 (18.2)	14.4	1–113
Chevrolet gearshift interlock [a] (n=16)	1,309	84	1,225	22.5 (23.0)	15.0	1–203
Subaru enhanced reminder [b] (n=16)	1,259	141	1,118	24.1 (26.8)	16.7	1–558
BMW enhanced reminder [b] (n=17)	1,503	193	1,310	28.2 (44.9)	16.5	1–558
BMW speed-limiting interlock [b] (n=16)	1,584	249	1,335	24.4 (33.4)	16.6	1–585
Combined sample (n=81)	6,974	817	6,157	23.9 (31.2)	15.8	1–585

Notes. [a] Participants in Kidd et al. (2018). [b] Participants in this study.

Seat belt use

Table A1 in the Appendix summarizes the results from a Poisson regression modeling the week-to-week changes in the rate of belt use during travel time for part-time belt users in each vehicle technology condition. The amount of time that the seat belt was used per hour of travel for participants in the Chevrolet enhanced reminder group significantly decreased 10% across study weeks (Figure 4). Relative to the Chevrolet enhanced reminder condition, the rate of belt use per hour of travel increased 15.8% across study weeks for part-time belt users in the Chevrolet gearshift interlock condition, 34.3% for part-time belt users in the Subaru enhanced reminder condition, and 30.0% for part-time belt users in the BMW enhanced reminder condition (Table 4). The rate of seat belt use for part-time belt users in the BMW speed interlock condition increased 2.0% (exp(0.13+(−0.11)) across study weeks,

and was 32.7% (95% CI [7.0%, 64.6%]) higher than the week-to-week change in belt use observed for the Chevrolet enhanced reminder condition (exp(0.13+(−0.11)+0.26)). The week-to-week change in the rate of belt use for the Chevrolet gearshift interlock, Subaru enhanced reminder, BMW enhanced reminder, and BMW speed-limiting interlock conditions were not significantly different.

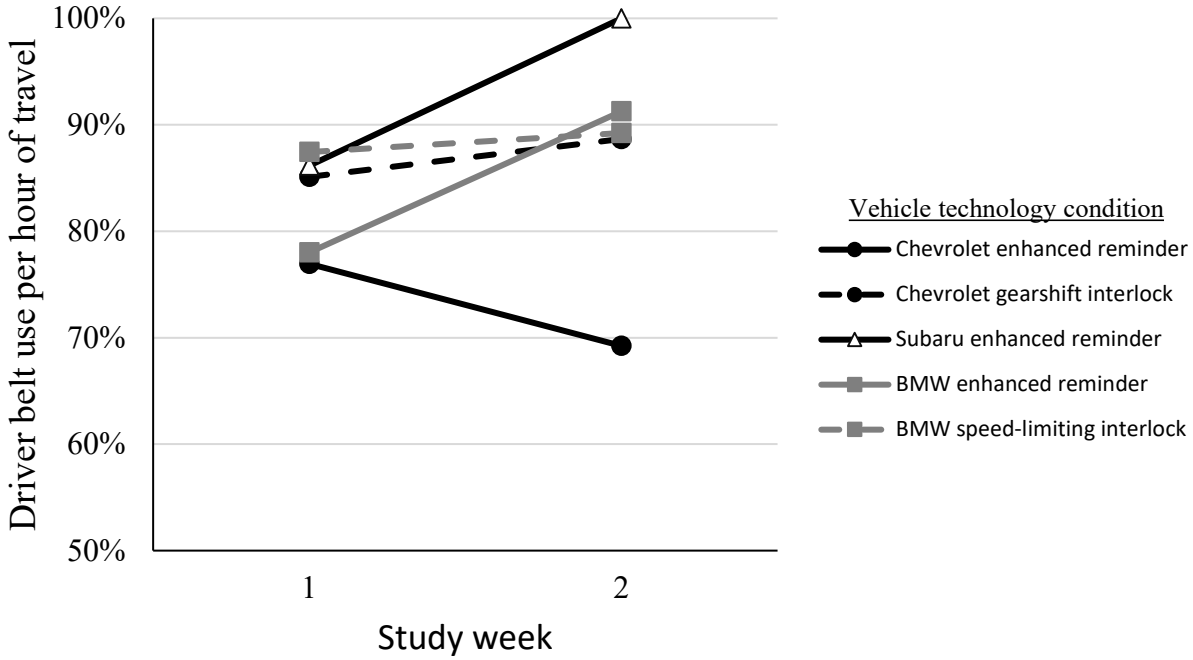


Figure 4. Least squares means estimate of the percentage of driver seat belt use per hour of travel each study week by vehicle technology condition. Note that participants in the BMW speed-limiting interlock condition drove a BMW vehicle with an enhanced reminder in study week 1.

Table 4. Summary of the percent difference in the week-to-week change in the seat belt use of part-time belt users between different vehicle technologies and the Chevrolet enhanced reminder.

	Estimated percent difference	95% Confidence Interval
BMW speed-limiting interlock	32.7	(7.0, 64.6)
Chevrolet gearshift interlock	15.8	(−1.6, 36.2)
Subaru enhanced reminder	34.3	(12.7, 59.9)
BMW enhanced reminder	30.0	(10.9, 52.4)

Circumvention

Information from the poststudy survey and the coding of vehicle interior photos were used to identify participants who circumvented the Subaru enhanced reminder, BMW enhanced reminder, or the BMW speed-limiting interlock. The poststudy survey asked participants to self-report if they sought out ways to get around enhanced reminder or speed-limiting interlock system to drive the second study vehicle without using a seat belt. A total of 12 participants, four in the BMW enhanced reminder condition, three in Subaru enhanced reminder condition, and five in the BMW speed-limiting interlock condition, said they circumvented the vehicle technology. A follow-up question asked participants to report how they got around the technology. Of the 12 participants, six said they buckled the seat belt behind their back or behind the seat; two said they waited for the enhanced reminder to stop; and the other three said they buckled a separate buckle that was not part of the vehicle, depressed the gas pedal to override the speed-limiting feature, or turned up the entertainment system volume. Coding of vehicle interior photos revealed two additional participants circumvented the BMW speed-limiting interlock by sitting on a buckled seat belt or placing the shoulder belt behind the back with the lap belt buckled.

In total, 14 of the 49 (29%) participants in this study circumvented the enhanced reminder or speed-limiting interlock in the second study vehicle; the majority (57%) of these participants sat on a buckled seat belt or buckled the seat belt behind their back. Due to concern that the rate of seat belt use for participants who circumvented the vehicle technologies could bias the comparisons being made, the main analysis was repeated after excluding the 14 participants who circumvented the vehicle technology in this study and the six participants who circumvented the Chevrolet gearshift interlock in Kidd et al.'s (2018) study. The results from this Poisson regression are reported in Table A2 in the Appendix. Relative to the 10% decrease in the rate of belt use across study weeks for participants in the Chevrolet enhanced reminder condition, the change in the rate of belt use was 21.7% higher for participants in the BMW speed-limiting interlock condition, 24.2% higher for participants in the Chevrolet gearshift interlock condition, 23.2% higher for participants in the Subaru enhanced reminder condition, and 25.0% higher for participants in the BMW enhanced reminder condition (Table 5). The estimated increase in the rate of seat belt use for every vehicle technology condition relative to the Chevrolet enhanced reminder condition was statistically significant except for the BMW speed-limiting interlock condition.

Table 5. Summary of the percent difference in the week-to-week change in the seat belt use of part-time belt users between different vehicle technologies and the Chevrolet enhanced reminder after excluding those who circumvented the technology.

	Estimated percent difference	95% Confidence Interval
BMW speed-limiting interlock	21.7	(−0.4, 48.7)
Chevrolet gearshift interlock	24.2	(3.7, 48.8)
Subaru enhanced reminder	23.2	(6.5, 42.6)
BMW enhanced reminder	25.0	(8.2, 44.3)

Perceptions of the vehicle technologies

Participants competed a poststudy survey that collected information about their perceptions of the Subaru enhanced reminder, BMW enhanced reminder, and the BMW speed-limiting interlock technologies experienced in the second week and whether they thought these technologies would be acceptable in their vehicle, influence their purchasing decisions, or influence their joy of driving. Most participants in the Subaru enhanced reminder and BMW enhanced reminder conditions agreed or strongly agreed that the technology was acceptable (Table 6). In contrast, significantly fewer participants in the BMW speed-limiting interlock condition agreed or strongly agreed that restricting the vehicle's top speed was acceptable. When asked if the enhanced reminder or speed-limiting interlock should be a standard or optional feature in every new vehicle or not available at all, three quarters of participants in the BMW enhanced reminder condition said standard, compared with 44% of participants in the Subaru enhanced reminder condition and 20% of participants in the BMW speed-limiting interlock condition. Almost three quarters of participants in the BMW speed-limiting interlock condition said the feature should be optional in new vehicles and a little more than half of participants in the Subaru enhanced reminder condition said the same; these relationships were statistically significant. The number of participants in each vehicle technology condition who agreed or strongly agreed with the other statements was not significantly different. Overall, a little less than half of all participants (46%) agreed or strongly agreed that the enhanced reminder or speed-limiting interlock was annoying, and few agreed or strongly agreed that they would not enjoy driving (19%) or avoid purchasing a vehicle with the technologies they experienced (25%).

Table 6. Number (percent) of part-time belt users in each vehicle technology condition who agreed or strongly agreed with statements about the vehicle technology.

Statement	Vehicle technology condition			
	Subaru enhanced reminder (n=16)	BMW enhanced reminder (n=16)	BMW speed-limiting interlock (n=16)	Two-tailed Fisher's exact test *p*-value
Receiving audible tones and visual alerts from the enhanced seat belt reminder when I was unbuckled was acceptable to me. / Restricting the vehicle's top speed until my seat belt was fastened was acceptable to me.	12 (75%)	13 (81%)	5 (31%)	0.01
The enhanced seat belt reminder/speed-limiting interlock system was annoying.	10 (62%)	6 (38%)	6 (38%)	0.30
I would not enjoy driving if my vehicle was equipped with this enhanced reminder/speed-limiting interlock system.	2 (12%)	1 (6%)	6 (38%)	0.11
I would not purchase a vehicle with this enhanced seat belt reminder/speed-limiting interlock system.	6 (38%)	1 (6%)	5 (31%)	0.07
Enhanced seat belt reminder/speed-limiting interlock systems like this one should be available in every new vehicle as:				
a standard feature	7 (44%)	12 (75%)	3 (20%)	0.01
an optional feature	9 (56%)	4 (25%)	11 (73%)	0.05
not available	0 (0%)	0 (0%)	1 (7%)	1.00

Note. One participant in the BMW enhanced reminder condition did not respond to the poststudy survey.

Participants were asked if they would support or oppose having different technologies in their vehicles to increase belt use. About 60% supported having a constant buzzer or chime when the driver was unbuckled, 42% supported preventing the use of in-vehicle entertainment and communication systems if the driver belt was not in use, 31% supported restricting the vehicle's speed to 15 mph, 25% supported preventing the vehicle from being placed in gear, and 14% supported preventing the engine from starting when the belt was not buckled. The number of participants in each vehicle technology condition who supported or opposed having these technologies in their vehicles was not statistically significant across vehicle technology conditions, but was almost significant when participants were asked if they would support or oppose restricting speed to 15 mph (Table 7). Half of participants in the BMW speed-limiting interlock condition who experienced this type of system supported this statement compared with seven of 32 (22%) of participants in the Subaru and BMW enhanced reminder conditions that did not experience this system.

Table 7. Number (percent) of participants who would support various methods of increasing seat belt use in their own vehicle by belt user group

Statement	Vehicle technology condition			
	Subaru enhanced reminder (n=16)	BMW enhanced reminder (n=16)	BMW speed-limiting interlock (n=16)	Two-tailed Fisher's exact test *p*-value
Preventing the engine from starting if the driver's seat belt is not buckled.	3 (19%)	2 (12%)	2 (12%)	1.0
Preventing the vehicle from being operated at a speed faster than 15 mph if the driver's seat belt is not buckled.	2 (12%)	5 (31%)	8 (50%)	0.07
Preventing the vehicle from being placed in Drive or Reverse gear if the driver's seat belt is not buckled.	4 (25%)	6 (38%)	2 (12%)	0.32
Preventing the use of the radio, CD player, and other in-vehicle entertainment and communication systems if the driver's seat belt is not buckled.	8 (50%)	6 (38%)	6 (38%)	0.81
Sounding a constant chime or buzzer until the driver's seat belt is buckled.	10 (62%)	8 (50%)	11 (69%)	0.66

Note. One participant in the BMW enhanced reminder condition did not respond to the poststudy survey.

Manipulation check

Participants were asked to describe the purpose of the study in the poststudy survey to determine if the ruse was successful. Six of the 48 (13%) participants mentioned seat belts or seat belt use in their response; three were in the BMW speed-limiting interlock condition, two were in the Subaru enhanced reminder condition, and one was in the BMW enhanced reminder condition.

The vehicle evaluation survey helped to reinforce the idea that the purpose of the study was to evaluate new vehicles. All but one participant in the BMW enhanced reminder condition completed a vehicle evaluation survey for both study vehicles. Wilcoxon signed-rank tests were performed to compare the number of statements that participants in each vehicle technology condition agreed or strongly agreed with. The number of statements that the participants in the BMW speed-limiting interlock condition ($Z = -1.78$, $p = 0.08$) and Subaru enhanced reminder condition ($Z = -1.29$, $p = 0.20$) agreed or strongly agreed with about the vehicle they drove each week were not significantly different. Participants in the BMW enhanced reminder condition agreed or strongly agreed with significantly more statements when evaluating the BMW X5 than when evaluating the Chevrolet Cruze ($Z = -3.36$, $p < 0.05$).

DISCUSSION

Persistent enhanced seat belt reminders with at least 90 seconds of audible tones and seat belt interlocks that restricted the vehicle transmission from being placed into gear or limited vehicle speed to 15 mph increased the seat belt use of part-time belt users between 15.8 and 34.3% relative to a Chevrolet enhanced reminder that provided 7 seconds of audible tones intermittently when the driver was not using a seat belt. In 2017, 89.7% of front-row occupants observed at controlled intersections in the daytime were using a seat belt (Li & Pickrell, 2018), and 8,733 front-row occupants older than 15 years who died in motor vehicle crashes were not using a seat belt. Based on the estimated 45% fatality reduction for seat belts in passenger cars and 60% in various types of light trucks (Kahane, 2000) and assuming 89.7% of front-row occupants use a seat belt, then increasing the seat belt use of unbelted front-row occupants by 15.8–34.3% could save 583–1,489 lives each year. Should the effect of these vehicle technologies on the seat belt use of unbelted front-row occupants be more modest and increase belt use by 21.7–25.0%, as indicated by an analysis that excluded participants who circumvented the technologies, then an estimated 873–1,035 lives could be saved each year.

Most automakers equip vehicles with enhanced seat belt reminder systems that have audible tones that exceed the 4–8 second requirement in FMVSS 208, but the findings of this study illustrate that some enhanced reminders are more effective for increasing seat belt use than others. The BMW and Subaru enhanced reminder systems presented audible tones lasting at least 90 seconds and were significantly more effective for increasing belt use than the Chevrolet enhanced reminder. These findings are consistent with a previous study that found seat belt use among Swedish drivers was significantly higher in vehicles with a seat belt reminder system with at least 90 seconds of audible tones compared with a seat belt reminder system with a shorter duration of audible tones (Krafft, Kullgren, Lie, & Tingvall, 2006).

Until recently, NHTSA could not require automakers to install seat belt reminders with audible tones lasting longer than 8 seconds when the driver or front right passenger seat belt was not in use at ignition, but the Moving Ahead for Progress in the 21st Century Act, passed in 2012, removed this restriction. Based on these findings, strengthening existing safety standards to require seat belt reminders with audible tones lasting at least 90 seconds in duration like what is required by Euro NCAP (2017) would increase seat belt use. However, it takes decades before a new vehicle feature becomes common in the registered vehicle fleet (e.g., Highway Loss Data Institute, 2018), so other proven countermeasures for increasing seat belt use, like seat belt use laws with primary

enforcement and publicized enforcement campaigns (Shults, Elder, Sleet, & Thompson, 2004; Williams, Reinfurt, & Wells, 1996), must continue to be pursued.

Based on Kidd et al.'s (2018) findings, the gearshift interlock and speed-limiting interlock systems were expected to be more effective for increasing seat belt use than the enhanced reminder systems. The speed-limiting interlock system significantly increased the belt use of part-time belt users more than the Chevrolet enhanced reminder system, but not the BMW and Subaru enhanced reminder systems. Most part-time seat belt users do not use a seat belt because they forget, are in a rush, or are driving a short distance (Boyle & Lampkin, 2008; Kidd et al., 2014). A persistent audible tone appears to be as sufficient as restricting vehicle function for overcoming these common barriers to belt use for people who occasionally do not use a seat belt.

Some part-time belt users found ways to remain unbelted while operating the vehicle. Twenty-nine percent of participants in this study circumvented one of the enhanced reminders or the speed-limiting interlock. Participants most commonly circumvented these systems by sitting on the seat belt. This behavior also was observed among participants who circumvented the gearshift interlock in Kidd et al. (2018) and was one of the most common strategies reported in another study that instructed participants to find ways or describe ways of circumventing the speed-limiting interlock or gearshift interlock systems in three different vehicles (Kidd & Singer, 2018). Information from vehicle sensors that measure the amount of seat belt webbing extended from the retractor mechanism or that measure the angle of forces placed on the mechanism could be used to infer if the driver is appropriately using a seat belt and improve the effectiveness of these vehicle technologies.

Circumvention was more common among part-time belt users who experienced the speed-limiting interlock than one of the enhanced reminders; 44% of part-time belt users circumvented the speed-limiting interlock compared with 21% of participants in the BMW or Subaru enhanced reminder conditions. More drivers may have circumvented the speed-limiting interlock than the enhanced reminder systems because interlock systems are less acceptable than enhanced reminders (Kidd et al., 2014). Significantly fewer participants in the speed-limiting interlock condition said the technology was acceptable than the number of participants who said the same about the BMW or Subaru enhanced reminders, and fewer thought the speed-limiting interlock technology should be a standard feature on every new vehicle. Similar to past research (Kidd et al., 2014; 2018), less than half of participants in this study supported increasing seat belt use by preventing the vehicle from going over 15 mph, being placed in gear, or providing entertainment and communication functionality when the driver seat belt is not in use.

These findings add to the mounting evidence that consumer acceptance of various types of seat belt interlock systems remains weak.

Seat belt reminder systems are equipped to every private passenger vehicle, but seat belt interlocks are not available in any private passenger vehicle models. Seat belt interlocks may be more acceptable if the feature was more common, because hands-on experience with a technology helps consumers develop more objective perceptions of a technology and encourages acceptance (Venkatesh, 2008). Half of the participants in the BMW speed-limiting interlock condition said they would support using the technology to increase belt use in their vehicle compared with about one third of participants in the BMW enhanced reminder condition. Similarly, Kidd et al. (2018) found that 73% of part-time belt users who experienced a gearshift interlock said they would support using the technology to increase belt use in their vehicle compared with 46% of part-time belt users who did not experience the system. Kidd and Singer (2018) found no significant differences in the perceived acceptance of various seatbelt reminder systems, a gearshift interlock system, and two speed-limiting interlock systems after drivers briefly experienced each technology while driving on a closed course. Together, these findings suggest that hands-on experience may bolster consumer acceptance of seat belt interlock technology.

Limitations

There were several limitations in this study. First, the number of part-time belt users in each vehicle technology condition was small, and, consequently, there was limited statistical power when comparing the change in rate of belt use between the different vehicle technology conditions. Increasing the sample size of this study would have increased the statistical power, but additional recruitment would have exceeded budget constraints due to a low recruitment rate. Less than 50% of the 32,945 potential participants researchers attempted to contact were eligible to participate in this study.

The estimated change in belt use for part-time belt users in the BMW speed-limiting interlock condition relative to the Chevrolet enhanced reminder condition assumed that their belt use would have been unchanged had they drove a BMW with an enhanced reminder in the second study week. This assumption may not be accurate considering that the rate of belt use among part-time belt users who only drove a Chevrolet with an enhanced reminder decreased 10% across study weeks. Consequently, this study may have underestimated the effect of the BMW speed-limiting interlock on belt use. However, the rate of belt use for part-time belt users in the BMW speed-limiting interlock condition who drove a BMW with an enhanced reminder in the first study week (87%) was similar

to the rate of belt use of part-time belt users in the BMW enhanced reminder condition who drove a similar vehicle in the second study week (91%), so the assumption that belt use would be unchanged if part-time belt users drove a BMW with an enhanced reminder both study weeks seems reasonable.

Part-time belt users in this study may not be representative of all part-time belt users in the United States. First, the demographics of this study sample differs from part-time belt users nationwide. Among respondents in a national telephone survey (Kidd et al., 2014) who reported using a seat belt rarely, some of the time, or most of the time, 54% were male, 51% had some college education or were college graduates, and 30% had a household income of $75,000 or more. A larger proportion of participants in this study were male (67% of participants), had at least some college education (79% of participants), and had a household income of $75,000 or more (38% of participants). Second, participants in this study were recruited from Maryland. Maryland is one of 34 states that has a seat belt use law with primary enforcement, and part-time belt users in these states may react differently to interventions aimed at increasing seat belt use.

Finally, some participants circumvented the vehicle technologies (e.g., by sitting on the seat belt) to drive without using a seat belt. It was not possible to reliably identify individual trips where participants circumvented the enhanced reminder, gearshift interlock, or speed-limiting interlock systems, but circumvention was most common among participants in the speed-limiting interlock condition. The rate of belt use during a trip would have been inflated if it occurred more frequently on trips taken in vehicles with seat belt interlocks than trips taken in vehicles with enhanced reminders resulting in an upwardly biased estimated changes in belt use. Future studies will need to identify reliable ways of detecting circumvention to filter affected data and more accurately measure the effects of vehicle technologies on seat belt use.

Conclusions

Seat belt use dramatically reduces the risk of fatal injury in a crash (Kahane, 2000), but nearly half of front-row occupants killed in crashes in 2016 were not using seat belts (National Center for Statistics and Analysis, 2018). In the current study, persistent enhanced seat belt reminders with audible tones 90 seconds or longer in duration and seat belt interlock systems that restricted vehicle speed or restricted the vehicle from being placed into gear increased the seat belt use of part-time belt users by 15.8–34.3% relative to an enhanced reminder with intermittent audible tones. However, more persistent enhanced reminders were more acceptable than seat belt interlocks to part-time belt users. Consumer acceptance continues to be a barrier for adopting seat belt interlock systems.

Practical Applications

NHTSA can require, or otherwise incentivize, more persistent seat belt to increase seat belt use. Based on the increases in seat belt use observed in this study, strengthening FMVSS 208 to require seat belt reminder systems to meet or exceed Euro NCAP's requirements for a final audible signal lasting at least 90 seconds could save up to 1,489 lives of front-row occupants each year in the United States and would be acceptable to the public.

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APPENDIX

Table A1. Poisson regression of the rate of belt use by study week, technology condition, and the two-way interaction between study week and vehicle technology condition.

Parameter	Estimate	Standard error	95% Confidence Interval	*p*-value
Intercept	–0.26	0.18	(−0.61, 0.08)	0.136
Study week (ref = week 1)	–0.11	0.05	(−0.20, -0.01)	0.033
Vehicle technology condition (ref = Chevrolet enhanced reminder)				
BMW speed-limiting interlock	0.13	0.18	(−0.22, 0.48)	0.476
Chevrolet gear shift interlock	0.10	0.19	(−0.28, 0.48)	0.600
Subaru enhanced reminder	0.11	0.19	(−0.26, 0.48)	0.550
BMW enhanced reminder	0.01	0.20	(−0.38, 0.40)	0.945
Study week x Vehicle technology condition				
BMW speed-limiting interlock	0.13	0.06	(0.02, 0.23)	0.023
Chevrolet gearshift interlock	0.15	0.08	(−0.02, 0.31)	0.077
Subaru enhanced reminder	0.29	0.09	(0.12, 0.47)	0.001
BMW enhanced reminder	0.26	0.08	(0.10, 0.42)	0.001

Note. The first study vehicle in the BMW speed-limiting interlock condition was different from the other vehicle technology conditions, so the estimate for the BMW speed-limiting interlock condition is not directly comparable to the estimates for the other vehicle technology conditions.

Table A2. Poisson regression of the rate of belt use by study week, technology condition, and the two-way interaction between study week and vehicle technology condition after excluding those who circumvented the technology.

Parameter	Estimate	Standard error	95% Confidence Interval	*p*-value
Intercept	−0.26	0.18	(−0.61, 0.09)	0.139
Study week (ref = week 1)	−0.11	0.05	(−0.20, -0.01)	0.032
Vehicle technology condition (ref = Chevrolet enhanced reminder)				
BMW speed-limiting interlock	0.12	0.18	(−0.24, 0.48)	0.520
Chevrolet gear shift interlock	0.12	0.21	(−0.29, 0.53)	0.561
Subaru enhanced reminder	0.19	0.18	(−0.17, 0.55)	0.311
BMW enhanced reminder	0.08	0.19	(−0.30, 0.45)	0.686
Study week x Vehicle technology condition				
BMW speed-limiting interlock	0.08	0.05	(−0.02, 0.18)	0.123
Chevrolet gearshift interlock	0.22	0.09	(0.04, 0.40)	0.019
Subaru enhanced reminder	0.21	0.07	(0.06, 0.35)	0.005
BMW enhanced reminder	0.22	0.07	(0.08, 0.37)	0.002

Note. The first study vehicle in the BMW speed-limiting interlock condition was different from the other vehicle technology conditions, so the estimate for the BMW speed-limiting interlock condition is not directly comparable to the estimates for the other vehicle technology conditions.