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16 Abstract

Intelligent Speed Adaptation (ISA) represents a promising approach to reduce speeding. A core principle for ISA systems is that they provide real-time feedback to drivers, prompting them to reduce speed when some threshold at or above the limit is reached. The overall goal of the study was to provide insight into the effectiveness and acceptance by young drivers in the United States, of an ISA consisting of an Active Accelerator Pedal (AAP) system. The project involved the design, development, and production of an AAP that included speed mapping and data logging and its installation in two vehicles used for data collection. The AAP system provided increased accelerator pedal resistance above the 2 lbs. of the original pedal up to a maximum total of 38 lbs. if a person exceeded the posted speed limit. If drivers allowed the vehicle speed to drop back to or below the speed limit, the pedal force returned to normal. After successful development and pilot testing of the system, researchers conducted two separate studies with young drivers (18-24 years old) to examine its speed reduction effects, the workload experienced, and satisfaction with the system. For one study, researchers defined a driving route within the Kalamazoo/Portage area of Michigan consisting of 6 segments. Twenty-two pairs of participants (n=44) matched on age and gender drove the route twice on a single day—morning and afternoon— with one participant in each pair having the AAP active in the afternoon drive. Results of this study showed the AAP led to less speeding and somewhat increased driver workload when activated. The second study involved giving an AAP-equipped vehicle to 4 participants to use for 15 days in place of their personal vehicles. The system was off during the first 5 days, activated during the second 5 days, and again turned off for the final 5 days. Results of this study were encouraging with 2 of the 4 participants showing significantly reduced speeding 5+ mph over the limit when the pedal was active. Participants expressed support for the widespread use of the AAP if it saved them money (e.g., lower insurance premiums).They liked the increased awareness of the speed limit but disliked being slower than prevailing traffic. Overall, the studies produced results not unlike those reported in the literature from Europe. The AAP system showed promise for reducing speeding among young drivers in the United States, but more research is needed to further refine the system and understand how best to introduce it into the total vehicle fleet.

17 Key Words Speed, Accelerator pedal, ISA, AAP, Speed control, Active Accelerator Pedal, Intelligent Speed Adaptation, Adaptive Accelerator Pedal	**18 Distribution Statement** Document is available to the public from the National Technical Information Service www.ntis.gov

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Although this study could not have been accomplished without the assistance of these individuals, the findings and conclusions cited here are those of the authors and are not intended to represent the positions of any of the cooperating agencies or individuals.

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Executive Summary

Background and Objectives

Speeding is a major problem on roadways in the United States contributing to thousands of deaths each year and increasing injury severity when a crash is survived. In 2012, the National Highway Traffic Safety Administration (NHTSA) estimated that "speeding was a contributing factor in 30 percent of all fatal crashes, and 10,219 lives were lost in speeding-related crashes" (NHTSA, 2014). Intelligent Speed Adaptation (ISA) using an Active Accelerator Pedal (AAP) represents a promising approach to reduce speeding (e.g., Schulman, 2005, Varhelyi & Makinen, 2001; Warner & Aberg, 2008). When driving a vehicle equipped with this AAP, drivers experience added accelerator pedal resistance (haptic feedback) when they exceed a pre-set speed (e.g., the speed limit). The AAP can impose a differential force schedule to the accelerator pedal as a function of the extent of the driver's speeding. Although drivers can easily and safely override the system by pressing harder (e.g., to pass, to avoid a crash), the concept of the AAP is that it is uncomfortable to maintain an override for sustained periods of time. The added force also represents a cue to the driver that he or she has exceeded the speed limit. The specific objective was to determine whether the use of a haptic AAP system that linked the speed of the vehicle and the speed limits of the road upon which the vehicle traveled could reduce speeding by young drivers in a wide range of speed limit zones.

Method

The study consisted of two main portions. The first focused on the development of an appropriate AAP and data logging system as well as equipping 2 vehicles with the systems. The second portion of the study involved data collection using the developed systems and the analysis of the resulting data.

Pedal development. The final pedal system consisted of the pedal itself, a speed limit determination subsystem, a motor to provide increased force, and a microcontroller to operate all system functions. Experimenters installed the pedal system in 2 similar 4-door Ford Taurus sedans for data collection—a gold 2000 model year and a red 2002 model year (Figure ES-1).

Figure ES-1. Test Vehicles

Fixed route drives. Experimenters defined a driving route consisting of 6 segments within the Kalamazoo/Portage area of Michigan. Twenty-two pairs of Western Michigan University (WMU) student participants drove the route twice on a single day—morning and afternoon—in either the experimental car (2002 Red Taurus) or the control vehicle (2000 gold Taurus). Experimenters chose the route segments to present participants with a variety of speed limits (ranging from 25 mph to 70 mph), traffic conditions, and road types. During the morning drive, researchers turned off the AAP in the experimental vehicle so that both participants drove the cars without any added haptic feedback. In the afternoon, the participants repeated the route with the AAP turned on in the experimental car. The control participant again drove the route with the normal pedal response.

Free drives. The second data collection method involved giving an AAP-equipped vehicle to 4 participants from the same volunteer pool to use for 15 days in place of their personal vehicles. The protocol divided the 15 days of data collection into 3 periods of 5 days each—AAP off, AAP on, AAP off.

Results

Fixed drive results. Analyses examined the percent of speed data recorded during each of the 6 road segments in the following speed classes: 1) any speed over the limit; 2) 5+ mph over the limit; and 3) 10+ mph over the limit. Researchers conducted a series of analyses to determine if any differences in speeding on each measure appeared as a function of treatment (experimental or control) and drive (morning or afternoon).

Analysis of Variance (ANOVA) was used to test the statistical significance of differences among the mean scores of groups on factors of interest. The results for the 5+ mph over the limit measure are representative of the speed findings. Table ES-1 presents the results for speeding 5+ mph over the limit by treatment and drive. The mixed ANOVA interaction effects were statistically significant ($p < 0.05$) for Segments 1, 2, 4, 5, and 6, indicating meaningful changes in speeding 5+ mph over the limit by experimental group from the morning to afternoon drives. Segment 3 evidenced little speeding by anyone. The simple contrasts of the experimental group versus the control group in the morning showed the control group had more speeding 5+ mph over the limit for Segments 2, 3, 4, 5, and 6 ($p < 0.05$) and no difference for Segment 1 ($p > 0.05$). For the afternoon drives, the contrasts showed the control group had significantly higher percentages of speeding 5+ mph over the limit for all 6 segments compared to the experimental group ($p < 0.05$).

The within groups contrasts showed the experimental group's reductions in speeding 5+ mph over the limit from morning to afternoon were statistically significant for Segments 1, 2, 4, 5 and 6 ($p < 0.05$), but not for Segment 3 ($p > 0.05$). The control group showed significant increases in speeding 5+ mph over the limit for Segments 1, 2, and 4 ($p < 0.05$), but not for the other segments ($p > 0.05$).

Table ES-1. Average Percent of Data 5+ MPH Over the Speed Limit by Drive, Experimental Group, and Segment

Segment	Morning					Afternoon				
	Experimental		Control			Experimental		Control		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1	18.83	11.37	13.87	8.59	.110	***6.11***	***6.94***	***22.60***	***8.84***	***<.001***
2	***8.99***	***10.99***	***17.57***	***13.40***	***.025***	***2.01***	***3.86***	***23.79***	***8.80***	***<.001***
3	***0.12***	***0.47***	***1.90***	***3.90***	***.040***	***0.02***	***0.10***	***1.71***	***2.39***	***.002***
4	***10.45***	***13.85***	***22.45***	***19.66***	***.024***	***2.39***	***10.00***	***31.60***	***21.53***	***<.001***
5	***4.18***	***4.56***	***7.68***	***5.18***	***.022***	***1.75***	***2.75***	***9.24***	***6.20***	***<.001***
6	***8.70***	***4.75***	***17.70***	***8.31***	***<.001***	***3.30***	***3.30***	***19.52***	***10.88***	***<.001***

Note. Significant effects are in bold italics.

Segment	Experimental					Control				
	Morning		Afternoon			Morning		Afternoon		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1	***18.83***	***11.37***	***6.11***	***6.94***	***<.001***	***13.87***	***8.59***	***22.60***	***8.84***	***<.001***
2	***8.99***	***10.99***	***2.01***	***3.86***	***.007***	***17.57***	***13.40***	***23.79***	***8.80***	***.013***
3	0.12	0.47	0.02	0.10	.342	1.90	3.90	1.71	2.39	.810
4	***10.45***	***13.85***	***2.39***	***10.00***	***.002***	***22.45***	***19.66***	***31.60***	***21.53***	***.007***
5	***4.06***	***4.64***	***1.75***	***2.75***	***.004***	7.56	5.28	9.24	6.20	.153
6	***8.73***	***4.87***	***3.46***	***3.29***	***<.001***	17.64	8.52	20.05	10.88	.090

Note. Significant effects are in bold italics. *M* and *SD* Values may differ slightly from the experimental vs. control comparisons above since analyses only include participants who had valid data for the segment in both the morning and afternoon.

Segment	Interaction Effects (Drive x Treatment) *p* value
1 (25 mph)	***<.001***
2 (35 mph)	***<.001***
3 (45 mph)	.912
4 (70 mph)	***<.001***
5 (55 mph)	***.005***
6 (30 mph)	***<.001***

Note. Significant effects are in bold italics.

Free drive results. Researchers collected the same speeding measures from the 4 free drive participants as had been obtained from the fixed drive participants.

Table ES-2 provides the percentage of speeding for 5+ mph over the limit by participant and study period. A review of the results indicates that Participants 2 and 3 showed significant reductions from Period 1 (AAP off) to Period 2 (AAP on) while Participant 1 showed a significant increase for this measure and Participant 4 no change. All participants showed reversions back to near baseline levels during Period 3 (AAP off) with only Participant 3 showing significantly lower speeding 5+ mph over the limit for Period 3 compared to Period 1.

Table ES-2. Percentage of Speeding 5+ mph Over the Limit by Participant and Period

	5+ MPH Over the Limit		
Participant	Period 1 (AAP off)	Period 2 (AAP on)	Period 3 (AAP off)
1	9.39	***14.47***	7.46
2	7.28	***3.47***	9.90
3	15.89	***6.38***	***9.11***
4	4.88	4.42	5.28

Note: Values in bold italics represent statistically significant ($p<0.05$) changes in speeding from baseline (Period 1).

Discussion

In general, the study uncovered results consistent with those found previously in Europe (e.g., Hjalmdahl & Varhelyi, 2004; Biding & Lind, 2002) even though the present study only included 18 to 24 year old participants. The activation of the AAP produced a marked speed reduction in many but not all of the participants in both the fixed and free drives. In the fixed drive, the significant treatment by drive effect for all segments except one (on which virtually nobody sped due to congestion and traffic signals) strongly suggested that the pedal worked as intended. During the free drives, any reduced speeding during the period with the AAP active did not persist in the third 5-day period with the AAP turned off. Thus, an AAP of the type tested is likely to act more as a governor than as an agent for long-term behavioral change.

Overall, this study supports the basic potential of an AAP as a countermeasure for speeding. A fully operational system will, however, require additional development and testing. The problems associated with the introduction of an AAP into the vehicle population remain thorny and may even prove intractable. A mixed fleet of vehicles equipped and not equipped with an AAP could create speed differentials that might compromise safety and, based on the findings of this and other research, would certainly generate a negative reaction from the motoring public. Therefore, it would be beneficial to have additional research to examine innovative alternatives for introducing an AAP.

Background

Speeding is a major problem on roadways in the United States, contributing to thousands of deaths each year and increasing injury severity when a crash is survived. In 2012, the National Highway Traffic Safety Administration (NHTSA) estimated that “speeding was a contributing factor in 30 percent of all fatal crashes, and 10,219 lives were lost in speeding-related crashes” (NHTSA, 2014). Moreover, the percentage of all fatalities that were speeding-related has remained basically unchanged since 1992 in spite of a declining trend in total fatalities. The speeding-related crash rate per mile is highest on local roads (2005 U.S. DOT National Forum on Speeding, 2004). Speed not only affects the severity of a crash, but is also related to the risk of being involved in a crash. Aarts and van Schagen (2006), in a review of papers on speeding, found evidence for an exponential relationship between speed and crash rate. Studies also revealed that crash rates increased with higher speeds and that crash rates went up more rapidly on minor roads than on major roads. Young male drivers are overrepresented in the speeding problem.

Intelligent Speed Adaptation (ISA) represents a promising approach to reduce speeding (e.g., Schulman, 2005, Varhelyi & Makinen, 2001; Warner & Aberg, 2008). Emerging technologies, such as the Global Positioning System (GPS) and sophisticated mapping software, have made it more practical to employ adaptive speed controls within vehicles. These adaptive systems determine the prevailing speed limit and adjust the countermeasure system thresholds accordingly. This approach has demonstrated significant reductions in speeding among driving populations outside of the United States (e.g., Hjalmdahl & Varhelyi, 2004). There are multiple ways to implement ISA systems, but each system follows the core principle of a dynamic reaction to speed limits.

The ISA approach studied herein consisted of an Active Accelerator Pedal (AAP). This concept has been employed in previous studies to provide haptic feedback to increase seat belt use (Van Houten, Hilton, Schulman, & Reagan, 2011) and to control speeding (e.g., Schulman, 2005; Adell & Várhelyi, 2008). Specifically, when driving a vehicle equipped with this AAP, drivers experience added accelerator pedal resistance (haptic feedback) when they exceed a pre-set speed (e.g., the speed limit). The AAP can impose a differential force schedule to the accelerator pedal as a function of the extent of the driver’s speeding. Although drivers can easily and safely override the system by pressing harder (e.g., to pass, to avoid a crash), the concept of the AAP is that it is uncomfortable to maintain an override for sustained periods of time. The added force also represents a cue to the driver that he or she has exceeded the speed limit. The Schulman (2005) study almost completely eliminated speeding on interstate highways, the only road type on which it was tested.

A large-scale, multi-year study in Sweden examined an AAP along with warning and informative ISA approaches (Biding & Lind, 2002). The warning ISA tested in one city presented an audio and visual signal to the driver when the speed limit was exceeded. The informative ISA tested in another city combined the features of the warning ISA with a display to present the prevailing speed limit to the driver. The active accelerator ISA approach tested in a third city combined a display of the speed limit with a system that rendered the accelerator pedal harder to push when the driver exceeded the speed limit.

The results of the study by Biding and Lind (2002) suggested that all three approaches produced improved speed-keeping behavior, and motorists considered all three acceptable. Participants also strongly expressed the belief that any ISA device installation should be universal to make sure traffic speeds would be homogeneous and so that drivers equipped with an ISA system do not feel they are in the way. Rather than affecting a permanent behavior change with respect to speeding, the ISA systems studied by Biding and Lind (2002) essentially served as a way of actively controlling it. Biding and Lind (2002) also highlighted the three basic functions a mature ISA would need to fulfill:

- Calculating an appropriate maximum speed for a vehicle's current location based on speed limit, weather, and road conditions
- Accurately measuring the speed of the vehicle
- Supporting the driver in adapting vehicle speed to the appropriate level (e.g., by increasing pedal force).

Another Swedish study (Hjalmdahl & Varhelyi, 2004) examined the relationship of driver behavior to long-term driving with an AAP. The results showed several encouraging shifts in behavior towards other road users. They also suggested that the improved behavior extinguished when the AAP system was removed from the vehicles of the participants.

Carsten and Tate (2005) did an extensive theoretical analysis of the crash reduction benefits of universal use of an ISA in the United Kingdom. They concluded that a system that prevented exceeding the speed limit would save 20% of injury crashes and 37% of fatal crashes. A more complex system that took into account traffic and weather conditions would be even more effective resulting in a 36% decline in injury crashes and 59% of fatal crashes. As with many of the other ISA studies, Carsten and Tate (2005) believed it would be necessary to equip the entire fleet of vehicles on the road with the ISA system in order to achieve this benefit.

After more than 15 years of research, Transport for London believed ISA technology to be sufficiently mature to warrant conducting a study to determine if deployment of an ISA in London would be beneficial. The resulting literature review and scoping study (Jamson, Carsten, Chorlton & Fowkes, 2006) examined alternative ISA implementation approaches and estimated the benefits, including potential collision savings, that could be achieved if an ISA were required in all vehicles traveling within London. Jamson et al. (2006) strongly concluded that an imposed system would be necessary for London and, by implication, any other large city in order to achieve the identified benefits and avoid problems from mixed fleets of vehicles operating on the same roadways at significantly different speeds. They also documented quite convincingly that the ISA concept has been extensively investigated in theoretical, laboratory, and field studies.

A study in Australia examined the combination of an ISA with a Following Distance Warning, a Reverse Collision Warning, and a Seat Belt Reminder in what was termed a SafeCar (Regan et al., 2007). Although only 23 drivers participated, they did accumulate 16,500 km (10,252 mi) on the road with the safety systems. The ISA included in the SafeCar alerted a driver when speed was 2 kph (1.2 mph) above the speed limit using a combination of a visual alert on an add-on display, a short duration auditory signal, and continuous upward pressure on the accelerator pedal. The results of this study indicated that the ISA only affected speeds while it was active. Speeds returned to higher values when the system was disconnected in the final experimental period. The ISA was also more effective in reducing the amount of time drivers spent above the speed limit than it was in reducing mean speed. This was evidenced by a significant reduction in the standard deviation of speed when the ISA was active (Regan, et al., 2007).

Adell and Várhelyi (2008) employed a questionnaire to assess the long-term impressions of drivers using an AAP. They found that drivers exposed to the system rated the concept positively. Drivers did, however, think of themselves as an obstacle on the roadway when using the system, likely because they were traveling slower than the prevailing traffic. In spite of generally positive ratings towards the system and its benefits, Adell and Várhelyi (2008) reported a low willingness to keep the system and an even lower interest in paying for it. Middle-aged drivers were significantly more willing to keep and pay for the system than were younger drivers (Adell and Várhelyi, 2008).

The AAP approach also has applicability to the control of behaviors related to highway safety other than speed. In another NHTSA-sponsored study related to automated feedback to foster safe driving in young drivers, Van Houten, Reagan, and Hilton (In Press) used an AAP system to increase the seat belt use of 20 young drivers aged 18 to 21 who did not consistently wear their seat belt. The AAP was activated when an unbelted driver's vehicle exceeded 20 mph (32 kph). Unbelted drivers could continue to drive and exceed 20 mph (32 kph) by pressing harder than the counterforce, but doing so required focused attention and increased physical effort. The system gradually removed the force if drivers fastened their seat belt. The results indicated that seat belt use increased from 56.2% during baseline to 99.7% during the intervention. Drivers also rated the system favorably. In the Van Houten et al. (In Press) study, software controlled the activation of the AAP, and a cable mechanism applied pressure to add force to the accelerator pedal. Since software managed the onset of the increased pedal force in the Van Houten et al. (In Press) seatbelt study, the possibility existed that a relatively simple software modification would allow the same pedal system to be used as an AAP for speed in the present study.

Objective

Since most of the previous AAP research took place outside of the US, the current study had the overall goal of providing insight into the effectiveness and acceptance of an AAP system to control speeding by young drivers in the US. Researchers adopted the following specific objectives to achieve this goal:

- Design, develop, and produce an AAP that included speed mapping and data logging. To the extent possible, adapt the AAP used in the prior seat belt study (Van Houten et al., In Press) by altering the software to increase pedal force in response to speeding rather than for failure to wear a seat belt.

- Identify a test site either with existing speed mapping or that could be easily speed mapped for the data collection portion of the study.

- Instrument 2 vehicles with the developed AAP system and data recording equipment and pilot test the vehicles to ensure safe, reliable and accurate performance of speed detection, pedal feedback, and data recording.

- Test the AAP system for speed reduction effects and the reactions of young drivers (18-24 years old) with respect to acceptance of the system and the possibility that it increased driving workload.

In summary, the specific objective was to determine whether the use of a haptic AAP system that linked the speed of the vehicle and the speed limits of the road upon which the vehicle travels can reduce speeding by young drivers in a wide range of speed limit zones. The study objectives included the use of 2 different data collection methods. The first method involved driving a fixed course twice on a single day. The second method had 4 drivers operating a test vehicle in their normal driving for 3 multi-day periods (pedal off, pedal on, pedal off).

Pedal Development

The study consisted of two main portions. The first focused on the development of an appropriate AAP and data logging system as well as equipping 2 vehicles with the systems. The second portion of the study involved data collection using the developed systems and the analysis of the resulting data.

The general requirements for an AAP for this study followed the functional recommendations of Biding and Lind (2002), enumerated above, augmented by a Failure Modes and Effects Analysis (FMEA)[1] performed by the project researchers. In order to collect representative data without creating unacceptable safety risks, any AAP used by the study had to render the vehicle safe after all reasonably likely failures.

Initial system development efforts focused on modifying the pedal used in the previous study by Van Houten et al. (In Press). Developers attempted to modify the software controlling the pedal force so that it would engage when the vehicle exceeded the speed limit and withdraw smoothly and rapidly when the driver slowed to the speed limit or less. Although the software could be altered to command the necessary forces, the overall pedal design was not sufficiently robust for the revised purpose of speed control. For the prior system objective of prompting seat belt use, the pedal force generally activated only once because a driver did not buckle up at the start of a trip. After drivers responded by fastening their belts, the force retracted and stayed off. Thus, the system typically experienced only a single duty cycle per drive.

In order to serve as an ISA, an AAP must continuously apply and retract pedal force as a function of the speeding behavior of the driver and the prevailing speed limit. The pedal system employed by Van Houten et al. (In Press) utilized a cable and pulleys to generate pedal force. This design worked well for providing a reminder force if a driver did not buckle up. However, the FMEA identified some potential failure modes, failure rates, and associated consequence severities for this design when used to control speed that exceeded levels acceptable to the researchers. As a result, the development team embarked upon a totally revised design that did not employ pulleys or cables.

Pedal Design

The final pedal system consisted of the pedal itself, a speed limit determination subsystem, a motor to provide increased force, and a microcontroller to operate all system functions. Staff analyses indicated that the standard Original Equipment Manufacturer (OEM) accelerator pedal did not have sufficient strength to withstand the increased forces produced by the AAP. The project team therefore fabricated a matching pedal and bracket constructed of steel that had twice the thickness of the OEM pedal. The OEM pedal connected to its mounting bracket using a splined pin through the pedal at the pivot point. For added strength, designers

[1] An FMEA is a structured analysis that examines system functions, possible failures and their frequency, and the consequences of those failures. The objective of an FMEA as used in this study was to identify design facets that potentially increased risk to an unacceptable level. Once identified, these weaknesses could be offset by design changes or operational countermeasures.

replaced the OEM spline system with a double-thick pin welded to the pedal at the pivot point. The new design also substituted hardened plastic bushings locked into place with "M" clips for the OEM pin bushings. The new design retained all angles and bracket arm lengths of the OEM pedal. The only additional component added to the pedal was a steel plate welded to the upper arm to allow for interaction with the motor system. Thus, with no force added, the study pedal felt like the OEM version.

A 12 volt rare-earth magnet motor provided the force to the pedal system. The design included a rack and pinion system attached to the motor and constructed of high-strength and low coefficient of friction materials. One end of the rack ended with a motor stop sensor that would disengage the motor when the rack reached the limit of its travel. The other end of the rack terminated with a steel roller.

With the pedal system activated, the motor engaged whenever the driver exceeded the speed limit by 1 mph (1.6 kph). The system provided a brief light onset of force or "slap" to the upper arm of the pedal to cue drivers initially that they had exceeded the posted speed limit. If the driver continued to exceed the limit, the system would immediately begin adding pressure to the pedal to make it harder to push.[2] The system could provide increased accelerator pedal resistance from 0 lbs to 36 lbs (16.3 kg) over a 4 second period.[3] After the onset of full force, drivers could continue to speed by depressing the accelerator pedal with a force sufficient to overcome the added pedal resistance. If drivers allowed the vehicle speed to drop back to or below the speed limit, the pedal force would return to normal over a period of 10 seconds. The pedal force profile tracked the vehicle speed so the force would reengage if a driver exceeded the speed limit again before the motor had fully retracted.

AAP Electronics

The AAP electronics included a microprocessor, solid-state memory, and a motor controller all installed in the vehicle trunk. The microprocessor commanded the motor control unit to engage, retract, or "lock" the pedal system thereby providing the desired accelerator pedal resistance. Experimenters could program the controller to provide different degrees of pedal resistance. The system employed the locking feature to hold the pedal in any programmed position. This effectively permitted the system to apply a consistent counter-force on the pedal without stressing or overheating the motor. The pedal could still be manually depressed with the application of sufficient force to overcome the resistance.

The microprocessor also accessed key data parameters by receiving input from sensors throughout the vehicle that monitored: 1) vehicle speed; 2) presence of weight on the driver seat; 3) ignition on or off; 4) brake on or off; 5) seat belt closure switch on or off; and 6) accelerator pedal force on or off. In addition to vehicle-based data, the microprocessor also recorded speed limit and vehicle latitude and longitude.

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[2] Functionally, the pedal system added force by rotating the motor which would push the rack and roller ball toward the upper arm of the pedal and then contact and use counter force to press the lower arm of the pedal upward.

[3] Since the OEM pedal produced a force of 2 lbs (0.91 kg), a driver could experience a maximum total pedal force of 38 lbs (17.2 kg).

The system derived speed from the anti-lock brake sensors by measuring electrical pulses created by the rotation of the wheel assembly. An after-market Ottomate™ GPS system[4] programmed with the speed limits of all the streets in and around Kalamazoo and Portage, Michigan provided input on the prevailing speed limit at the vehicle's position. The system sensed activation of the automobile ignition system from a jumper to the ignition fuse. Other components of the harness included a 12-volt buzzer and an emergency shut-off switch.

The microprocessor sampled the status of each monitored function twice a second. Experimenters could set the recording rate of the data using a laptop connected to the microprocessor. The microprocessor also recorded time and date as well as the occurrence of specified events such as the start and end of trips.[5] A custom built electrical wiring harness connected all sensors, whether OEM equipment or researcher-installed, to the microprocessor. Experimenters downloaded data using a laptop computer with a cellular connection to a data modem located in the trunk of the vehicle and an antenna located at the rear window. In addition to the program to download data, the laptop computer also contained a program to perform a preliminary analysis of the raw data and to enter the results into a spreadsheet.

Pedal Safety Systems

The design of the AAP precluded the ability of the system to increase vehicle speed without input from the driver because the rack could only push the accelerator pedal up. As an added safety precaution, designers also included an emergency disconnect switch located in the center of the dashboard below the audio equipment that would immediately disengage the AAP. Use of the switch set a data flag in the logging system so participants could not surreptitiously bypass the system once an experimenter activated it. Once deactivated using the switch, the AAP remained off until reset by an experimenter using the laptop.

The microprocessor programming also retained the last speed limit for 5 seconds in case the GPS system temporarily lost signal. This prevented the AAP from erroneously disengaging due to a brief GPS signal loss. After a GPS data loss of more than 5 seconds, the system would completely disengage until the GPS reacquired the signal, and the pedal force would slowly retract as if the speed of the car had dropped below the speed limit. If the participant drove the vehicle outside of the speed limit mapped area, the pedal system (but not the data logger) disengaged until the car returned to the speed-mapped area. The increased accelerator force would not activate if the system disengaged or lost power.

The system design also included a protection against accidental slow speed crashes with pedestrians and other vehicles when accelerating following a stop. If drivers who were speeding and encountering increased pedal resistance came to a complete stop (e.g., at a traffic signal, stop sign) they might not be aware the force had been withdrawn during the period of braking and stopping. As a result, they might apply too much force when accelerating under the assumption that the increased AAP force remained. To compensate for this possibility, designers

[4] The Ottomate™ is a portable road safety device marketed by PERSENTECH Inc. Technology that provides drivers with information about their driving environment.

[5] The system recorded start of trip when it measured a speed at or above 20 mph for over 20 seconds and end of trip when it detected the ignition off for 30 seconds or no weight on the seat for 30 seconds.

programmed the system to sound a buzzer when the likelihood was high that a driver might inadvertently press the accelerator too hard. The buzzer sounded as a warning to the driver when the situation met all of the following conditions: 1) a speed-limit of 35 mph (56 kph) or less; 2) vehicle speed of 15 mph (24 kph) or less; 3) retraction of the AAP system to 30% or less of maximum force; and 4) the pedal force had recently been fully engaged providing counter pressure to the driver's accelerator inputs.

Vehicles

Experimenters installed the pedal system in 2 similar 4-door Ford Taurus sedans for data collection—a gold 2000 model year and a red 2002 model year (Figure 1). The vehicles had 6-cylinder 3-liter engines and automatic transmissions. The Western Michigan University Motor Pool serviced both vehicles and maintained them in excellent working condition.

Figure 1. Test Vehicles

Method

The data collection portion of the study consisted of two separate driving experiments. The first experiment involved a drive on a specified 6-segment route. Free drives in which participants could use the AAP-equipped cars anywhere in the Kalamazoo/Portage area in place of their personal vehicles constituted the second type of data collection. The WMU Human Subjects Institutional Review Board (HSIRB) reviewed and approved all study procedures.

Fixed Route Drives

Experimenters defined a driving route consisting of 6 segments within the Kalamazoo/Portage area of Michigan. Pairs of participants drove the route twice on a single day—morning and afternoon—in either the experimental car (2002 Red Taurus) or the control vehicle (2000 gold Taurus). Only the red car contained the developed AAP system because of a delay in receiving components for the second vehicle.

Route. Experimenters chose the route segments to present participants with a variety of speed limits, traffic conditions, and road types while they drove the AAP. The route consisted of:

- Segment 1 (speed limit 25 mph; approximate length 5 miles)—a ring road that traveled around the Western Michigan University (WMU) campus. It had one lane in each direction and occasional turning lanes. The segment contained several stop signs and 2 traffic signals. Drivers traversed the ring road twice to complete Segment 1.

- Segment 2 (speed limit 35 mph; approximate length 4.5 miles)—consisted of several roads all of which had 2 lanes in each direction and a center turning lane for a total of 5 lanes. It contained 12 traffic signals. Participants traveled away from the WMU campus and then turned around in a parking lot and returned. Land use along the segment consisted of mixed residential with business use.

- Segment 3 (speed limit 45 mph; approximate length 3.5 miles)—included major thoroughfares with two lanes in each direction and a center turning lane for the entire route and 9 signals. Traffic volume was high and often stop-and-go. Land use was primarily commercial with automobile dealerships and strip malls located along most of the route.

- Segment 4 (speed limit 70 mph; approximate length 14.4 miles)—consisted of 2- and 3-lane limited access highway segments including a stretch on an Interstate highway.

- Segment 5 (speed limit 55 mph; approximate length 6.9 miles)—followed a major grade-level thoroughfare with two lanes in each direction and a center turning lane. The segment contained traffic signals spaced approximately a mile apart. Land use consisted of commercial, some industrial, and occasional short rural stretches.

- Segment 6 (speed limit 30 mph; approximate length 5.8 miles)—combined several roads. The first portion had two lanes in each direction with a center turning lane and sporadic signals. The second section was one-way with 4 lanes and more frequent traffic signals. Land use for the first part was industrial with some residential use, and the one-way segment was entirely commercial and passed through the downtown area of Kalamazoo.

Participants. Experimenters selected 44 WMU students between the ages of 18 and 24 as participants from a pool of volunteers for a variety of studies conducted by the WMU Psychology Department. Because the study provided insured vehicles for participants to operate on the public highways, researchers established criteria to screen volunteers for acceptable driving records. These criteria included: 1) currently valid drivers' license; 2) no license suspensions within the past 5 years; 3) no impaired driving convictions; 4) no reckless driving convictions; and 5) no more than 3 convictions for moving violations in the 12 months prior to participation. In order to verify adherence to these criteria without having researchers learn the details of a volunteer's driving record, a third-party screener (the WMU Chief of Police) reviewed the driving records of the selected volunteers. The screener only returned a judgment of acceptable or not acceptable to the researchers.

Participants completed 2 drives of the same route on a single day. Researchers selected participants from the available pool based on matching sex and age as well as availability on days scheduled for data collection. A total of 22 participant pairs completed the fixed route drives. Eleven pairs of males and an equal number of pairs of females participated.

Procedures. The fixed route data collection consisted of morning and afternoon drives by the same pair of participants. During the morning drive, researchers turned off the AAP in the experimental vehicle so that both participants drove their cars without any added haptic feedback. In the afternoon, the participants repeated the route, and the experimenter activated the AAP in the experimental car. The control participant again drove the route with the normal pedal.

Researchers scheduled a pair of matched participants on each data collection day. The participants reported to a designated starting point in the morning. The on-site experimenter randomly assigned each participant to either the experimental or control condition and the associated car (red for experimental; gold for control). The two participants then received a briefing on the 6-segment route, and the experimenter provided them with a book of instructions and on-route data collection forms. The instructions specifically requested that the participant only look at the information in the book on one segment at a time, but the pre-drive route briefing did provide an overview of the entire drive.

After the route briefing, the experimenter entered the gold car with the control participant to provide a briefing on the controls, displays, and operation of the Ford Taurus. When the participant exhibited an understanding of the car, the experimenter dispatched the participant on the morning drive.

Once the control participant began the drive, the experimenter briefed the experimental participant while seated in the red car. In addition to the same briefing on normal vehicle operation given to the controls, the experimental briefing for the morning drive included an acknowledgment that the vehicle contained experimental systems (not further defined). The experimenter also showed the participant the cutoff switch in the highly unlikely event that the AAP activated itself during the drive. Once the experimenter had completed the briefing, the participant began the drive.

Experimenters dispatched participants independently to avoid any implication of competition. Since the AAP had the objective of slowing down the experimental participants, the protocol always had the control participant leaving first to avoid the possibility that a control participant dispatched second in the afternoon might overtake an experimental participant with the AAP on.

The protocol included dispatching participants in pairs in order to attempt to control for time of day, day of week, weather, lighting, traffic conditions, and roadway conditions. The morning drive started after the height of the rush hour (between 9:30 and 10:00 am), and the afternoon drive ended well before rush hour to avoid the heaviest traffic that could impede the opportunity to speed.

After the morning drive, experimenters off-loaded data from the on-board system and checked with the participant pair individually to determine that the vehicles operated properly. They then provided the participants with $10 for lunch and asked them to return in 45 minutes. The participant pair started their second drive between 1:00 and 2:00 pm. Before the second drive, the researcher activated the AAP in the experimental participant's vehicle. The control participant's vehicle did not change from the morning drive. Prior to dispatch, the experimenter again briefed the participants. As part of this briefing, the researcher demonstrated the AAP for the experimental participant by turning it on while driving in the parking lot so the participant could experience the pedal force. The experimental participant also received a complete review of the normal and possible abnormal behavior of the AAP and on the use of the built-in safety systems.

The afternoon drive duplicated the morning drive except that the experimental participants drove with the AAP activated. The protocol involved identical data collection procedures for both drives. Each segment ended at a safe off-road location where the participant could pull over and stop. While stopped, the participants completed a 6-item workload assessment based on the NASA Task Load Index (TLX) developed by Hart and Staveland (1988) for use in aviation. Participants completed the same TLX scoring after each segment but on separate sheets numbered for that segment. The protocol included the TLX scores for the purpose of examining the possible effects of the AAP and its higher force on the perceived workload experienced by the experimental participants.

Researchers set the AAP electronics to record a data record every 2 seconds. However, GPS dropouts due to loss of satellite signals and other interference sometimes resulted in missing or erroneous data points. When researchers removed these points, the sampling rate varied by participant and segment but without any discernible bias. Thus, each valid data point represented an instantaneous reading of speed limit and vehicle speed that researchers could use to analyze the proportion of samples during which each participant exceeded the speed limit.

In addition to the TLX and the speed data from the on-board electronics, researchers collected two other measures only from experimental participants concerning experiences with the AAP. The first, a debriefing, covered their subjective reaction to the AAP. The second consisted of a battery to assess the extent to which the experimental participants trusted and accepted the AAP.

Free Drives

The second data collection method involved giving an AAP-equipped vehicle to 4 participants to use for 15 days in place of their personal vehicles. After the fixed drives, the project team upgraded the software in the microprocessors of both vehicles based on the experience with the 44 participants. None of these upgrades affected the feel of the AAP. All focused on increased reliability and avoidance of failures. In addition, the team also equipped the gold car with an AAP so that both vehicles could be used for data collection. As mentioned earlier, the delay in equipping the gold car stemmed from the unavailability of some of the components.

Participants. Researchers selected 4 male participants from the same volunteer pool used to recruit participants for the fixed drive data collection. The decision to use only males was based on the limited sample size and the higher crash involvement of young male drivers. As with the participants in the fixed drives, the WMU Chief of Police screened the driving records of the free drive participants to ensure they met study criteria.

Procedures. The protocol divided the 15 days of data collection into 3 periods of 5 days each. During the first period, participants drove the experimental vehicles with the AAP turned off (3 drove the red 2002 Taurus and 1 drove the 2000 gold Taurus). After the first period, an experimenter debriefed the participants on the operation of the vehicle, gave them the TLX battery to complete, downloaded on-board data, and turned on the AAP for the second data collection period. Upon completing 5 days with the AAP on, experimenters again debriefed the participants, administered the TLX, downloaded data, and turned off the AAP. At the end of the third 5-day period, the participants returned the vehicle, and completed a final TLX plus the impressions debriefing and trust and acceptance rating.

Researchers used the same on-board speed recording system for the free drives as had been used for the fixed drive data collection. Because of the extended duration of the free drives, the sampling rate was set to every 5 seconds to avoid overflowing the available on-board memory.

Results

This study included two different data collection techniques and several measures to assess the performance of the AAP. The sections below present the results separately for each method.

Fixed Drive Results

The following sections present the data analyses for the measures collected during and after the fixed drives. In general, a full data record existed for each participant. The few cases of missing data are highlighted in the text or in table notes.

Speeding. Analyses examined the percent of speed data recorded during each of the 6 road segments that exceeded the following speed thresholds: 1) any speed over the limit; 2) 5+ mph over the limit; and 3) 10+ mph over the limit. Higher speed thresholds could not be examined because of sparse data. A percentage of speeding at each threshold was calculated for each participant by dividing the number of data points that exceeded the threshold in a segment by the total number of data points recorded for the segment. Researchers then averaged these percentages across all participants in a group (experimental or control) to provide a mean percentage for each group for each segment. Researchers then conducted a series of analyses to determine if any differences in speeding at each threshold appeared as a function of treatment and drive. It should be remembered that the experimental group only had the AAP activated during the afternoon drive. The control group did not have an AAP active for either drive.

Analysis of Variance (ANOVA) was used to test the statistical significance of differences among the mean scores of groups on factors of interest. A first set of analyses examined speeding at each threshold within a segment through the use of mixed ANOVA where drive (morning or afternoon) was the repeated factor and treatment (experimental or control) was the between subjects factor. Driver sex was included as a covariate in these analyses. Researchers analyzed data for each segment separately. The drive by treatment interaction effect was of most interest for this study since it indicated if the speeding behaviors of the two experimental groups differed as a function of activation of the AAP for the experimental group in the afternoon drive. After conducting this omnibus level analysis, researchers then utilized a series of one-way ANOVAs to examine simple contrasts of the experimental groups within each drive (e.g., experimental morning vs. control morning) and for each experimental group separately across drives (e.g., experimental group morning vs. experimental group afternoon). Driver sex did not show any significant effects as a covariate for any of the omnibus analyses. Therefore, the results presented below combine data from males and females.

Table 1 presents the results for ***any speeding over the limit*** by treatment and drive. The mixed ANOVA interaction effects were statistically significant ($p < 0.05$) for Segments 1, 2, 4, 5, and 6, indicating meaningful changes in speeding behaviors by experimental group from the morning to afternoon drives for these segments. The simple contrasts of the experimental group versus the control group in the morning showed the experimental group had more speeding for Segment 1 ($p < 0.05$), no difference for Segment 2 ($p > 0.05$), and the control group had more speeding for Segments 3, 4, 5 and 6 in the morning ($p < 0.05$). For the afternoon drives, the contrasts showed the control group had significantly higher percentages of any speeding over the limit for all 6 segments compared to the experimental group ($p < 0.05$).

The within groups contrasts revealed the experimental group's reductions in speeding from morning to afternoon were statistically significant for Segments 1, 2, 4 and 6 ($p < 0.05$), approached significance for Segment 5 ($p = 0.083$), and showed no change for Segment 3 ($p > 0.05$) where speeding was virtually nonexistent for all participants. The control group showed significant increases in speeding for Segments 1 and 5 ($p < 0.05$), but not for the other segments ($p > 0.05$).

Table 1. Average Percent of Data Over the Speed Limit by Drive, Experimental Group, and Segment

Segment	Morning					Afternoon				
	Experimental		Control			Experimental		Control		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1	***49.21***	***8.48***	***39.89***	***10.58***	***.002***	***34.78***	***17.96***	***47.03***	***7.78***	***.005***
2	34.03	9.47	37.74	8.54	.180	***18.50***	***13.09***	***38.79***	***7.56***	***<.001***
3	***2.66***	***4.43***	***10.71***	***10.53***	***.002***	***2.59***	***6.75***	***9.01***	***8.91***	***.010***
4	***37.19***	***20.40***	***50.99***	***15.19***	***.015***	***13.01***	***20.40***	***52.38***	***14.46***	***<.001***
5	***15.58***	***7.07***	***22.17***	***7.07***	***.004***	***11.77***	***11.20***	***26.45***	***10.03***	***<.001***
6	***33.07***	***10.77***	***39.39***	***8.98***	***.045***	***25.53***	***14.50***	***42.02***	***8.33***	***<.001***

Note. Significant effects are in bold italics.

Segment	Experimental					Control				
	Morning		Afternoon			Morning		Afternoon		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1	***49.21***	***8.48***	***34.78***	***17.96***	***.001***	***39.89***	***10.58***	***47.03***	***7.78***	***<.001***
2	***34.03***	***9.47***	***18.50***	***13.09***	***<.001***	37.74	8.54	38.79	7.56	.593
3	2.66	4.43	2.59	6.75	.946	10.71	10.53	9.01	8.91	.461
4	***37.19***	***20.40***	***13.01***	***20.40***	***<.001***	50.99	15.19	52.38	14.46	.727
5	15.57	7.24	11.77	11.20	.083	***22.07***	***7.23***	***26.45***	***10.03***	***.034***
6	***33.05***	***11.05***	***26.59***	***14.00***	***.024***	39.63	9.14	42.02	8.54	.154

Note. Significant effects are in bold italics. *M* and *SD* values may differ slightly from the experimental vs. control comparisons above since analyses only include participants who had valid data for the segment in both the morning and afternoon.

Segment	Interaction Effects (Drive x Treatment) *p* values
1 (25 mph)	***<.001***
2 (35 mph)	***<.001***
3 (45 mph)	.527
4 (70 mph)	***<.001***
5 (55 mph)	***.007***
6 (30 mph)	***.006***

Note. Significant effects are in bold italics.

Table 2 presents the results for ***speeding 5+ mph over the limit*** by treatment and drive. The mixed ANOVA interaction effects were statistically significant ($p < 0.05$) for Segments 1, 2, 4, 5, and 6, indicating meaningful changes in speeding 5+ mph over the limit by experimental group from the morning to afternoon drives for these segments. Again, Segment 3 evidences little speeding by anyone. The simple contrasts of the experimental group versus the control group in the morning showed the control group had more speeding 5+ mph over the limit for Segments 2, 3, 4, 5, and 6 ($p < 0.05$) and no difference for Segment 1 ($p > 0.05$). For the afternoon drives, the contrasts showed the control group had significantly higher percentages of speeding 5+ mph over the limit for all 6 segments compared to the experimental group ($p < 0.05$).

The within groups contrasts showed the experimental group's reductions in speeding 5+ mph over the limit from morning to afternoon were statistically significant for Segments 1, 2, 4, 5 and 6 ($p < 0.05$), but not for Segment 3 ($p > 0.05$). The control group showed significant increases in speeding 5+ mph over the limit for Segments 1, 2, and 4 ($p < 0.05$), but not for the other segments ($p > 0.05$).

Table 2. Average Percent of Data 5+ MPH Over the Speed Limit by Drive, Experimental Group, and Segment

Segment	Morning					Afternoon				
	Experimental		Control			Experimental		Control		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1	18.83	11.37	13.87	8.59	.110	***6.11***	***6.94***	***22.60***	***8.84***	***<.001***
2	***8.99***	***10.99***	***17.57***	***13.40***	***.025***	***2.01***	***3.86***	***23.79***	***8.80***	***<.001***
3	***0.12***	***0.47***	***1.90***	***3.90***	***.040***	***0.02***	***0.10***	***1.71***	***2.39***	***.002***
4	***10.45***	***13.85***	***22.45***	***19.66***	***.024***	***2.39***	***10.00***	***31.60***	***21.53***	***<.001***
5	***4.18***	***4.56***	***7.68***	***5.18***	***.022***	***1.75***	***2.75***	***9.24***	***6.20***	***<.001***
6	***8.70***	***4.75***	***17.70***	***8.31***	***<.001***	***3.30***	***3.30***	***19.52***	***10.88***	***<.001***

Note. Significant effects are in bold italics.

Segment	Experimental					Control				
	Morning		Afternoon			Morning		Afternoon		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1	***18.83***	***11.37***	***6.11***	***6.94***	***<.001***	***13.87***	***8.59***	***22.60***	***8.84***	***<.001***
2	***8.99***	***10.99***	***2.01***	***3.86***	***.007***	***17.57***	***13.40***	***23.79***	***8.80***	***.013***
3	0.12	0.47	0.02	0.10	.342	1.90	3.90	1.71	2.39	.810
4	***10.45***	***13.85***	***2.39***	***10.00***	***.002***	***22.45***	***19.66***	***31.60***	***21.53***	***.007***
5	***4.06***	***4.64***	***1.75***	***2.75***	***.004***	7.56	5.28	9.24	6.20	.153
6	***8.73***	***4.87***	***3.46***	***3.29***	***<.001***	17.64	8.52	20.05	10.88	.090

Note. Significant effects are in bold italics. *M* and *SD* values may differ slightly from the experimental vs. control comparisons above since analyses only include participants who had valid data for the segment in both the morning and afternoon.

Segment	Interaction Effects (Drive x Treatment) *p* values
1 (25 mph)	***<.001***
2 (35 mph)	***<.001***
3 (45 mph)	.912
4 (70 mph)	***<.001***
5 (55 mph)	***.005***
6 (30 mph)	***<.001***

Note. Significant effects are in bold italics.

Table 3 presents the results for ***speeding 10+ mph over the limit*** by treatment and drive. The reader should note the experimental group showed very little speeding 10+ mph over the limit during either drive session thereby making statistical comparisons tenuous at best. *These results should therefore be interpreted with caution.* The mixed ANOVA interaction effects were statistically significant ($p < 0.05$) for Segments 1, 2, and 4 indicating meaningful changes in speeding 10+ mph over the limit by experimental group from the morning to afternoon drives for these segments. The simple contrasts of the experimental group versus the control group in the morning showed the control group had more speeding 10+ mph over the limit for Segment 6

($p < 0.05$) and no differences for the other segments ($p > 0.05$). For the afternoon drives, the contrasts showed the control group had significantly higher percentages of speeding 10+ mph over the limit for Segments 1, 2, 4, and 6 compared to the experimental group ($p < 0.05$).

The within groups contrasts revealed the experimental group's reduction in speeding 10+ mph over the limit from morning to afternoon was statistically significant for Segment 1 only ($p < 0.05$). The control group showed significant increases in speeding 10+ mph over the limit for Segments 1, 2, and 4 ($p < 0.05$).

Table 3. Average Percent of Data 10+ MPH Over the Speed Limit by Drive, Experimental Group, and Segment

Segment	Morning					Afternoon				
	Experimental		Control			Experimental		Control		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1	1.63	1.94	1.55	2.42	.900	***0.51***	***0.88***	***4.79***	***4.09***	***<.001***
2	1.35	3.80	2.77	5.54	.327	***0.32***	***0.77***	***5.65***	***7.01***	***.001***
3	0.00	0.00	0.05	0.25	.323	0.00	0.00	0.16	0.45	.096
4	1.89	5.15	5.80	11.13	.142	***1.02***	***4.78***	***10.16***	***14.73***	***.008***
5	0.46	0.88	1.08	2.04	.198	0.53	1.49	1.27	1.99	.177
6	***0.70***	***0.77***	***4.44***	***5.27***	***.003***	***0.55***	***0.88***	***5.53***	***7.06***	***.003***

Note. Significant effects are in bold italics.

Segment	Experimental					Control				
	Morning		Afternoon			Morning		Afternoon		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1	***1.63***	***1.94***	***0.51***	***0.88***	***.018***	***1.55***	***2.42***	***4.79***	***4.09***	***<.001***
2	1.35	3.80	0.32	0.77	.228	***2.77***	***5.54***	***5.65***	***7.01***	***.028***
3	0.00	0.00	0.00	0.00	--	0.05	0.25	0.16	0.45	.342
4	1.89	5.15	1.02	4.78	.080	***5.80***	***11.13***	***10.16***	***14.73***	***.044***
5	0.35	0.72	0.53	1.49	.498	1.01	2.06	1.27	1.99	.437
6	0.69	0.79	0.58	0.89	.679	4.56	5.38	5.75	7.17	.094

Note. Significant effects are in bold italics. *M* and *SD* values may differ slightly from the experimental vs. control comparisons above since analyses only include participants who had valid data for the segment in both the morning and afternoon.

Segment	Interaction Effects (Drive x Treatment) *p* value
1 (25 mph)	***<.001***
2 (35 mph)	***.012***
3 (45 mph)	.321
4 (70 mph)	***.014***
5 (55 mph)	.839
6 (30 mph)	.077

Note. Significant effects are in bold italics.

TLX workload ratings. After each segment, participants completed a 6-item TLX battery to assess the workload experienced while driving that segment. Figure 2 shows the battery as used for the first segment. Participants completed the same battery after the other 5 segments. The short descriptions of each item (e.g., mental demand, physical demand, temporal demand, performance, effort, frustration level) duplicated those used by Hart and Staveland (1988). Researchers added the more extensive supplementary explanation of each item in order to adapt the TLX to the driving situation in this study. Also, the response scale used for this study contained 10 possible response positions whereas the scale used by Hart and Staveland (1988) included 20.

The first analysis step involved subjecting the scale data to a factor analysis using SPSS®[6] to determine if some of the 6 scales actually clustered into a smaller number of factors. The results did not reveal any meaningful clustering and therefore all further analyses examined the 6 scales separately for each of the 6 driving segments.

Researchers then conducted a series of one-way ANOVAs to analyze the effect of experimental condition (use of the AAP vs. normal accelerator pedal) on TLX scores. These analyses tested for changes in mean TLX score across experimental condition, within each drive (morning or afternoon). The top portions of Table 4 to Table 9 below show the mean scale scores for each experimental group and drive (morning or afternoon). The relevant *p* values for the test of differences between the experimental groups are presented adjacent to their associated morning and afternoon means.

Researchers next conducted a series of repeated measures ANOVAs to analyze the effect of drive (first/morning vs. second/afternoon) on TLX scores. These analyses tested for changes in the mean TLX values across morning and afternoon within each experimental condition. Relevant *p* values are presented adjacent to their associated experimental and control group means in the second part of Table 4 to Table 9 below.

The final series of analyses involved running mixed ANOVAs to analyze the interaction effect of drive (morning or afternoon) and experimental condition on TLX scores. These analyses tested for changes in mean TLX score as a function of both drive (morning or afternoon) and experimental condition. The third part of Table 4 to Table 9 below shows the relevant *p* values for the interaction effect for each of the 6 TLX components. A significant interaction effect indicates that any observed differences between the values for the morning to the afternoon drives were differential for the experimental and control groups. The reader must examine the individual data values in the tables in order to determine the direction and magnitude of any significant interaction effects.

[6] As stated in the SPSS Version 20 documentation (IBM): "Factor analysis attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables. Factor analysis is often used in data reduction to identify a small number of factors that explain most of the variance that is observed in a much larger number of manifest variables." The factor analysis employed the Varimax Rotation technique.

Please Complete this Form (2 pages) After Driving Segment 1

Please rate the mental workload demand associated with the overall driving task (steering, navigating, maintaining speed, avoiding hazards, and so forth) **that you experienced on Segment 1**. There are 6 mental workload dimensions to rate, and the definitions are provided below. Before completing the rating, think about the mental workload you experienced when driving **on the last segment** taking into consideration the vehicle you operated. **Place an "X" on each line to indicate the rating for each dimension.**

(1) Mental demand: **How much mental and perceptual activity was required** (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

1 Very Low — 10 Very High

(2) Physical demand: **How much physical activity was required** (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

1 Very Low — 10 Very High

(3) Temporal demand: **How much time pressure did you feel due to the rate or pace at which the task or task elements occurred?** Was the pace slow and leisurely or rapid and frantic?

1 Very Low — 10 Very High

Participant Number ____________________

Segment 1 – Continued

(4) **Performance**: **How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)?** How satisfied were you with your performance in accomplishing these goals?

1 Very Low — 10 Very High

(5) Effort: **How hard did you have to work (mentally and physically) to accomplish your level of performance**?

1 Very Low — 10 Very High

(6) Frustration level**: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task**

1 Very Low — 10 Very High

Participant Number ____________________

Figure 2. TLX battery used after each segment

Table 4. TLX Scores for Segment 1 (25 mph)

TLX Scale	Morning					Afternoon				
	Experimental		Control			Experimental		Control		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1 (Mental)	2.73	1.55	3.18	1.71	.360	***4.45***	***2.67***	***1.45***	***0.67***	***<.001***
2 (Physical)	3.27	2.29	2.36	1.09	.101	***5.23***	***2.10***	***1.86***	***1.04***	***<.001***
3 (Temporal)	2.55	1.41	2.50	1.10	.906	***4.36***	***2.40***	***1.18***	***0.40***	***<.001***
4 (Performance)	8.64	1.79	7.50	2.41	.083	7.95	2.08	8.91	2.09	.137
5 (Effort)	2.77	1.27	3.32	1.62	.220	***5.41***	***2.26***	***1.91***	***1.07***	***<.001***
6 (Frustration)	2.50	2.09	2.36	1.56	.807	***5.05***	***2.87***	***1.32***	***0.72***	***<.001***

Note. Significant effects are in bold italics.

TLX Scale	Experimental					Control				
	Morning		Afternoon			Morning		Afternoon		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1 (Mental)	***2.73***	***1.55***	***4.45***	***2.67***	***.015***	***3.18***	***1.71***	***1.45***	***0.67***	***<.001***
2 (Physical)	***3.27***	***2.29***	***5.23***	***2.10***	***.003***	***2.36***	***1.09***	***1.86***	***1.04***	***.008***
3 (Temporal)	***2.55***	***1.41***	***4.36***	***2.40***	***.003***	***2.50***	***1.10***	***1.18***	***0.40***	***<.001***
4 (Performance)	8.64	1.79	7.95	2.08	.163	***7.50***	***2.41***	***8.91***	***2.09***	***.002***
5 (Effort)	***2.77***	***1.27***	***5.41***	***2.26***	***<.001***	***3.32***	***1.62***	***1.91***	***1.07***	***<.001***
6 (Frustration)	***2.50***	***2.09***	***5.05***	***2.87***	***.006***	***2.36***	***1.56***	***1.32***	***0.72***	***.003***

Note. Significant effects are in bold italics.

TLX Scale	Interaction Effects (Drive x Treatment) *p* values
1 (Mental)	***<.001***
2 (Physical)	***<.001***
3 (Temporal)	***<.001***
4 (Performance)	***.001***
5 (Effort)	***<.001***
6 (Frustration)	***<.001***

Note. Significant effects are in bold italics.

Table 5. TLX Scores for Segment 2 (35 mph)

TLX Scale	Morning					Afternoon				
	Experimental		Control			Experimental		Control		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1 (Mental)	3.55	1.60	3.36	1.53	.702	***4.05***	***2.50***	***2.05***	***1.00***	***.001***
2 (Physical)	2.50	1.41	2.64	1.09	.721	***4.73***	***2.14***	***1.82***	***1.10***	***<.001***
3 (Temporal)	2.64	1.33	2.86	1.55	.605	***3.91***	***2.05***	***1.68***	***0.72***	***<.001***
4 (Performance)	8.68	1.46	7.86	2.08	.138	7.73	2.44	8.77	1.54	.096
5 (Effort)	3.36	1.65	3.23	1.75	.791	***5.00***	***2.35***	***2.14***	***1.32***	***<.001***
6 (Frustration)	2.50	1.68	2.68	1.81	.732	***4.77***	***2.35***	***1.45***	***0.74***	***<.001***

Note. Significant effects are in bold italics.

TLX Scale	Experimental					Control				
	Morning		Afternoon			Morning		Afternoon		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1 (Mental)	3.55	1.60	4.05	2.50	.352	***3.36***	***1.53***	***2.05***	***1.00***	***<.001***
2 (Physical)	***2.50***	***1.41***	***4.73***	***2.14***	***<.001***	***2.64***	***1.09***	***1.82***	***1.10***	***<.001***
3 (Temporal)	***2.64***	***1.33***	***3.91***	***2.05***	***.022***	***2.86***	***1.55***	***1.68***	***0.72***	***<.001***
4 (Performance)	8.68	1.46	7.73	2.44	.092	***7.86***	***2.08***	***8.77***	***1.54***	***.020***
5 (Effort)	***3.36***	***1.65***	***5.00***	***2.35***	***.001***	***3.23***	***1.75***	***2.14***	***1.32***	***.006***
6 (Frustration)	***2.50***	***1.68***	***4.77***	***2.35***	***<.001***	***2.68***	***1.81***	***1.45***	***0.74***	***.003***

Note. Significant effects are in bold italics.

TLX Scale	Interaction Effects (Drive x Treatment) *p* values
1 (Mental)	***.004***
2 (Physical)	***<.001***
3 (Temporal)	***<.001***
4 (Performance)	***.006***
5 (Effort)	***<.001***
6 (Frustration)	***<.001***

Note. Significant effects are in bold italics.

Table 6. TLX Scores for Segment 3 (45 mph)

TLX Scale	Morning					Afternoon				
	Experimental		Control			Experimental		Control		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1 (Mental)	3.68	1.89	2.68	1.36	.050	***3.00***	***1.48***	***2.00***	***0.98***	***.011***
2 (Physical)	2.73	1.45	2.59	1.30	.744	***3.18***	***1.47***	***1.86***	***1.08***	***.002***
3 (Temporal)	3.00	1.88	2.68	1.49	.537	***3.14***	***1.91***	***1.68***	***0.89***	***.002***
4 (Performance)	8.95	1.00	8.32	1.86	.165	8.82	1.68	8.68	1.96	.806
5 (Effort)	3.23	1.90	2.82	1.56	.440	***3.59***	***2.22***	***2.32***	***1.59***	***.034***
6 (Frustration)	2.50	1.23	2.27	1.39	.568	***3.77***	***2.39***	***1.64***	***1.22***	***.001***

Note. Significant effects are in bold italics.

TLX Scale	Experimental					Control				
	Morning		Afternoon			Morning		Afternoon		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1 (Mental)	3.68	1.89	3.00	1.48	.074	***2.68***	***1.36***	***2.00***	***0.98***	***.008***
2 (Physical)	2.73	1.45	3.18	1.47	.226	***2.59***	***1.30***	***1.86***	***1.08***	***.002***
3 (Temporal)	3.00	1.88	3.14	1.91	.790	***2.68***	***1.49***	***1.68***	***0.89***	***.003***
4 (Performance)	8.95	1.00	8.82	1.68	.719	8.32	1.86	8.68	1.96	.134
5 (Effort)	3.23	1.90	3.59	2.22	.502	2.82	1.56	2.32	1.59	.126
6 (Frustration)	***2.50***	***1.23***	***3.77***	***2.39***	***.030***	***2.27***	***1.39***	***1.64***	***1.22***	***.036***

Note. Significant effects are in bold italics.

TLX Scale	Interaction Effects (Drive x Treatment) *p* values
1 (Mental)	1.00
2 (Physical)	***.007***
3 (Temporal)	.061
4 (Performance)	.263
5 (Effort)	.170
6 (Frustration)	***.003***

Note. Significant effects are in bold italics.

Table 7. TLX Scores for Segment 4 (70 mph)

TLX Scale	Morning					Afternoon				
	Experimental		Control			Experimental		Control		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1 (Mental)	4.86	2.51	4.23	1.57	.320	3.45	1.82	2.77	1.66	.201
2 (Physical)	***4.27***	***2.10***	***2.91***	***1.57***	***.019***	***4.05***	***1.70***	***2.45***	***1.71***	***.004***
3 (Temporal)	4.18	2.17	3.00	1.75	.053	***3.18***	***1.76***	***1.82***	***1.26***	***.005***
4 (Performance)	9.09	1.27	8.23	1.85	.078	8.77	1.72	8.73	1.80	.932
5 (Effort)	4.73	2.62	3.64	1.65	.106	***4.36***	***2.30***	***2.59***	***1.68***	***.006***
6 (Frustration)	***3.27***	***1.75***	***2.23***	***1.15***	***.024***	***3.77***	***2.09***	***1.91***	***1.31***	***.001***

Note. Significant effects are in bold italics.

TLX Scale	Experimental					Control				
	Morning		Afternoon			Morning		Afternoon		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1 (Mental)	***4.86***	***2.51***	***3.45***	***1.82***	***.013***	***4.23***	***1.57***	***2.77***	***1.66***	***.002***
2 (Physical)	4.27	2.10	4.05	1.70	.623	2.91	1.57	2.45	1.71	.125
3 (Temporal)	4.18	2.17	3.18	1.76	.088	***3.00***	***1.75***	***1.82***	***1.26***	***.010***
4 (Performance)	9.09	1.27	8.77	1.72	.246	8.23	1.85	8.73	1.80	.086
5 (Effort)	4.73	2.62	4.36	2.30	.561	***3.64***	***1.65***	***2.59***	***1.68***	***.006***
6 (Frustration)	3.27	1.75	3.77	2.09	.386	2.23	1.15	1.91	1.31	.259

Note. Significant effects are in bold italics.

TLX Scale	Interaction Effects (Drive x Treatment) *p* values
1 (Mental)	.945
2 (Physical)	.674
3 (Temporal)	.795
4 (Performance)	***.039***
5 (Effort)	.339
6 (Frustration)	.200

Note. Significant effects are in bold italics.

Table 8. TLX Scores for Segment 5 (55 mph)

TLX Scale	Morning					Afternoon				
	Experimental		Control			Experimental		Control		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1 (Mental)	5.09	2.09	4.64	1.87	.451	3.05	1.40	2.77	1.60	.553
2 (Physical)	4.05	1.86	3.36	1.87	.232	***3.71***	***2.05***	***2.18***	***1.26***	***.005***
3 (Temporal)	3.77	2.20	3.14	1.32	.252	***3.43***	***2.06***	***2.00***	***1.07***	***.006***
4 (Performance)	8.73	1.24	8.23	1.82	.294	8.29	2.13	8.95	1.36	.224
5 (Effort)	4.73	1.96	4.00	2.05	.253	***3.57***	***1.50***	***2.55***	***1.65***	***.040***
6 (Frustration)	3.55	1.77	2.82	1.50	.148	***3.76***	***2.36***	***1.64***	***0.85***	***<.001***

Note. Significant effects are in bold italics.

TLX Scale	Experimental					Control				
	Morning		Afternoon			Morning		Afternoon		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1 (Mental)	***5.10***	***2.14***	***3.05***	***1.40***	***<.001***	***4.64***	***1.87***	***2.77***	***1.60***	***<.001***
2 (Physical)	4.00	1.90	3.71	2.05	.444	***3.36***	***1.87***	***2.18***	***1.26***	***.006***
3 (Temporal)	3.81	2.25	3.43	2.06	.412	***3.14***	***1.32***	***2.00***	***1.07***	***.001***
4 (Performance)	8.71	1.27	8.29	2.13	.251	***8.23***	***1.82***	***8.95***	***1.36***	***.002***
5 (Effort)	***4.71***	***2.00***	***3.57***	***1.50***	***.009***	***4.00***	***2.05***	***2.55***	***1.65***	***.002***
6 (Frustration)	3.57	1.81	3.76	2.36	.746	***2.82***	***1.50***	***1.64***	***0.85***	***.001***

Note. Significant effects are in bold italics.

TLX Scale	Iinteraction Effects (Drive x Treatment) *p* values
1 (Mental)	.773
2 (Physical)	.101
3 (Temporal)	.161
4 (Performance)	***.008***
5 (Effort)	.589
6 (Frustration)	***.039***

Note. Significant effects are in bold italics. M and SD in the Experimental section of the second part of the table differ slightly from the first due to missing data from one participant.

Table 9. TLX Scores for Segment 6 (30 mph)

TLX Scale	Morning					Afternoon				
	Experimental		Control			Experimental		Control		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1 (Mental)	3.95	2.24	3.73	2.12	.731	3.36	1.71	2.55	1.71	.120
2 (Physical)	3.45	1.95	2.64	1.50	.125	***3.82***	***1.87***	***2.09***	***1.31***	***.001***
3 (Temporal)	3.32	2.30	2.82	1.56	.403	***2.95***	***1.43***	***2.00***	***1.35***	***.028***
4 (Performance)	8.23	2.05	8.05	2.42	.789	8.59	1.87	8.95	1.68	.500
5 (Effort)	3.86	2.34	3.45	1.95	.531	***4.18***	***2.06***	***2.45***	***1.60***	***.003***
6 (Frustration)	3.14	2.40	2.64	1.76	.435	***3.68***	***2.34***	***1.77***	***1.41***	***.002***

Note. Significant effects are in bold italics.

TLX Scale	Experimental					Control				
	Morning		Afternoon			Morning		Afternoon		
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*	*M*	*SD*	*p*
1 (Mental)	3.95	2.24	3.36	1.71	.091	***3.73***	***2.12***	***2.55***	***1.71***	***.001***
2 (Physical)	3.45	1.95	3.82	1.87	.364	2.64	1.50	2.09	1.31	.069
3 (Temporal)	3.32	2.30	2.95	1.43	.474	***2.82***	***1.56***	***2.00***	***1.35***	***.005***
4 (Performance)	8.23	2.05	8.59	1.87	.364	8.05	2.42	8.95	1.68	.052
5 (Effort)	3.86	2.34	4.18	2.06	.556	***3.45***	***1.95***	***2.45***	***1.60***	***.005***
6 (Frustration)	3.14	2.40	3.68	2.34	.442	***2.64***	***1.76***	***1.77***	***1.41***	***.016***

Note. Significant effects are in bold italics.

TLX Scale	Interaction Effects (Drive x Treatment) *p* values
1 (Mental)	.203
2 (Physical)	.068
3 (Temporal)	.424
4 (Performance)	.361
5 (Effort)	.***040***
6 (Frustration)	.074

Note. Significant effects are in bold italics.

Examination of Table 4 to Table 9 above reveals several interesting patterns germane to the objectives of this study. First, no meaningful differences existed between the TLX scale scores of the experimental and control participants during the morning (baseline) drive. Only two of the 36 total comparisons (both on Segment 4, the 70 mph segment), reached statistical significance. This represents no more than would have been expected by chance.

The absence of differences between the two participant groups during the morning drive with the AAP off in the experimental car suggests both that the random assignment of participants succeeded and that the two cars performed in an essentially similar fashion at least with respect to the 6 dimensions covered by the TLX.

A comparison of the afternoon TLX scores for the two groups shows that the experimental group indicated they experienced higher mental, physical, and temporal demand, as well as greater effort and frustration levels during all segments than did the control participants. Experimental and control participants had approximately equivalent performance scale means.

The afternoon mean TLX scale scores for all of the scales except performance increased significantly for the experimental participants during segment 1 and all scales except mental demand and performance after segment 2. For segments 3 to 6, the morning and afternoon TLX scale values for the experimental participants generally did not exhibit significant differences.

For the control participants, the afternoon mean values for all scales except performance showed significant reductions from the morning values. The interaction of drive by treatment showed significance for all scales for the first two segments and then was generally not significant for the remaining 4 segments.

Taken together, the pattern in the TLX mean scores of the control participants suggests that the second drive involved lower workload than did the first drive likely because the participants had greater familiarity with both the route and the test vehicles. The experimental participants initially responded to the activation of the AAP with higher workload scores. After they gained familiarity with the AAP, the experimental group gave TLX responses that generally did not differ significantly from those they had given on the morning drive. Thus, while control participants reported lower workload on their second drive, the activation of the AAP for the experimental group appeared to offset this reduction, but generally did not elevate workload as measured by the TLX above the levels experienced during the morning drive.

Debriefing. Researchers debriefed the experimental participants after their afternoon drive concerning their feelings about the pedal system. The controls were not debriefed as they never experienced the pedal. With respect to effectiveness, 14 of the 22 participants (63.6%) thought the pedal was very effective. The remaining 8 participants (36.4 %) thought it was somewhat effective. Of note was that none of the 22 participants who experienced the pedal responded that the pedal was either somewhat or very ineffective.

Only 3 of the 22 (13.6%) admitted to trying to bypass the system. All 3 attempted the bypass by pushing hard on the pedal to get well above the speed limit and then letting the car coast above the limit. Two of the 3 who tried this thought they had successfully defeated the system while the third felt this bypass approach lacked effectiveness.

Most of the participants (20 of 22 or 90.9%) thought the pedal would be effective for 16 to 19 year old drivers. Somewhat fewer (17 of 22 or 77.3%) believed it would be effective for 20 to 24 year old drivers. Less than half (8 of 22 or 36.4 %) thought the pedal effectiveness extended to drivers 25 to 64, and less than half (10 of 22 or 45.5%) also believed it would work for those 65 and over.

All 22 participants indicated that the pedal made them more aware of the speed limit. Half of the participants felt it caused a distraction. Eight of the 22 (36.4%) indicated in the affirmative when asked if they specifically felt less safe when driving the pedal. When asked if they felt more safe, 12 of the 22 (54.5%) indicated that they did.

Almost all participants (21 of 22 or 95.5%) noted that driving with the pedal system made them more aware of the speed of others. Some of the participants (5 or 22.7% of the total), however, did not appreciate this awareness because it made them notice the impatience and tailgating of drivers behind them.

Researchers discussed the concept of making the pedal mandatory in all vehicles if it reduced insurance costs. Of the 22 participants, 12 (54.5%) favored universal pedal use and most made it clear that their support hinged on a cost savings such as through reduced insurance premiums.

Half of the participants liked the additional awareness of the speed limit that the pedal system provided. A few mentioned that it could save them from getting a speeding ticket. The major dislike related to the pedal concerned the fact that it deterred speeding in areas where they wanted to exceed the limit.

With respect to the pedal system design itself, 3 participants (13.6%) mentioned that the beeping emitted by the system became an annoyance. The same number of participants also mentioned that they questioned the accuracy and timing of the withdrawal of the pedal force. The remainder of the participants accepted the design as they experienced it and, presumably, in the context of an experimental, prototype implementation.

Trust and acceptance ratings. In addition to the debriefing by researchers, participants also completed a set of eight 10-point scales. Each scale ranged from Disagree (value 1) to Agree (value 10). The stems or prompts for the eight scales were:

- The accelerator pedal was reliable.
- The accelerator pedal was predictable.
- The accelerator pedal was trustworthy.
- The accelerator pedal was acceptable.
- The accelerator pedal was pleasing.
- The accelerator pedal was annoying.
- The accelerator pedal was accurate.
- The accelerator pedal was agreeable.

Researchers calculated the mean score on each scale. Note that a value of 10 would indicate complete agreement with each statement, and a value of 1 signifies complete disagreement. Therefore all means of less than 5.5 suggest disagreement, and means greater than 5.5 are indicative of some level of agreement.

When using multiple semantic scales of this type, the possibility exists that some of the individual scales are interrelated and therefore not measuring totally independent dimensions. To check for this possibility, researchers conducted a factor analysis using the same approach as had been used for the TLX data. The analysis revealed that two factors or components each consisting of 4 scales accounted for 66.2% of the variance in the data. The first factor encompassed predictable, trustworthy, acceptable, and accurate. The second factor combined reliable, pleasing, annoying, and agreeable.

Semantically, the concepts in the first factor all relate to a participant's assessment of the performance characteristics and performance level of the pedal system. The words composing the scales in the second factor deal with the extent to which the participants liked or disliked the system. The existence of only two strong factors in the 8 scales is noteworthy and suggestive that performance and likeability represent important dimensions to consider when designing systems of this type.

Table 10 shows the mean value for each scale separated into the two identified factors. Examination of the mean score for each scale suggested that participants strongly agreed that the pedal was reliable, predictable, trustworthy, acceptable, and accurate. Participants indicated somewhat less agreement that the pedal was annoying and agreeable and disagreed with the notion that the pedal was pleasing.

Table 10. Mean Trust and Acceptance Scale Scores (n = 22)

Scale	Mean	Std. Deviation
Factor 1: Performance		
Pedal was ***Predictable***	8.68	1.211
Pedal was ***Trustworthy***	8.27	1.549
Pedal was ***Acceptable***	7.45	1.870
Pedal was ***Accurate***	8.09	1.571
Factor 2: Likeability		
Pedal was ***Reliable***	8.27	1.723
Pedal was ***Pleasing***	3.77	2.369
Pedal was ***Annoying***	7.00	3.055
Pedal was ***Agreeable***	6.91	1.974

Free Drive Results

Researchers collected the same speeding and post-drive debriefing measures from the 4 free drive participants as had been obtained from the fixed drive participants. The results that follow are largely descriptive because of the small number of participants.

Speeding. In this portion of the study, researchers examined the speed data for each participant separately using the Chi Square analysis technique to test the proportion of speeding (at various thresholds) by 5-day study period. When the Chi Square values were statistically significant ($p < 0.05$), researchers used z-tests to compare the proportions for individual data collection periods to one another. The speeding threshold measures of interest examined included: 1) any speed over the limit; 2) 5+ mph over the limit; and 3) 10+ mph over the limit. These measures were calculated for the entire 5-day testing periods across all driving conditions.

A percentage of speeding at each threshold was calculated for each participant by dividing the number of speed data points that exceeded the threshold in a segment by the total number of speed data points recorded for the segment. For each participant, the pedal was inactive during Period 1, active during Period 2, and inactive during Period 3.

Table 11 provides the percentage of speeding for each measure by participant and study period. Values for Periods 2 and 3 that were significantly different (higher or lower) than the Period 1 baseline are highlighted in bold italics. A review of the results shows that 3 of the 4 drivers actually ***increased*** the amount of ***any speed over the limit*** from Period 1 (AAP off) to Period 2 (AAP on). All 4 participants then showed a reversal back to values near their baseline speeding rates for this measure during Period 3 (AAP off) with Participant 4 showing a slight decrease for Period 3 compared to Period 1. For the percentage of speed data that were ***5+ mph over the limit***, Participants 2 and 3 showed significant reductions from Period 1 to Period 2 while Participant 1 showed a significant increase for this measure and Participant 4 no change. All participants showed reversions back to near baseline levels during Period 3 with only Participant 3 showing significantly lower speeding 5+ mph over the limit for Period 3 compared to Period 1. For ***10+ mph over the limit***, Participants 2, 3 and 4 showed significant reductions from Period 1 to Period 2 while Participant 1 again showed a significant increase. For this measure during Period 3, only Participant 3 remained below his Period 1 percentage of speeding while the rest resumed their normal rates of speeding 10+ mph over the limit.

Table 11. Percentage of Speeding at Various Thresholds by Participant and Period

	Any Over the Limit			5+ MPH Over the Limit			10+ MPH Over the Limit		
Participant	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
1	20.18	***31.42***	17.90	9.39	***14.47***	7.46	4.06	***5.53***	3.21
2	22.53	***17.04***	26.20	7.28	***3.47***	9.90	1.62	***0.61***	0.96
3	30.49	***35.64***	24.53	15.89	***6.38***	***9.11***	4.75	***0.24***	***1.05***
4	17.59	***24.01***	***14.16***	4.88	4.42	5.28	1.16	***0.48***	1.12

Note: Values in bold italics represent statistically significant (p<0.05) changes in speeding from baseline (Period 1).

TLX workload scores. The 4 participants in the free drive data collection completed the same TLX battery as had the 44 participants in the fixed drives. The small sample size precluded the calculation of mean scores or any analyses comparing ratings for the two periods driving with the pedal off compared to the period with the pedal on. Nevertheless, an examination of the pattern of scores provides some interesting insights into the reactions of the participants and, perhaps, some additional understanding of their speeding behavior reported above.

The first TLX scale addressed mental demand (Figure 3). All 4 participants indicated an increased mental demand with the AAP on. Only Participant 3 rated the change greater than one step on the rating scale. For all but one of the participants, the demand decreased to below the initial period's value in the final period with the pedal again off. Participant 4 rated the mental demand equivalent in the final period and also rated it highest at the outset.

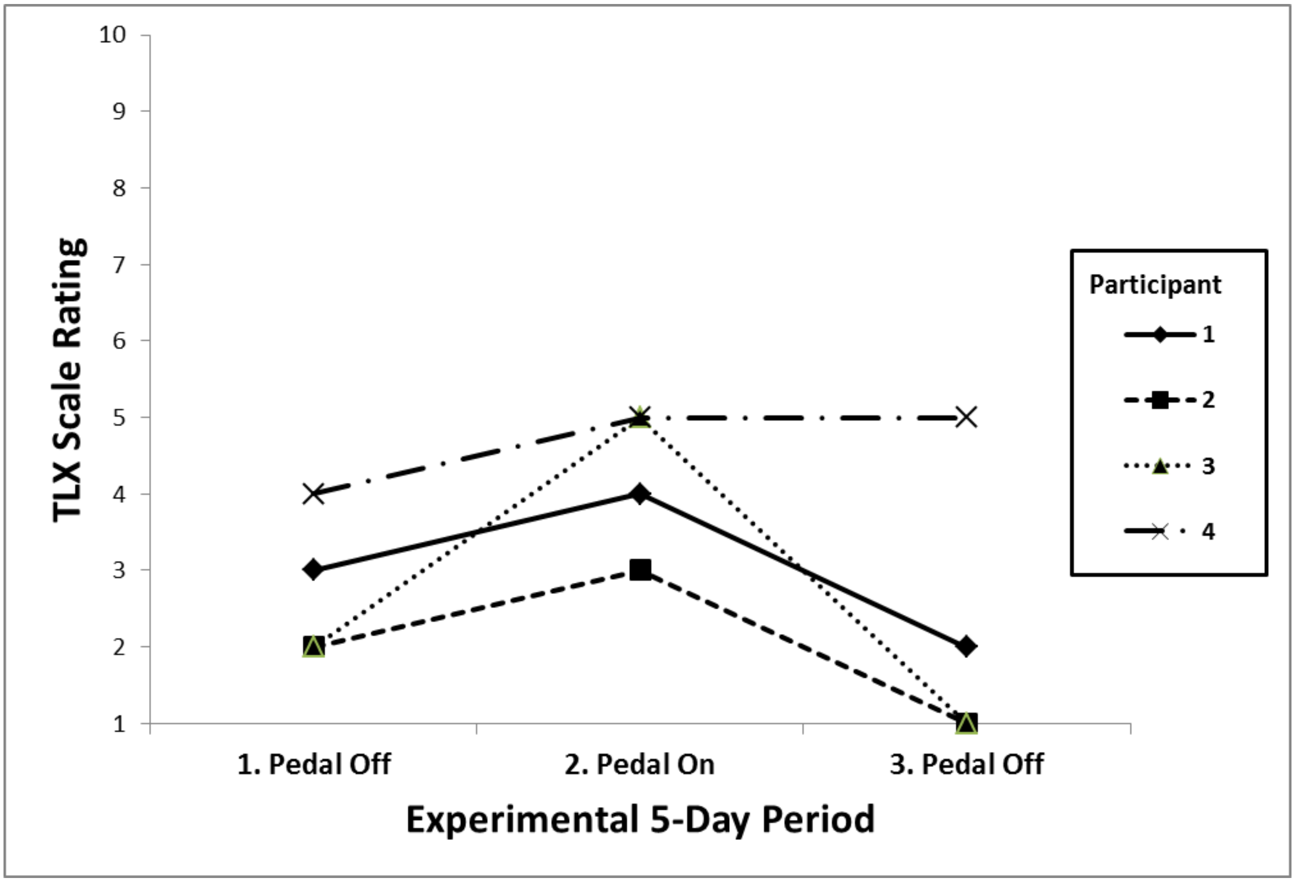

Figure 3. TLX Mental Demand

Physical demand was the topic of the second TLX scale (Figure 4). All 4 participants rated an increase in physical demand with the pedal on as might be expected. All 4 also noted a reduction in the physical demand from the peak in the third period with the pedal again off.

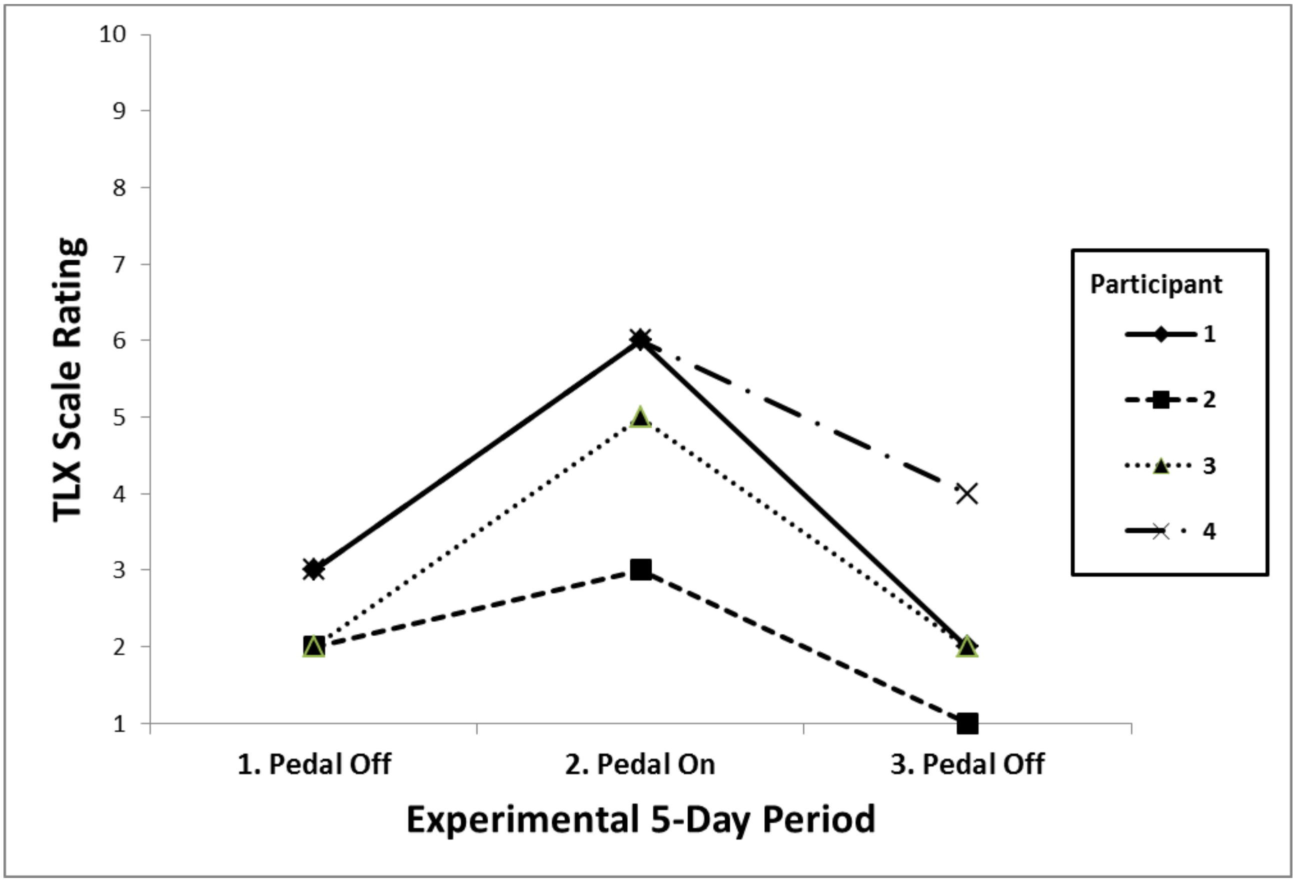

Figure 4. TLX Physical Demand

TLX scale 3 covered temporal demand and time pressure (Figure 5). Participants 2 and 3 scored increased temporal demand with the pedal on that diminished after the AAP was turned off. Participant 1 rated no higher temporal demand with the pedal on, but did rate this scale lower in the third period. Participant 4 rated increased time pressure in each successive data collection period. As the final participant, Participant 4 may have sensed that the project faced a completion deadline and translated that into a feeling of increased pressure.

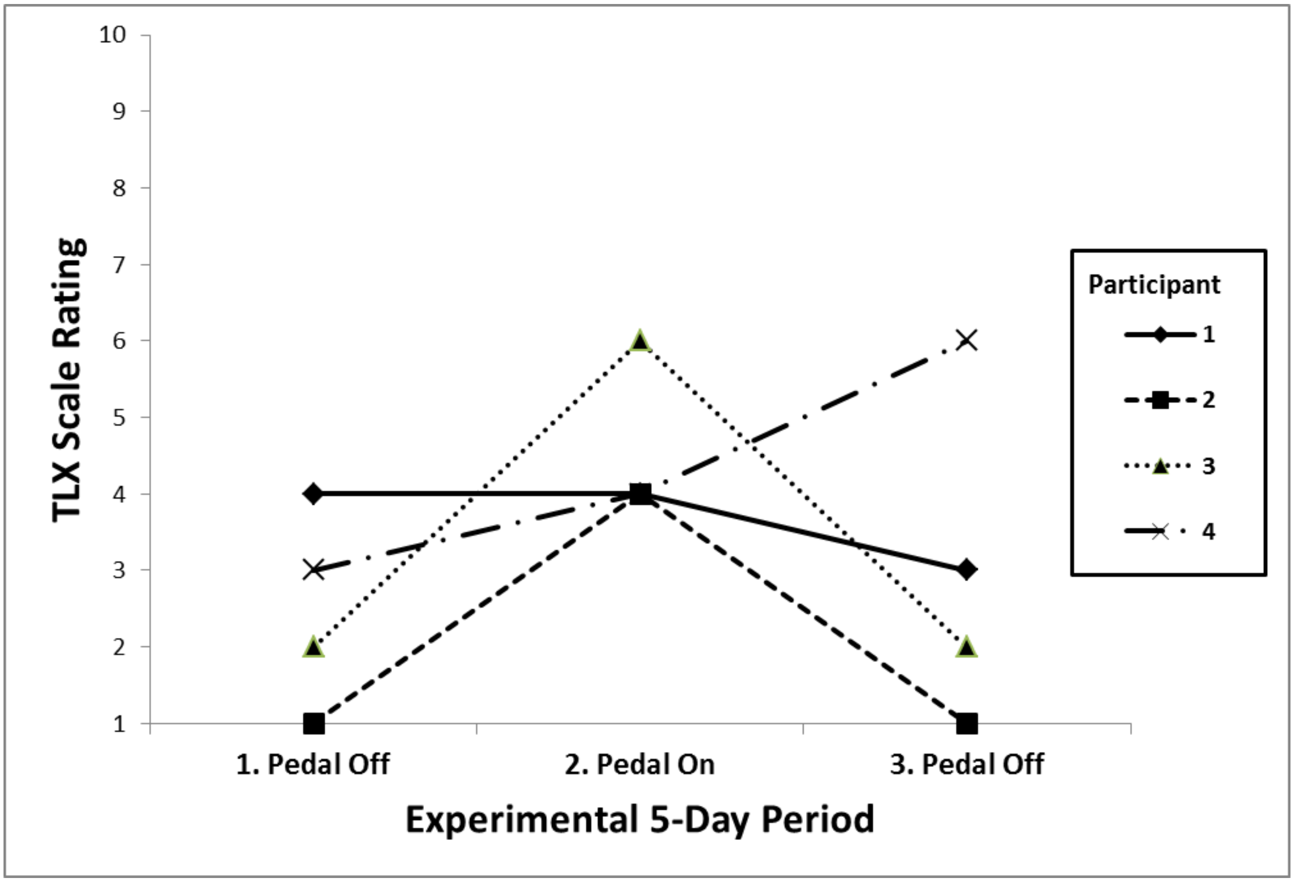

Figure 5. TLX Temporal Demand

Figure 6 shows the ratings on the fourth TLX scale that covered a self-assessment of personal performance in accomplishing goals. Only Participant 1 rated a decline in performance with the pedal activated. The other 3 participants rated their own performance uniformly high. The rating of Participant 1 is consistent with his speed results presented earlier and could suggest that he believed he had not achieved a personal goal of speeding at will in spite of the AAP.

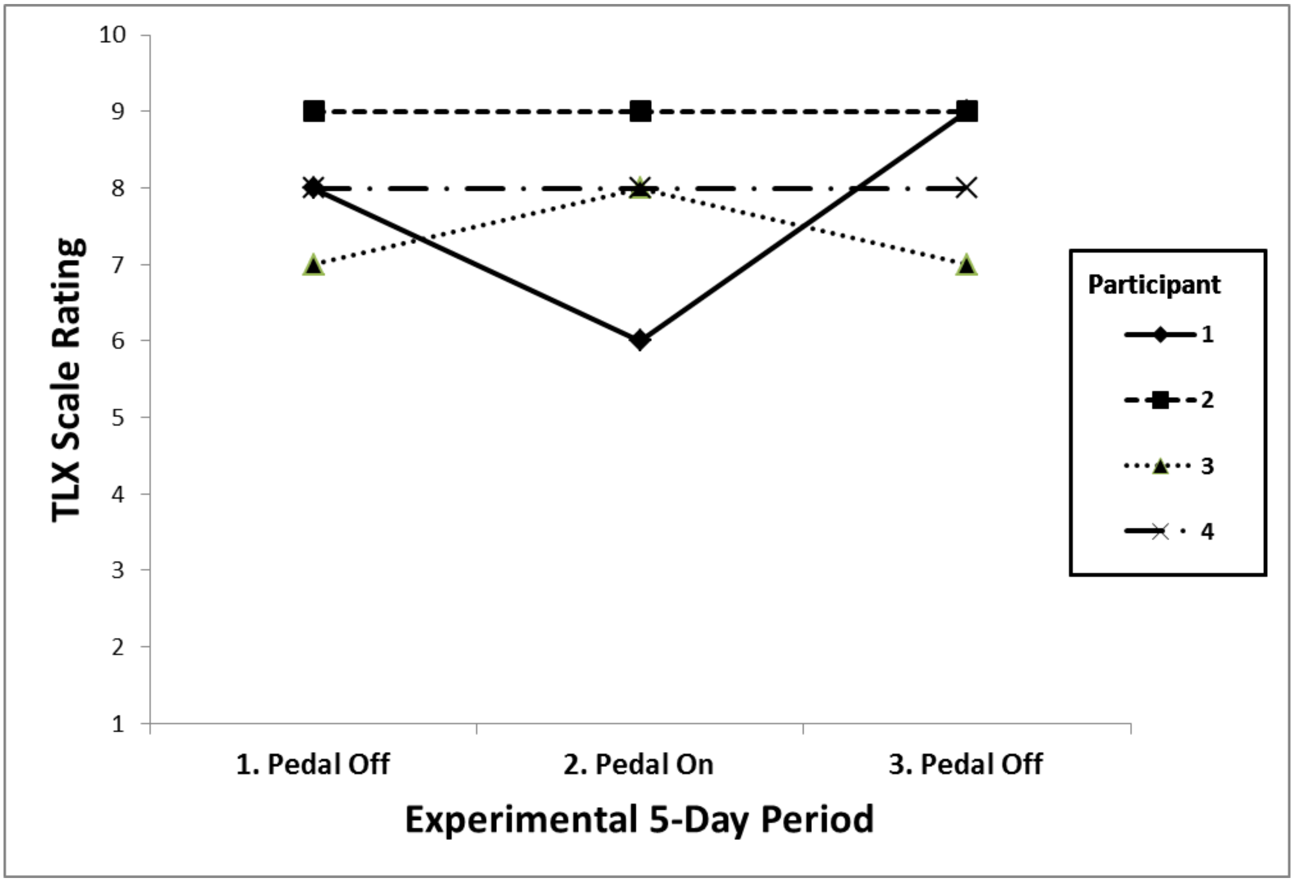

Figure 6. TLX Performance

Although some difference existed in the absolute rating level, all 4 participants rated higher effort with the pedal system engaged (Figure 7). Again, Participant 4 represented the outlier with the highest effort ratings.

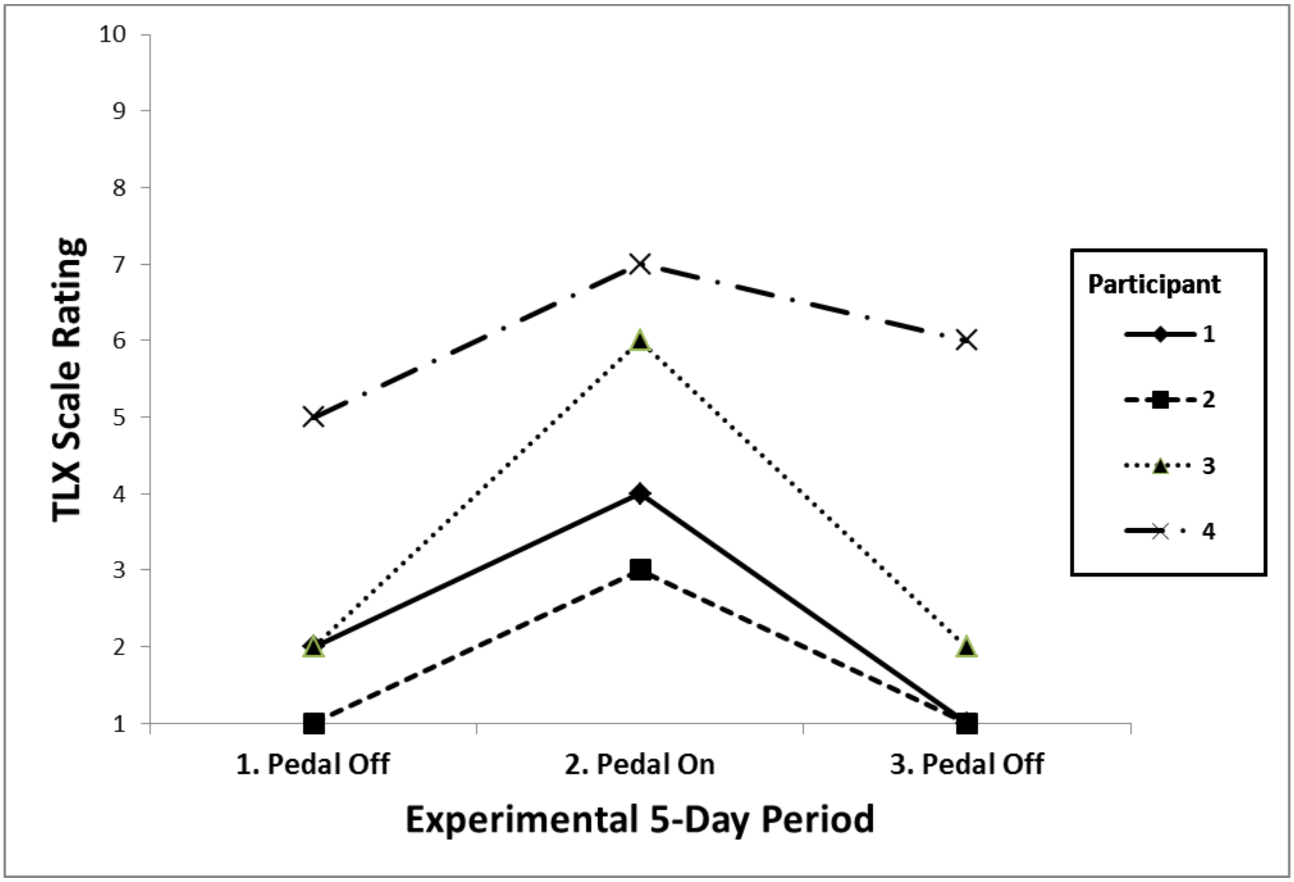

Figure 7. TLX Effort

All of the participants except Participant 1 rated decreased frustration in Period 2 with the AAP on (Figure 8). They also rated relatively high frustration levels throughout. Participant 1 rated notably lower frustration ratings than the other participants in all 3 periods and showed an increase with the pedal on. This pattern suggests that Participant 1 may have been actively attempting to speed with the AAP on and, although successful as shown by the speed results above, still had to “fight” the system to achieve his aims.

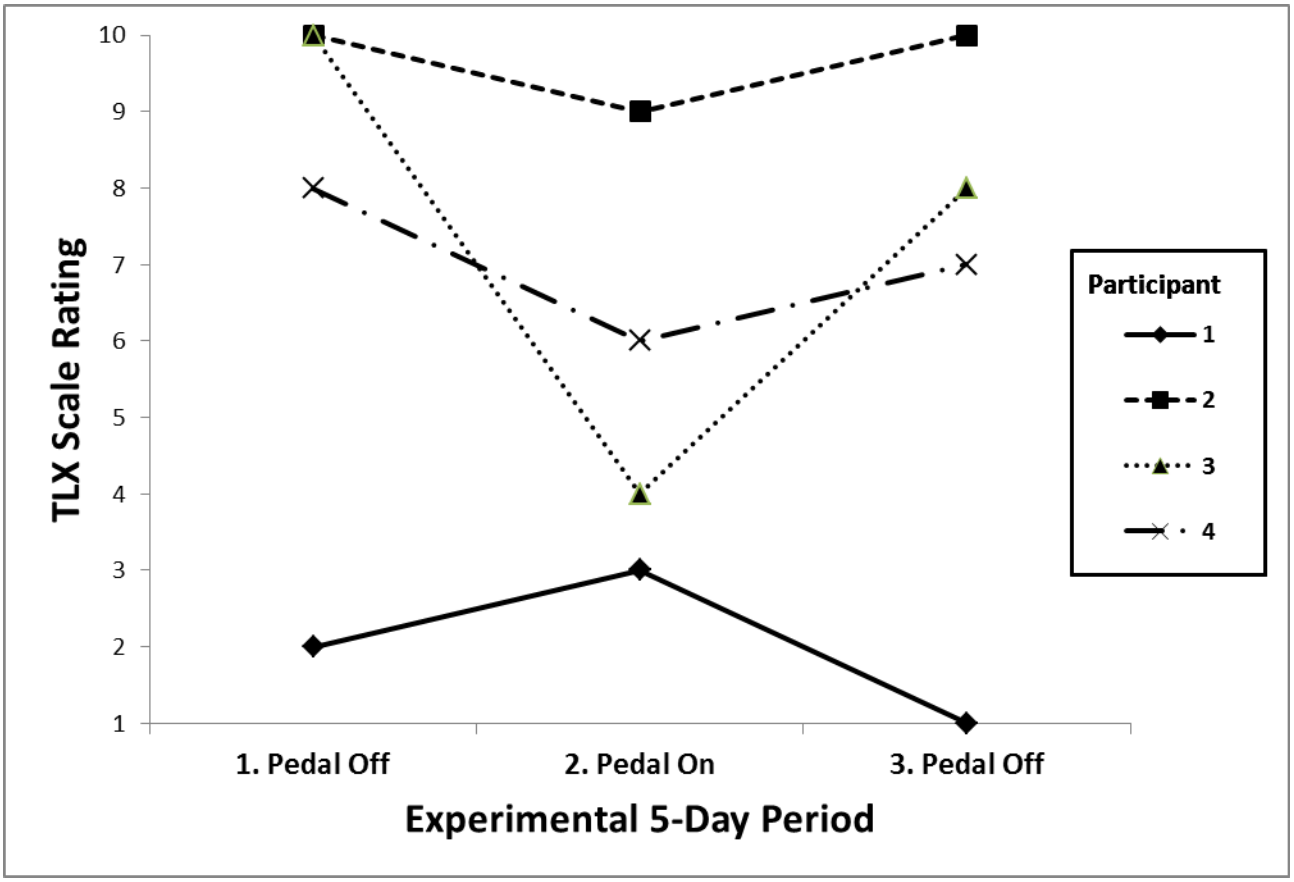

Figure 8. TLX Frustration Level

Debriefing. Researchers debriefed each of the 4 participants following the third data collection period using the same topic list as applied to the fixed drive participants. Table 12 displays the results for each participant and provides some further insights into their observed performance.

Table 12. Free Drive Participant Debriefing

Question	Participant 1	Participant 2	Participant 3	Participant 4
How effective was the pedal system in getting you to stay within the speed limit?	Somewhat ineffective	Somewhat effective	Very effective	Somewhat effective
Did you try to find a way to bypass the pedal system?	No	No	Yes, I would try to work the gears to get a "bump" of speed, mostly on the highway.	Yes, I pressed harder.
Did driving with the pedal system make you more aware of speed limit changes ?	Yes	Yes	Yes	Yes
Did driving with the pedal system cause a distraction?	No	No	Yes	No
Did driving with the pedal system make you feel less safe?	No	No	No	No
Did driving with the pedal system make you feel more safe?	No	Yes	No	Yes
Did driving with the pedal system make you more aware of the speed of other drivers?	Yes	Yes	Yes	Yes
Would you be in favor of putting the pedal system in all vehicles if it reduced insurance rates? Why?	Yes, money.	Yes, for money.	Yes, insurance is expensive.	Yes, I would like lower rates and for safety.
What aspect of the system did you like best?	It would show you (me) how much I actually sped.	Nothing.	I didn't like it.	Made me more aware of speed limits.
What aspect of the system did you dislike most?	On the highway fighting the system to speed up.	Around Western in the 25MPH zone.	I would like it if it came in slow when speeding, I didn't like the smack.	It didn't let me speed.

Only Participant 1 thought the AAP was not at least somewhat effective, and he exhibited the most speeding behavior. Two participants (3 and 4) admitted to trying to bypass the AAP. All four indicated that the AAP made them more aware of speed limit changes and more aware of the speed of other drivers. These thoughts were consistent with those of the participants in the fixed drive data collection.

Only Participant 3 felt the AAP caused a distraction. Nobody indicated that the AAP made them feel *less* safe. The participants split evenly on whether the pedal system made them feel *more* safe. As with many of the fixed drive participants, all of those in the free drive indicated they would favor putting an AAP in all vehicles if it saved money on insurance.

Two of the participants liked nothing about the system. The other two appreciated getting greater awareness of speed. The main participant dislike of the AAP was that it did not allow them to speed, especially in areas in which speeding generally was the norm (e.g., on the campus ring road). Participant 3 mentioned that he did not like the initial "slap" the system utilized to cue the driver when first exceeding the speed limit.

Trust and acceptance ratings. The 4 participants completed the same trust and acceptance scales described above for the fixed route drive study. Their individual ratings on the 10-point scale are shown in Table 13 below in the same order as they were shown previously in Table 10. Researchers could not conduct a factor analysis on these ratings similar to that performed for the fixed drive participants because of the small sample size. A rating of 1 indicated complete disagreement and a rating of 10 indicated complete agreement with the statement. In general, the participants agreed the pedal was predictable, trustworthy, acceptable, annoying, and accurate. There were some differences on ratings of reliable, pleasing, and agreeable. The biggest differences were for ratings of pleasing with Participants 1 and 3 disagreeing that the pedal was pleasing while Participants 2 and 4 somewhat agreed that the pedal was pleasing.

Table 13. Trust and Acceptance

Scale	Participant 1	Participant 2	Participant 3	Participant 4
Pedal was ***Predictable***	7	10	10	8
Pedal was ***Trustworthy***	7	10	7	7
Pedal was ***Acceptable***	6	9	6	8
Pedal was ***Accurate***	6	9	10	9
Pedal was ***Reliable***	5	8	5	8
Pedal was ***Pleasing***	2	6	1	6
Pedal was ***Annoying***	8	8	10	9
Pedal was ***Agreeable***	4	8	5	8

Note: Each scale ranged from Disagree (value 1) to Agree (value 10).

Discussion

The results of this study led to the findings discussed below. When interpreting these findings, the reader must consider the limitations inherent in the current approach.

Findings

The first part of this study focused on the development of an AAP that could be tested with a population of 18 to 24 year old drivers. Initial attempts to modify a previous pedal system used to prompt drivers to buckle their seat belt proved unsuccessful. The major stumbling blocks included the need for a physically stronger pedal than the OEM version and the requirement for much higher duty cycles since speed changes much more dynamically than does seat belt use. The researchers' use of an FMEA and the application of rigorous safety criteria highlighted the need to revise the pedal design and to develop a more robust system for the study's data collection. These steps constituted an important part of the development process.

The pedal that resulted from the development effort performed as intended and generated the desired resistance when participants attempted to speed. Researchers employed two data collection methods—a fixed, 6-segment drive and a 15-day free use of a pedal-equipped car—to assess pedal effectiveness. Measures included speeding behavior, participant judgment of their own mental and physical workload, a debriefing on impressions, and a set of trust and acceptance ratings. In general, the results were consistent with those found previously in Europe (e.g., Hjalmdahl & Varhelyi, 2004; Biding & Lind, 2002) even though the present study only included 18 to 24 year old participants.

The activation of the AAP produced a marked speed reduction in many but not all of the participants in both the fixed and free drives. In the fixed drive, experimental participants drove slower on their afternoon runs with the AAP on than they had driven in the morning with the pedal off. Control participants, who drove morning and afternoon with the normal OEM pedal, tended to speed up in the afternoon, likely due to greater familiarity with the route and the test car. The significant treatment by drive effect for all segments except one (on which virtually nobody sped due to congestion and the density of traffic signals) strongly suggested that the pedal worked as intended. The ANOVA analysis took into consideration the fact that experimental participants drove significantly slower than controls in the morning when both groups had the pedal off. This difference was unexpected since researchers randomly assigned participants to experimental group, and the morning TLX scores for the two groups did not differ significantly. The extra safety briefing received by the experimental participants concerning the emergency cutoff switch represents a possible explanation for the morning difference. This briefing may have instilled a greater sense of caution in the experimental group at the outset before they actually drove the study-equipped car with the AAP off and discovered it behaved normally.

The free drives involved using a test car for an initial period of 5 days with the AAP off followed by 5 days with it on and a final 5 day period with it again off. For two of the participants, activation of the AAP reduced speeding of any magnitude. For a third participant, the AAP did not eliminate low exceedance of the speed limit (less than 5 mph) but did sharply reduce driving more than 5 mph over the limit. The fourth participant displayed aberrant behavior that involved increased speeding with the AAP on. Based on the post-drive subjective data provided by this participant, researchers concluded that he likely made a deliberate attempt to defeat the AAP system.

As found previously in the studies by Hjalmdahl & Varhelyi (2004) and Regan et al. (2007), any reduced speeding during the period with the AAP active did not persist in the third 5-day period with the AAP turned off. Although only based on a short time, this finding is consistent with previous conclusions by Hjalmdahl & Varhelyi (2004) and others that an AAP is likely to act more as a governor than as an agent for long-term behavioral change. Therefore, an AAP's effectiveness likely depends on its widespread or even universal deployment.

The workload scores, debriefing, and trust and acceptance data only indicated support for the widespread application of an AAP of the type tested if the user received some economic benefit (e.g., a reduction in insurance premiums). Participants generally indicated increased mental and physical taskload with the AAP on and some increase in frustration level. These increases, however, were not extreme.

Many participants appreciated the increased awareness of the speed limit provided by the onset of pedal force. Several specifically expressed that the pedal system could save them from getting a speeding ticket when they entered a lower speed zone. On the other hand, virtually every participant disliked driving slower than the stream of traffic and the negative reactions of other motorists (e.g., tailgating). Adell and Várhelyi (2008) found very similar results in Europe among a wider age range of drivers.

Overall, this study supports the basic potential of an AAP as a countermeasure for speeding. A fully operational system will, however, require additional development and testing. It would be beneficial to have future efforts that examine the best system specifications for the full range of driver ages and include a specific look at whether an activation threshold for an AAP at some higher level above the speed limit (e.g., 5 mph rather than the 1 mph used herein) would produce better compliance and satisfaction. A study that permitted participants to use an AAP-equipped car for a longer period might also shed additional light on the ability of an AAP to produce long-term modification of speeding behavior.

The problems associated with the introduction of an AAP into the vehicle population remain thorny and may even prove intractable. A mixed fleet of vehicles equipped and not equipped with an AAP could create speed differentials that might compromise safety and, based on the findings of this and other research, would certainly generate a negative reaction from the motoring public. Therefore, it would be beneficial to have more research to examine innovative alternatives for introducing an AAP.

Finally, the finding that many participants appreciated the speed limit cueing inherent in the studied AAP suggests that productive future research could focus on the use of haptic speed limit cueing. Even without the added force of an AAP, haptic cueing through the accelerator pedal (e.g., a slap, vibration) might serve to moderate speed.

Limitations

This study focused only on 18 to 24 year old drivers because of their high involvement in speed-related crashes. The reader should remember, however, that Adell and Várhelyi (2008) found this age group to be more resistant to an AAP than were older drivers. Also, the participants in this study all came from the ranks of university students with at least a basic awareness of the study's purpose. As such, they represented only one segment of the total possible user population for an AAP—a homogeneous, educated subset of younger drivers. Caution must therefore be exercised when generalizing these results to other age and demographic groups. The consistency of the reactions of the present participants to those reported from studies in Europe using broader participant populations does, however, provide some suggestion that the present findings might apply beyond the specific participant pool used.

The suggestion from the speed results that one or more participants might have tried to override the system by purposely holding the force in spite of the discomfort caused by the increased pedal resistance is also noteworthy. It could mean that at least some of the participants altered their normal behavior during their involvement in the study.

The limited length of the exposure of the participants to the AAP may also have influenced the findings and possibly biased the results against showing the system in its best light. Fixed drive participants only drove with the pedal on a single day for approximately 2 hours or less. Only 4 participants took part in the free drive, and the active pedal period for that phase of the data collection only lasted 5 days for each participant. The possibility exists that participants were still exploring the characteristics of the pedal at the close of their data collection periods and therefore had not settled into steady-state use behaviors. The pattern of results certainly suggests the exploration of the system's characteristics by at least some of the participants.

These limitations neither invalidate the basic finding of the potential effectiveness of an AAP of the type tested nor the validity of the identified impediments to the widespread deployment of an AAP. Rather, they establish goals for future research that could beneficially broaden the participant populations, improve AAP or haptic feedback designs, and examine ways to counter the various design and implementation issues identified.

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