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RESEARCH IN BRIEF

Effects of Electronic Stability Control on J and Bootleg Turns

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Between 2005 and 2014 over 400 law enforcement officers lost their lives to automobile crashes. This ranked second only to firearms related fatalities as a leading cause of death for police and other law enforcement officials (National Law Enforcement Officers Memorial Fund). Police leaders have increasingly utilized policy and training to help reduce the likelihood of these tragic events. Additionally, calls for research into the impact of technology have increased (IACP, 2011). However, these calls have been primarily directed at how technology in vehicles poses a risk either as a distraction or due to how the equipment inside the vehicle is configured (IACP, 2011).

While this line of research is admirable, it neglects the potential impact of how automobile safety innovations might impact police vehicle operations (PVO). Innovations, such as Electronic Stability Control (ESC), can prove beneficial under normal driving conditions. However, police vehicle operations frequently occur outside the range of what might be described as "normal driving conditions". This article is part of a series of research briefs being written by the Portland Police Bureau on how vehicle safety innovations may be impacting police driving techniques.

Electronic Stability Control systems were first introduced in the mid-1990s. They are characterized by the use of sensors and a computer system to assist drivers when they over or under-steer. This is accomplished by using the vehicle's other safety features, such as anti-lock brakes or traction control, to correct driving patterns perceived by the computer as "mistakes".

A primary component of ESC is the yaw control sensor[1]. Located near the middle of the car this sensor detects movement around the z-axis of the vehicle. Theoretically this feature may impact different PVO maneuvers.

A previous article in this series addresses the potential impact of ESC on Pursuit Intervention Techniques (PIT)[2]. This article is focused on the

[1] According to the Federal Motor Vehicle Safety Standard (FMVSS 126) the sine and dwell test for ESC is where a vehicle travels 50 mph into the exercise with a 30 degree input in steering and after one second the yaw rate should not increase 35 degrees more than the initial peak yaw and after 1.75 seconds the yaw rate should not increase 20 degrees more than the initial peak yaw rate. More information can be obtained from the National Highway Traffic Safety Administration's 49 CFR Parts 571 and 585 report, which can be found at http://www.nhtsa.gov/Laws+&+Regulations/Electronic+Stability+Control+(ESC).

[2] See: *https://www.portlandoregon.gov/police/article/560078* for the PPB's research brief on the impact of ESC on the PIT maneuver.

About this study

As electronic stability control systems (ESC) have been developing, questions have emerged among researchers and practitioners of law enforcement regarding the impact of these technologies on police vehicle operations.

The Portland Police Bureau began contributing to this research in 2015 with a study on the effects of ESC on the pursuit intervention technique. This study continues to explore the impacts of ESC on police vehicle operations, by examining the effects on the J-turn and bootleg turn maneuvers. The key personnel for this study were:

Officer Tracy Burleson, Principal Investigator, Portland Police Bureau; Sergeant Greg Stewart, Analyst, Portland Police Bureau; Lieutenant Jeff Bell, Portland Police Bureau; Mark Rose, Videographer, Portland Police Bureau; Emily Covelli, Analyst, Portland Police Bureau; Officer Josh Howery, Portland Police Bureau

The results of this study are available for review and are not intended as a policy statement nor are they a recommendation for agencies to adopt, revise, or remove tactics from their operational policies.

Agencies are encouraged to review the findings in light of their mission and jurisdiction.

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potential impact of ESC on evasive driving maneuvers such as a J-turn (a 180° turn performed when the vehicle travels in reverse) or a bootleg turn (a 180° turn performed when the car is traveling forward).

Methodology – J-turn

The vehicles used for the J-turn testing were a 2006 Ford Crown Victoria Police Interceptor (CVPI), 2007 and 2011 Dodge Police Charger, 2011 and 2013 Chevrolet Caprice Police Patrol Vehicles (PPV), and a 2015 Ford Police Interceptor Utility. These are cars currently utilized by the PPB.

With the exception of the 2006 Ford CVPI, all of these vehicles were equipped with their manufacturer's ESC system. All the ESC systems were confirmed operational prior to testing. Each vehicle was driven through the J-turn maneuver, mostly by the same driver, on the same surface, and under dry conditions. The coefficient of friction for the surface was .75 measured by the Portland Police Bureau's Traffic Division.

The J-turns were performed at a target speed of 25 to 35 mph. Speeds above 35 mph may cause the vehicle to over-rotate, negating the benefit of the technique (to quickly reverse the direction the vehicle is facing).

The driving technique for each J-turn test was to drive straight back in reverse until the vehicle reached the target speed then come off the gas. After coming off the gas the driver quickly inputs the steering. The vehicle was placed into drive as it approached a 180° turn and the driver attempted to accelerate out of the turn (ESC permitting).

Ten successful runs[3] were performed using each of the five vehicles (50 runs total). The driver reported that all the runs with the exception of run number seven, using the 2011 Dodge Charger, were performed as intended. Run seven with the 2011 Dodge was successful, however the driver reported that he did not do a good job of inputting steering and this impacted the rotation of the vehicle. It has been retained for the graphs (it can be seen in Figure 1) but excluded as an outlier from tables examining means and absolute deviation[4]. To remain consistent run seven is excluded for all the vehicles when calculating means and absolute deviation.

Each vehicle's performance was measured with Racelogic's Vbox Mini, supplied with internal yaw rate sensor and accurate 10Hz GPS engine. The vehicle's speed, yaw rate, lateral acceleration, longitudinal acceleration, distance, time, slip angle and total degrees of rotation were obtained during each J-turn. Racelogic's Vbox Tools and Circuit Tools software was used to analyze the data.

This sensor, along with the driver's qualitative perception (or feel) of the driving experience, are used to determine the findings of this report.

The measures provided for the J-turn include:

- The maximum lateral G force induced by the turn
- The yaw rate in degrees per second
- The time of rotation in seconds
- The total degree of rotation achieved

Qualitative Findings – J-turn

According to the Federal Motor Vehicle Safety Standard (FMVSS 126) Electronic Stability Control (ESC) is not active in reverse. Therefore, the presence of ESC should not impact the vehicles for the first portion of the turn. As the vehicle passes 135 degrees the ESC may activate as the vehicle would be moving "forward" at that point.

As expected, when conducting the J-turn tests the vehicles encountered no ESC correction while driving in reverse. Once the steering was input, beginning the J-turn maneuver, the driver reported that all the vehicles spun in a consistent manner. However, after approximately 135 degrees of rotation the ESC activation became noticeable. ESC intervened by correcting the yaw and delaying the throttle until the vehicle was laterally stable. The brief delay felt slightly different for each vehicle.

The driver reported a significant delay when accelerating forward after the rotation with the 2007 and 2011 Dodge Charger and the 2011 and 2013 Chevy Caprice. There was no delay in accelerating with the 2006 Ford CVPI and very little to none with the 2015 Ford Utility Interceptor.

The driver attempted to use the same amount of steering in each maneuver. This was not always possible and it was found there was better vehicle rotation with a 360 degree turn of the steering wheel. Also, the smoother the technique or driver inputs during the J-turn maneuver, the less the effects of ESC were felt and the quicker the throttle was able to activate, allowing the vehicle to drive away.

The driver also reported that the 2011 Dodge Charger and 2013 Chevy Caprice PPV stalled after the rotation of the J-turn maneuver 25 percent of the time[5]. A similar trend

[3] Defined as completing the J-turn and being able to accelerate out of the turn without stalling.

[4] The absolute deviation for this analysis is calculated from the mean. It is a summary statistic for variability and allows the reader to gain a sense of how consistent the measurements were to each other. A larger absolute deviation would indicate greater differences in how the same vehicle performed on each test.

[5] These runs were not included in the data as they were not complete.

was noticed during an examination of the effects of ESC on the PIT maneuver[6]. PIT maneuvers performed at speeds in excess of 35 mph appeared to be associated with vehicle stalls.

Quantitative Findings – J-turn

Table 1 displays the average (mean) lateral G forces, yaw, time and total rotation[7] for each of the vehicles tested. The Vbox findings are inconclusive. On average the ESC equipped vehicles exhibited slightly less yaw, with the greatest difference found among the newest vehicles in the study. This is consistent with the driver's impression that the ESC was activating when the vehicle's rotation passed 135 degrees and began to roll forward. However, this was not universal across all the vehicles, as the 2011 Dodge Charger's (ESC equipped) yaw exceeded that of the Ford CVPI (no ESC).

The findings pertaining to lateral G, time, and rotation were also inconclusive. The lateral G measures were similar to higher in the ESC equipped vehicles compared to the non-ESC vehicle, with the greatest difference found among the newer vehicles. No notable differences were found among the time and total rotation measures. Running additional trials would potentially allow for more statistical analysis to help gauge the impact of the inherent variability of each attempt. However, given the impact of ESC is not readily apparent in nine trials the practical significance of this effect during J-turns with these vehicles is likely minimal, particularly for the time and total rotation measures.

Figure 1 displays the actual yaw of each run (including run seven):

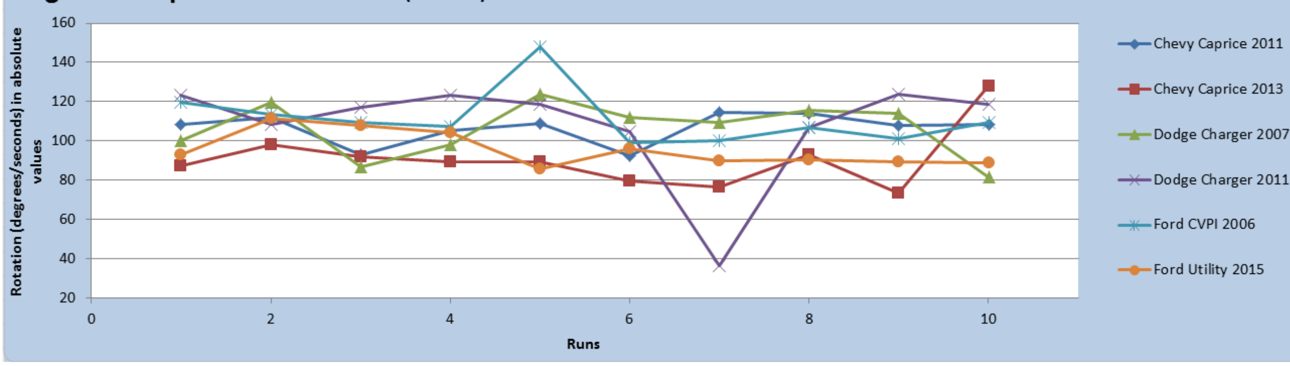
Figure 1 demonstrates that the bulk of the reduction in yaw is found in the performance of the 2013 Caprice and the 2015 Ford Utility, the newest vehicles in the study. The variability of the runs makes it difficult to draw definitive conclusions. However, it is possible a greater reduction in yaw will be found in vehicles of certain timeframes as the ESC settings have varied among make, model, and year of vehicles.

Table 1. Impact of Electronic Stability Control: J-Turn[1]

		Lateral G		Yaw		Time[2]		Rotation[3]	
	ESC	Mean	Abs. Dev.	Mean	Abs. Dev.	Mean	Abs. Dev.	Mean	Abs. Dev.
Chevy Caprice 2011	Yes	1.13	0.18	105.60	5.75	3.26	0.11	210.94	3.40
Chevy Caprice 2013	Yes	1.30	0.17	92.18	9.34	2.98	0.24	191.16	5.11
Dodge Charger 2007	Yes	1.18	0.21	105.79	12.47	2.84	0.30	196.90	6.16
Dodge Charger 2011	Yes	1.14	0.23	116.13	6.34	2.50	0.12	195.13	2.90
Ford Utility 2015	Yes	1.27	0.23	96.30	7.68	2.99	0.14	191.26	3.56
Ford CVPI 2006	No	1.13	0.17	112.77	9.61	2.92	0.29	196.88	3.14
Average ESC	Yes	1.20	0.20	103.20	8.32	2.91	0.18	197.08	4.23

[1] Excludes Run #7 ; [2] Time in Seconds ; [3] Rotation in Degrees

Figure 1: Impact of ESC on Yaw (rotation): J-Turn



[6] See: *https://www.portlandoregon.gov/police/index.cfm?&a=560078*

[7] The rotation was calculated by the sum of the yaw measurement (degrees per second) divided by 10 using the VBOX Processing Tool Software (∑ = total yaw deg/sec ÷ 10).

Overall Findings – J-turn

Overall, the presence or absence of ESC was difficult to detect in the data. This was not entirely unexpected given ESC is not designed to activate during reverse driving, which is a good proportion of the J-turn maneuver. The ESC software in the 2015 Ford Interceptor Utility has also been configured by the manufacturer to ensure performance of the J-turn[8].

The yaw did appear to be less in the 2015 Ford Utility and the 2013 Chevy Caprice. In addition, several runs of the 2013 Caprice were not included as the stalls prevented a successful J-turn. Variation in the inputs by the driver appeared to be at least as significant as the presence of ESC. Figures two through four display the lateral G force, time and rotation of the vehicles (see Appendix).

A visual inspection of these graphs does not show a noticeable difference between the vehicles equipped with ESC and the non-ESC equipped vehicle. There does not appear to be a consistent trend in these graphs with the possible exception of the 2011 Caprice, which overall had a more consistently higher total rotation compared to the other vehicles.

Another potentially important finding was the vehicle stalls. While only a limited number of runs were made with each vehicle, both the 2011 Dodge Charger and 2013 Chevy Caprice PPV stalled. These stalls are worth noting and may be valuable to explore further.

Methodology – Bootleg Turn

The vehicles used for the bootleg turn testing were a 2006 Ford Crown Victoria Police Interceptor, 2007 Dodge Police Charger, 2011 and 2013 Chevy Caprice Police Patrol Vehicle, and a 2015 Ford Police Interceptor Utility. The 2011 Dodge Police Charger was not used in this test, due to being unavailable at the time of testing.

With the exception of the 2006 Ford CVPI, all of the vehicles were equipped with their manufacturer's ESC system. All the ESC systems were confirmed operational prior to testing. Each vehicle was driven through the bootleg turn maneuver by the same driver, on the same surface, and under dry conditions. The coefficient of friction for the surface was .75 measured by the Portland Police Bureau's Traffic Division.

The speeds for performing the bootleg turns were targeted at 35 mph. The technique for each bootleg turn was to drive straight forward until the vehicle reached 35 mph then the parking brake was applied. This engaged the rear braking system of the vehicle and caused the rear wheels to skid. Once this occurred, a three-quarter turn of steering was input to the left and the rear end of the vehicle slid around rotating the vehicle. The goal was for this maneuver to rotate the vehicle 180 degrees and drive away. When the vehicle rotated around, the parking brake was released and the driver accelerated away. Five measured bootleg turns were completed with each vehicle in the test.

Each vehicle's performance was measured with the Racelogic VBOX Mini obtaining the vehicle's speed, braking distance, ESC activation, yaw rate, lateral acceleration, longitudinal acceleration, distance, time, slip angle, and degrees of rotation for each run.

The measures provided for the bootleg turn include:

- The yaw
- The time of rotation in seconds
- The total degree of rotation achieved (with 180° being optimal)
- The time to ESC activation (only for those vehicles with ESC)

[8] *http://blog.caranddriver.com/the-redesigned-ford-police-interceptor-utility-is-here-to-haul-stuff-to-jail/; http://www.gizmag.com/ford-new-police-interceptor/36089/; http://code3.jalopnik.com/what-the-police-spec-2016-ford-explorer-has-that-your-m-1685166241*

Qualitative Findings – Bootleg Turn

The driver reported a delay when accelerating in drive after the rotation of the bootleg turn with the 2007 Dodge Charger and the 2011 and 2013 Chevy Caprice. This was similar to the delay seen in the J-turn test. There was no delay in accelerating with the 2006 Ford CVPI and a slight delay was noted with the 2015 Ford Interceptor Utility.

The driver reported that the 2015 Ford Interceptor Utility demonstrated less rear end slide than any other vehicle in the bootleg turn test. The driver noted some differences in feel between the other vehicles but was generally able to perform the maneuver equally well with both ESC and non-ESC equipped vehicles.

Quantitative Findings – Bootleg Turn

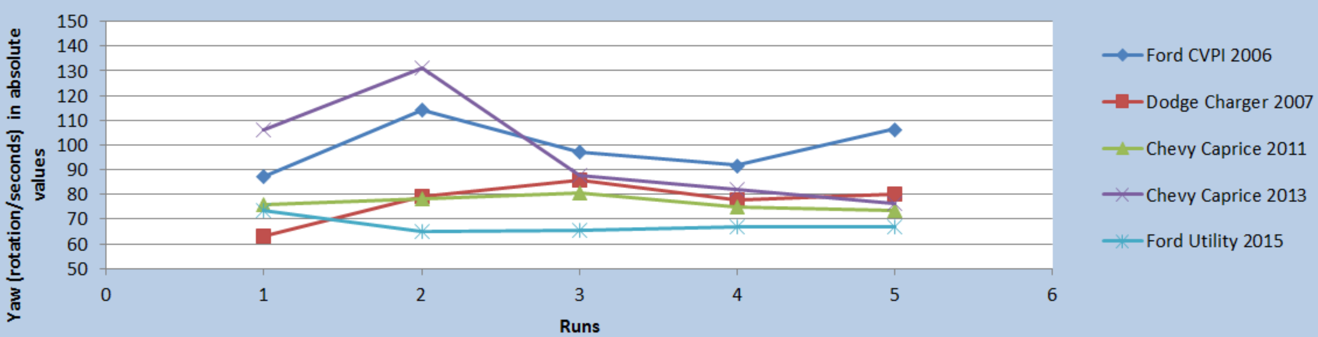
The findings from the data showed the 2015 Ford Interceptor Utility with the lowest average yaw rate measurement of 67.51 degrees/second (see Table 2 and Figure 5). However, this may be related to the difficulty of inducing rear-slide. Table 2 displays average yaw, time to ESC activation, time of rotation and degree of rotation.

Table 2. Impact of Electronic Stability Control: Bootleg Turn

		Yaw		Time[1] to ESC		Time[1] of Rotation		Rotation[2]	
	ESC	Mean	Abs. Dev.	Mean	Abs. Dev.	Mean	Abs. Dev.	Mean	Abs. Dev.
Chevy Caprice 2011	Yes	76.63	2.21	0.83	0.15	3.12	0.23	175.85	0.88
Chevy Caprice 2013	Yes	96.72	17.55	0.75	0.17	2.61	0.24	176.37	2.68
Dodge Charger 2007	Yes	77.17	5.63	0.63	0.05	2.30	0.49	178.96	6.00
Ford Utility 2015	Yes	67.51	2.46	0.80	0.12	4.64	0.67	177.56	1.39
Ford CVPI 2006	No	99.33	8.83	N/A	N/A	2.68	0.11	173.97	5.68
Average ESC	Yes	79.51	6.96	0.75	0.12	3.16	0.41	177.19	2.74

[1] Time in Seconds ; [2] Rotation in Degrees

Figure 5. Variation in Yaw (rotation): Bootleg Turn



As mentioned earlier, the driver reported difficulty inducing rear end slide. Subsequent data analysis revealed that on the four low yaw runs by the 2015 Ford Utility (runs two through five) displayed in figure five the longitudinal G force of the Ford Utility was markedly less than the other vehicles. Figure 6 displays these differences.

It is possible that the difficulty in inducing rear end slide was associated with inadequate longitudinal G force on runs two through five with the Ford Utility[9]. The ESC activation with all-wheel drive traction control made it difficult to decelerate rapidly enough to cause significant rear-end slide. This would be the product of braking and may have been related to the traction control impacting all four wheels as opposed to two. Given similar longitudinal G force the Ford Utility appears to be capable of turn lengths roughly comparable to the other vehicles (see Figure 7).

It was noted that on run one with the Ford Utility the G force is similar to the 2011 and 2013 Chevrolet runs, as well as having a comparable turn length. On that run the 2007 Dodge has a much lower G force (see Figure 6) and a much greater turn length.

The fact that the driver reported greater difficulty inducing rear end skid is demonstrated in these data but it also appears that the vehicle is capable of such braking. The reason for the difficulty cannot be determined from these data but is worth noting.

Figure 6. Longitudinal G Force: Bootleg Turn

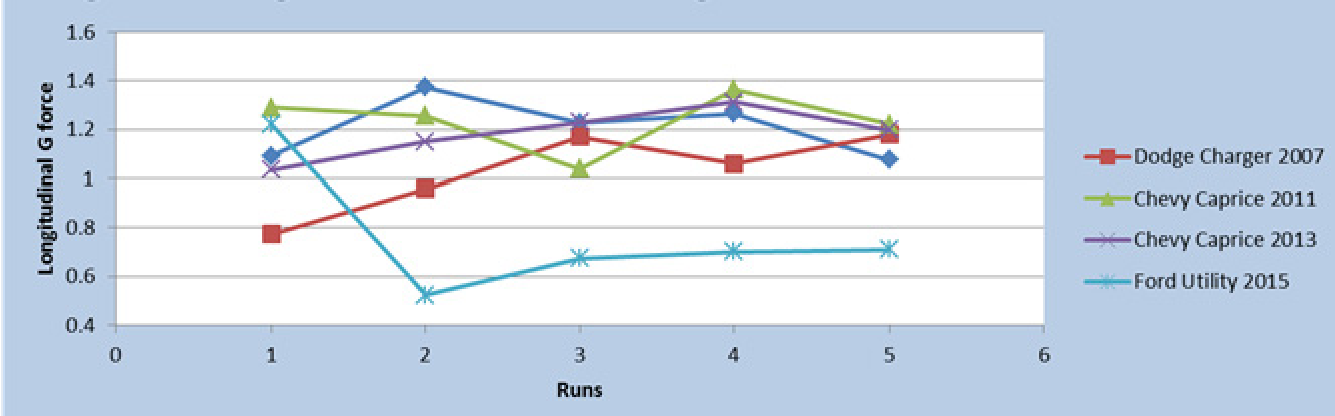
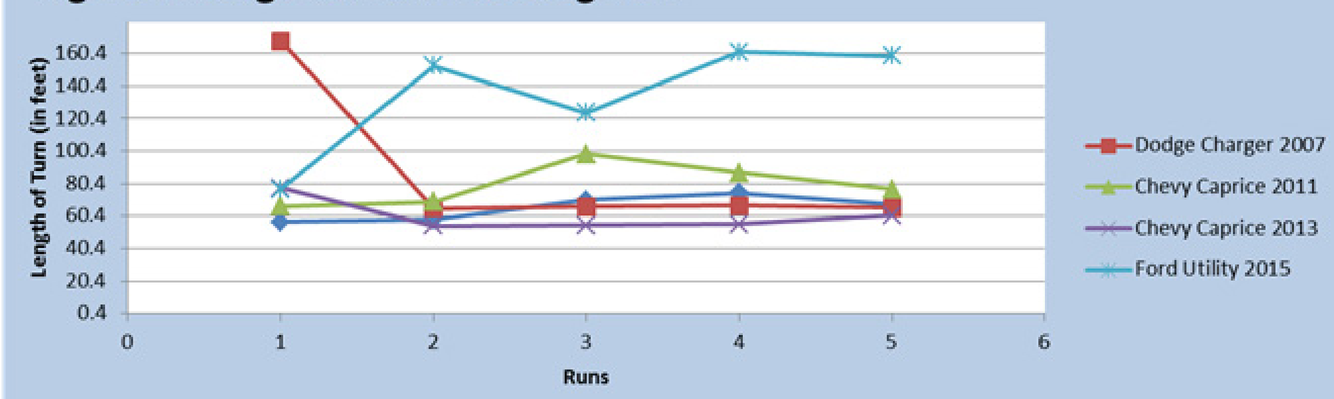


Figure 7. Length of Turn: Bootleg Turn



[9] The rotation was calculated by the sum of the yaw measurement (degrees per second) divided by 10 using the VBOX Processing Tool Software (Σ = total yaw deg/sec ÷ 10).

Overall Findings – Bootleg Turn

Based on both the drivers impression and the data available, it appears that ESC equipped vehicles are capable of bootleg turns. The Ford Utility has some differences from the other vehicles including being the heaviest and the only all-wheel drive vehicle which may be related to the difficulty in inducing rear-end slide. The clearance of the Ford Utility is 6.5" compared with 6" for the Ford Interceptor sedan. It drives like the sedan much more than expecting it to perform like a SUV.

Discussion

While there may be some differences in the performance of ESC equipped vehicles versus non-ESC equipped vehicles these tests provide evidence for, but do not prove, the hypothesis that variability in driving plays a larger role in the successful application of the J-turn and bootleg turn maneuvers than the presence of an ESC system. This document is not intended to influence PVO policy but does point toward other possible research.

Additional research into the relative impact of driver skill and how this may interact with ESC is warranted and may have valuable training implications. This study utilized a limited number of test runs with a skilled PVO instructor. Additional test runs to increase the sample size (allowing more definitive statistical analyses), as well as using drivers of varying skill levels, may prove informative. ■

Appendix

Figure 2. Impact of ESC on Lateral G Force: J-Turn

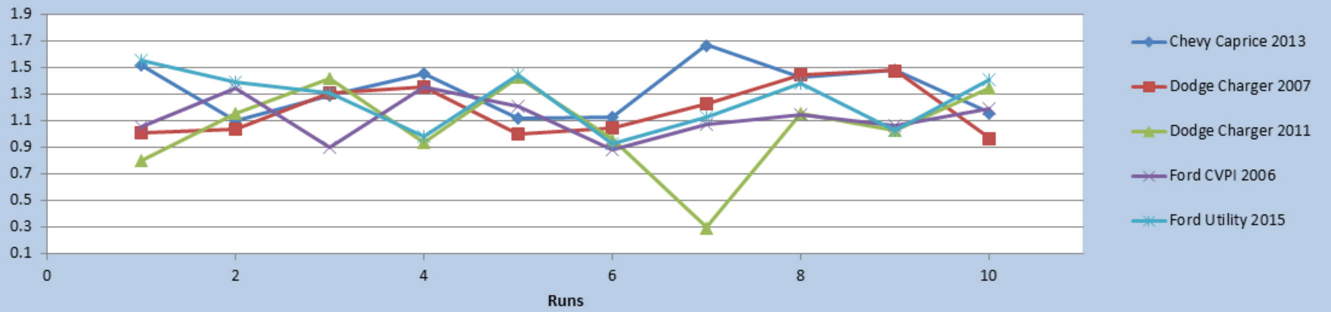


Figure 3. Impact of ESC on Time of Rotation: J-Turn

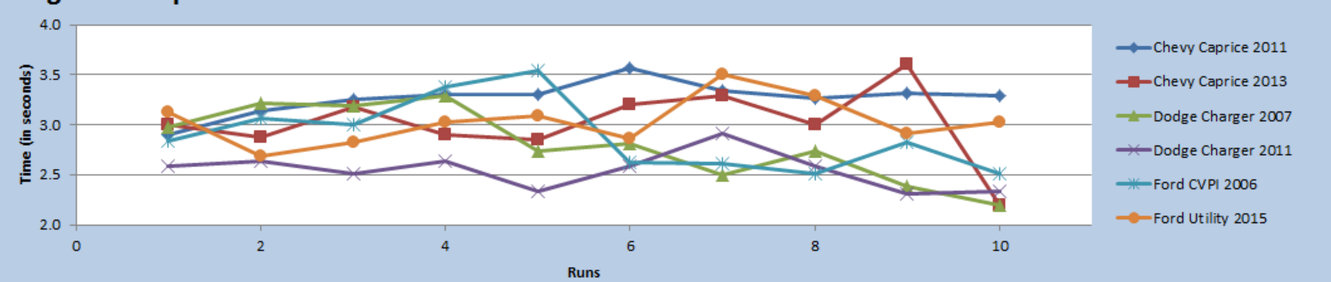


Figure 4. Impact of ESC on Rotation: J-Turn