P.J.D. Visser

MSc Thesis

The effect of engine sound and power-train enhancement on sportiness and driving behaviour

TU Delft

The effect of engine sound and power-train enhancement on sportiness and driving behaviour

A driving simulator study

by

P.J.D. Visser

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Preface

This thesis is the result of my research into perceived sportiness and driving behaviour resulting from engine sound and power-train enhancement. During my literature study, I found many techniques that supposedly increase the sportiness of a vehicle. However, studies that investigated an adaptable engine sound and adaptable pedal-to-throttle mapping did not investigate the resulting effect on the drivers' perceived sportiness and driving behaviour. Furthermore, it remains unknown how these adaptations, which intend to create the illusion of increased sportiness, relate to actually increasing the sportiness of a vehicle. In this study, we pioneer the investigation into the relative and combined effects of systems designed to alter a vehicle's perceived sportiness by conducting a human factors driving simulator experiment.

P.J.D. Visser
Rotterdam, February 2021

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I would like to thank Joost de Winter and Timo Melman for their supervision, enthusiastic guidance and support. Joost was always willing to read my material and was of great support during the determination of the details surrounding the experiment and the structure of the paper. At the same time, Timo motivated and challenged me to expand my ideas and analyses in order to produce a comprehensive study. In addition, I would like to extend my gratitude to Joris Giltay for his help with the design and development of the simulation and to everyone who participated in the experiments. Finally, I would like to thank my family, room mates and Josien for their incredible support. Thank you!

P.J.D. Visser
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Contents

1
Paper

The effect of engine sound and power-train enhancement on sportiness and driving behaviour

A driving simulator study

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ABSTRACT

Many modern vehicles are equipped with a sport mode, which intends to increase drivers' perceived sportiness of the vehicle, via e.g. power-train enhancement (PTE) or engine sound enhancement (ESE). However, to the best of authors' knowledge, no studies are available that investigated the individual or combined effects of PTE and ESE on perceived sportiness and driving behaviour. Therefore, this study aimed to investigate the effects of ESE, PTE and their combination on perceived sportiness and driving behaviour. In a within-subject driving simulator study, thirty-two participants drove under five conditions: no enhancement (Off), PTE, ESE, PTE and ESE combined (PTE-ESE) and a control condition (Control) with a physically sportier car (i.e., more engine power and a sports car sound). PTE provided a more sensitive pedal-to-throttle mapping and ESE an engine sound associated with increased engine speed. Both implementations did not increase engine power. Perceived sportiness was measured using a questionnaire, whereas driving behaviour was retrieved from the simulator. The results showed that ESE contributed significantly to perceived sportiness and perceived engine responsiveness, whereas PTE had no to limited effect. Furthermore, ESE created the impression of enhanced engine responsiveness, more so than PTE. PTE resulted in increased acceleration during acceleration from standstill, whereas driving behaviour was not significantly affected by ESE compared to Off. In addition, PTE significantly influenced control behaviour: it led to a decreased mean accelerator pedal depression angle and an increased mean throttle reversal rate compare to Off. We conclude that ESE increases perceived sportiness to the extent it approaches the perceived sportiness of an actual sportier car without altering the driving behaviour or decreasing safety margins. The findings of this study support the use of ESE in sport mode. PTE should be further explored in an experimental setup that provides vestibular feedback.

Keywords. perceived sportiness – engine sound enhancement – power-train enhancement – driving simulator

1. Introduction

Since the invention of the first automobile, engineers have made substantial changes to vehicles to improve drivers' comfort and vehicle stability. These improvements were achieved by decreasing vibrations and improving tire to road contact through innovations like inflatable tires, sprung suspensions, and, later, damped suspensions (Sharp and Crolla, 1987). Furthermore, inventions such as powered steering and automatic transmissions contributed to a decrease in the required driving effort (Green, 1984).

In most conventional vehicles, the vehicle dynamics components are passive, meaning that they are mechanically defined and unvarying. Passive components are a proven concept since many years. However, as Sharp and Crolla (1987) stated: "they have evolved to a point at which it is reasonable to suppose that they will not improve much without changes in principle". One of the underlying principles of passive components is that they are unvarying. This means that, they have to be designed to function in a wide range of driving conditions and across the vehicle's entire speed range. However, the optimal vehicle dynamics may vary for these different driving situations. For example, Kroes (2019) showed that low steering gain is preferred at high speeds (increased stability during highway driving) and a high steering gain at low speeds (increased manoeuvrability during city driving). In the same vein, Fu et al. (2013) showed that the power-train and automatic transmission should adapt during cornering to avoid undesired gear shifts.

To deliver variable vehicle dynamics for a wide range of driving conditions, manufacturers have developed active components. Compared to passive components with fixed design parameters, active components are able to change design parameters according to driving conditions. To facilitate such adaptive capabilities, active components contain a measurement system and control law (Sharp and Crolla, 1987). For example, variable suspension varies the damping ratio according to road vibration (Achleitner et al., 2005), variable power-train alters the timing for the switching of the gears according to lateral acceleration (Wehbi et al., 2017), and four-wheel steering changes the amount and direction of rear-wheel steering according to vehicle speed (Melman et al., 2019; Leith et al., 2005).

Besides active components facilitating adaptation to different driving conditions, adaptation to drivers' different preferences is also possible. To enable drivers to control and personalise active components, manufacturers have introduced so-called driving modes. Driving modes, such as eco, comfort, and sport, change the control law of one or more active components to prioritise a certain aspect of the driving experience. For example, the comfort mode prioritises the comfort of driver and passengers, eco mode the fuel economy, and sport mode the sportiness of the vehicle (Volvo, 2020a; Mercedes-Benz, 2020).

The sport mode, has gained a large presence in the car market today (Volvo, 2020b; BMW, 2020; Renault, 2020; Porsche, 2020). With the sport mode, manufacturers attempt to create the perception of a sporty car. Uselmann et al. (2015) explained that a sporty car should transmit information such as road type and driving mistakes to the driver. This characteristic is opposite to a comfortable car, which should provide a comfortable driving experience through compensating for bad road conditions and driver mistakes. In a sport mode, various active components that alter the vehicle dynamics may be used, e.g., active suspension of a car, which provides decreased damping in comfort mode and increased damping in sport mode (Havelka and Musil, 2014), and the active power-train, which decreases engine responsiveness in comfort mode and increases the engine responsiveness in sport mode (Melman et al., 2019). This latter feature can be called power-train enhancement (PTE), as it delivers increased engine responsiveness by altering the settings of the power-train. In sport mode, active components that alter the cabin ambience are also used. These active components change the driver's perception of the vehicle by altering the visual and auditory experience. Active components that alter the cabin ambience are often low-cost as the necessary technology is already present in the vehicle. Examples are adaptive gauge clusters that can display the album cover of the currently playing media in comfort mode versus a tachometer in sport mode (Petiot et al., 2015) and the engine sound that can be reduced in comfort mode (using a masking sound) versus amplified in sport mode using the vehicle's interior or exterior speakers (Jackson, 2013; Achleitner et al., 2005). This latter feature is referred to as engine sound enhancement (ESE) as it enhances the original engine sound of the vehicle.

ESE and PTE are incorporated in the sport mode of many vehicles and are the focus of this study. In this study, ESE is implemented via providing engine sounds associated with increased engine speed (increased RPM) and PTE is implemented via a more sensitive pedal-to-throttle mapping, a digital manipulation of the pedal input signal. This implementation of ESE was chosen for its ease of implementation and under the assumption that hearing sounds associated with a higher RPM leads to increased perceived sportiness. The digital manipulation of PTE produces more engine power for a given accelerator pedal input making the engine feel more responsive. Both adaptations used in this study do not mechanically alter the vehicle or increase maximum engine power. Thus, ESE and PTE can be described as creating the illusion of increased sportiness of the vehicle.

There is limited knowledge on the effect of ESE on perceived sportiness and driving behaviour. A number of studies have investigated perceived sportiness of engine sound in general (Krüger et al., 2004; Kwon et al., 2018; Coen et al., 2004). These studies showed that there exists a relation between engine sound and perceived sportiness. However, these experiments were performed in a non-driving context (i.e., sounds were played through headphones in a laboratory) so driving behaviour was not measured. Regarding the effect of engine sound on driving behaviour, Horswill and McKenna (1999) and Hellier et al. (2011) found that lower engine sound volumes (5dB lower) led to higher driving speeds (2.37 km/h higher). Furthermore, McLane and Wierwille (1975) showed that driving without engine sound led to an increase in driving speed of 3.2 km/h. These findings demonstrate that engine sound can influence driving behaviour. However, these studies did not investigate the effect of changing the RPM of the engine sound, nor did they investigate the effect on perceived sportiness.

Knowledge of the effect of PTE on perceived sportiness and driving behaviour is very limited. Existing studies on PTE (Wehbi et al., 2017; Hosoda, 2010) investigate the working principle of the active components and not the effects on perceived sportiness and driving behaviour.

In addition, there is a lack of studies that simultaneously investigate the effect of ESE and PTE in one experimental setting. Therefore, it is not clear what the individual and combined effects of PTE and ESE are on perceived sportiness and driving behaviour. Furthermore, studies that compare the perceived sportiness of ESE and PTE, which intend to create the illusion of increased sportiness, to perceived sportiness of an actual sporty vehicle, are non-existent. Therefore, it remains unknown how effective ESE and PTE are at increasing perceived sportiness compared to an actual sporty vehicle.

In summary, ESE and PTE are incorporated in many vehicles. However, there is a paucity of knowledge on the individual and combined effects of ESE and PTE on perceived sportiness and driving behaviour. Therefore, this study explores ESE and PTE in a single driving simulator study with the aim to investigate the effects of ESE, PTE and their combination on perceived sportiness and driving behaviour.

It was hypothesised that (1) ESE and PTE are effective at increasing perceived sportiness and deliver comparable results to increasing the actual sportiness of the vehicle and (2) ESE decreases driving speed and increases safety margins whereas PTE does not influence driving behaviour except control behaviour. PTE was hypothesised to affect control behaviour in the form of adaptation to the changes in accelerator pedal handling properties as

Fig. 1. Experimental setup and simulator environment.

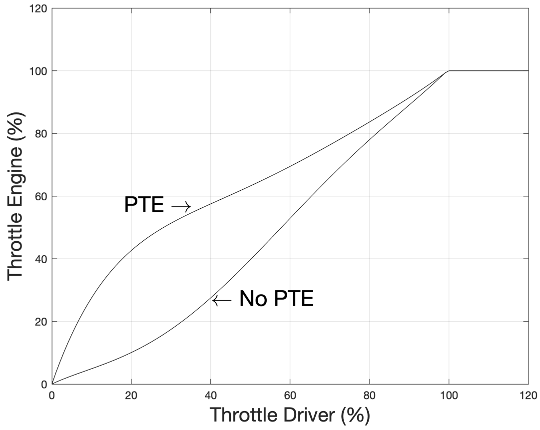

Fig. 2. The two throttle mappings for PTE and no PTE and labelled accordingly.

drivers frequently encounter situations that require different pedal input e.g., when changing cars or while driving up a hill. Furthermore Russell (2015) found that drivers display fast sensorimotor adaption to changes in automobile handling properties e.g., drivers quickly adapt to changes in steering ratio.

To test these hypotheses, a driving simulator study was performed. A virtual test track was designed, and participants were instructed to drive this test track five times while experiencing no enhancement, PTE, ESE, ESE and PTE combined and one control condition (the same car but with actual increased sportiness due to increased engine power and sporty engine sound). Perceived sportiness was measured through questionnaires, and driving behaviour and safety were measured through objective data retrieved from the simulator.

2. Method

2.1. Participants

Thirty-two participants (6 female) between 19 and 35 years old (M = 23.4, SD = 3.1) with normal or corrected-to-normal vision volunteered for the driving simulator experiment. In response to the question: "On average, how often did you drive a vehicle in the last months?" 3 participants reported every day, 5 drove 4 to 6 days a week, 12 drove 1-3 days a week, 11 drove once a month to once a week and 1 never. To the question: "Roughly how many kilometres did you drive in the last 12 months?" 2 participants reported 1-1,000 km, 14 reported 1,001-5,000 km, 7 reported 5,001-10,000 km, 4 reported 10,001-15,000 km, 4 reported 15,001-20,000 and 1 reported 35,001-50,000. On the question: "Have you ever heard of a sport mode in vehicles?" 29 participants responded "yes".

2.2. Apparatus

The experiment took place at the Cognitive Robotics Lab in the faculty Mechanical, Maritime and Materials Engineering (3mE) of the Technical University Delft. The simulator was of a fixed-base type. The vehicle was modelled after a sedan of 2316 kg, 2 m wide, a maximum engine RPM of 7415, a maximum engine torque of 350 Nm, a maximum speed of 149 km/h, a drag coefficient of 0.24, a single-speed gearbox (ratio: 7.73) and the vehicle dynamics were simulated by the Unreal Engine physics engine. The simulation was designed with the JOAN Simulator (Delft University, 2020) at its basis which in turn is based on the CARLA Simulator (CARLA Simulator, 2020). The steering wheel and pedals used in the simulation were from a Sensodrive Senso-Wheel with electronically actuated steering torques. The road and scenery visualisation was projected on a 65" 4k LCD TV and displayed a horizontal field of view of 90 degrees. The sound of the vehicle was played back using quality headphones. The car's interior and bonnet were visualised to enhance the perception of road position and vehicle speed (see Figure 1). Data of the simulator was recorded at 100Hz.

2.3. Designs Of Enhancement Systems

2.3.1. Engine Sound Enhancement (ESE)

The engine sound used for the simulation was the interior sound of a Volkswagen Golf. This engine sound, which was recorded while driving at a constant speed, was then pitch modulated according to the engine's simulated RPM. During the pitch modulation the playback speed of the engine sound was slowed down or sped up, which changed the pitch of the sound. The pitch multiplier, an Unreal Engine audio component variable which controls this manipulation, was calculated, while driving with and without ESE, using Equation 1.

$$P_{\text{multiplier}} = \frac{RPM}{C} + B \tag{1}$$

Here, C is a condition dependent variable and B the pitch multiplier at 0-rpm where $C_{\text{noESE}} = 10,000$ and $B_{\text{noESE}} = 0.35$ while driving without ESE, and $C_{\text{ESE}} = 6,000$ and $B_{\text{ESE}} = 0.45$ while driving with ESE. These parameters were heuristically tuned.

2.3.2. Power-Train Enhancement (PTE)

The implementation of PTE depended solely on one variable: accelerator-pedal-depression-angle. PTE was achieved by modifying the pedal-to-throttle mapping (Figure 2), which is defined as the relation between the normalised accelerator pedal depression angle (%) and the normalised requested engine torque (%). This study refers to the normalised depression angle and the normalised engine torque as 'throttle driver' and 'throttle engine', respectively.

The two pedal-to-throttle mappings used in the simulation were based on pedal-to-throttle mappings used in a commercially available product called the PedalBox, by DTE Systems (2020), and are shown in Figure 2. This figure shows the throttle driver on the horizontal axis and the throttle engine on the vertical axis. It can be noticed that for a certain throttle engine the amount of throttle driver is different and that the slopes of the two pedal-to-throttle curves vary.

The effects of PTE were: (1) less required throttle driver for a given amount of throttle engine and (2) less required Δthrottle driver for the same Δthrottle engine for depressions between 0-18%. These effects resulted in less accelerator pedal depression over the entire depression range and increased engine responsiveness at depressions between 0-18%. At a throttle driver of 18% for driving with PTE and 50% for driving without PTE, the throttle engine and the ratio Δthrottle engine/Δthrottle driver were the same. After these points driving with PTE required a larger Δthrottle driver to achieve a given Δthrottle engine resulting in a decrease in engine responsiveness. The implementation of PTE did not increase engine power, i.e., the maximum torque provided by the engine is the same for driving with and without and PTE.

During preliminary trails and a prior experiment at the department of cognitive robotics (Bruinsma et al., 2020) multiple measured instances of fully depressed accelerator pedals were recorded. Measurements of fully depressed accelerator pedals are less valuable as they limit the measurement signal. In order to extend the measurable range of the throttle driver signal the physical limit for the pedal depression angle of the driving simulator was extended by 20%. In addition, throttle driver was measured in the range 0-120% and any depression greater that 100% resulted in a throttle engine signal of 100% (see Figure 2).

2.3.3. Control Condition

As a reference, a control condition was designed with increased engine power and a sporty engine sound. In contrast to ESE and PTE, which altered the engine sound and engine responsiveness of the same car, the control condition represented a different and sportier. This condition had increased engine power, with larger acceleration and top speed, and had the sound of a commonly known exotic sports car. The car was modelled after the same heavy sedan (2316 kg, 2 m wide and single-speed gearbox ratio: 7.73), however this time with a maximum torque of 550 Nm, maximum RPM of 10590 and a maximum speed of 203 km/h. The pedal-to-throttle mapping for this condition was linear and as mentioned in Section 2.3.2 any throttle driver larger than 100% results in a throttle engine signal of 100%.

2.4. Road Environment

All participants drove each of the five trails on the same single-lane road (3.6 m wide and 8.1 km long). The route was divided in three sections: the first 2.6 km were designed to facilitate the task of decelerating from, accelerating to and maintaining a speed of 60 km/h. This task was completed four times during these first 2.6 kilometres (see Figure 3) and was instructed using stop and speed limit signs. This section of the road ended with a sign indicating that moving forward participants had no speed limit to adhere to. The middle 2 km were straight to facilitate a steady state driving behaviour where participants could discover a speed at which they felt comfortable. The last 3.5 km were curve driving which contained three types of curves with an inner radius of 100, 150 and 250 meters. Each curve type appeared three times, and the curves were connected by straight sections which had a length of 50 or 100 meters. To enhance the perception of speed and acceleration, simulated trees, buildings, landscapes and guardrails were placed next to the road. Preceding each experimental trial, the participants would drive in a familiarisation trial to get acquainted with the new vehicle setup. This familiarisation trial was driven on a different road which contained examples of the road signs used during the experiment (see Appendix A). No simulated traffic was present during both the experimental trial and the familiarisation trial.

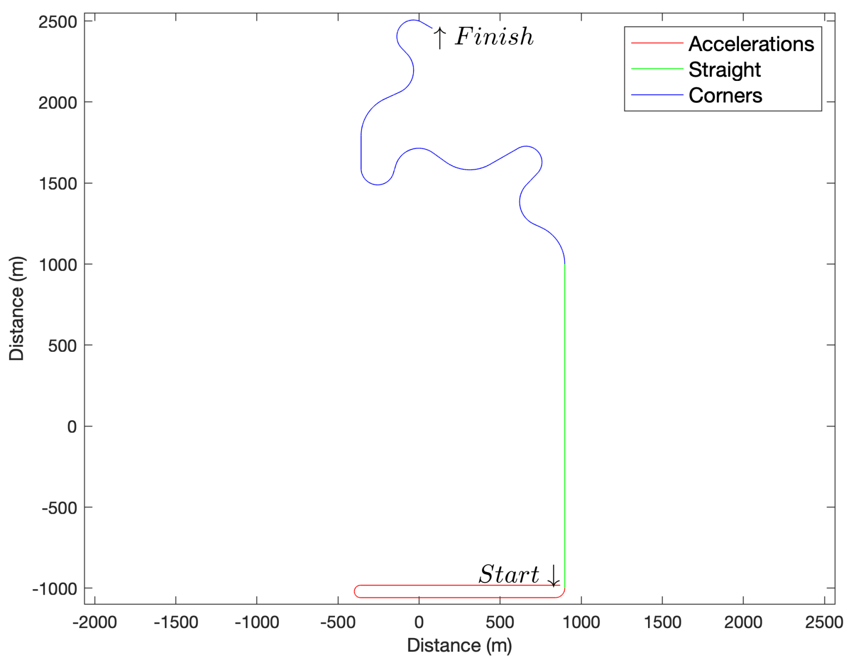

Fig. 3. A top view of the test track with highlighted in color the acceleration, straight and corners sections. Total length: 8.1 km

2.5. Experimental Procedure

Perceived sportiness and driving behaviour were collated in a Latin Square counterbalanced within-subject design with five conditions: no enhancement (Off), PTE, ESE, PTE and ESE combined (PTE-ESE) and a control condition (Control). Before starting the experiment, participants read and signed an informed consent form which stated the purpose, procedure, task instructions, risks, discomforts and Covid-19 requirements (see Appendix A). Participants were asked to drive as they usually would and adhere to traffic rules identified by road signs next to the road.

When entering the lab, participants filled out a questionnaire through which personal details and information about the driving experience were gathered (see Appendix B). The participant was requested to take a seat in the driving simulator. Before each trial a three-minute familiarisation period was driven. During this time, the participants were instructed to familiarise themselves with the vehicle settings by accelerating, decelerating and curve driving. After the familiarisation period, the test period, which would occur on the test road described in Section 2.4, was started.

When finishing each trial, participants would step out of the simulator and fill out a questionnaire. This questionnaire contained 4 questions regarding driving effort (graded on a 5 point Likert scale), 3 questions regarding attributes of the vehicle behaviour (graded on a 5 point Likert scale) and 7 questions on the driving experience (where various adjective pairs were graded on a 5 point scale). For the complete questionnaire see Appendix C. The entire experiment took approximately 75 minutes for each participant.

2.6. Dependent Measures

The dependent measures analysed in this study were divided into the following categories: perceived sportiness, driving behaviour, and safety margins.

2.6.1. Perceived Sportiness

After each experiment, the participants described their driving experience using a questionnaire. In addition to the perceived sportiness score, three other dependent measures were considered to provide additional insight into different facets of sportiness.

- Perceived sportiness score (-). Participants graded the statement: "I experienced this vehicle as: Sporty – not sporty" on a five-point scale. The scores (see Appendix D) were mirrored for analysis in order to have a score of five represent sporty. Perceived sportiness is the main result of this study.
- Perceived engine responsiveness score (-). Participants graded the statement: "The vehicle that I just drove had: Low engine responsiveness – High engine responsiveness" on a five-point scale.

- Perceived engine sound score (-). Participants graded the statement: "The vehicle that I just drove had: High engine sound – Low engine sound" on a five-point scale. The scores (see Appendix D) were mirrored for analysis in order to have a score of five represent high engine sound.
- Perceived comfort score (-). Participants graded the statement: "I experienced this vehicle as: Comfortable – Not comfortable" on a five-point scale. The scores (see Appendix D) were mirrored for analysis in order to have a score of five represent comfortable.

2.6.2. Driving Behaviour

The driving data from the simulator produced the following dependent measures regarding driving behaviour.

- Mean speed (km/h).
- Mean absolute acceleration (m/s^2). This dependent measure was determined for the acceleration trajectories and the total test track. A higher mean absolute acceleration represents, on average, higher and more accelerations and decelerations which could indicate an aggressive driving style.
- Mean throttle driver (%). This dependent measure represents the mean of the normalised accelerator pedal depression from 0-120%.
- Mean throttle engine (%). The mean of the normalised requested engine torque after the pedal-to-throttle mapping (as described in Section 2.3.2) from 0-100%.
- Mean throttle reversal rate (1/s). Accelerator pedal or throttle reversals occur when the driver changes the direction of the accelerator pedal. Pedal reversals occur, for instance, when the driver accelerates until a certain speed after which the pedal is reversed to a state with less depression. The mean throttle reversal rate is defined as the average pedal reversals per second (minimum difference for registration was set to 5% to account for unintentional movement) and reflects the participants' control activity. Determination of the pedal reversal rate was done by passing the throttle driver signal, through a low pas filter with a cut off frequency of 2 Hz and finding the peaks in this signal with a minimal difference of 5% pedal depression.
- Mean brake depression (%). The amount of depression of the brake pedal from 0-100%.

2.6.3. Safety

Potential decreased safety due to ESE or PTE is measured both in safety margins and perceived danger.

- 15^{th} percentile time to line crossing (TLC) (s). TLC represents the time available, when no input is given, until the moment at which any part of the vehicle reaches one of the lane boundaries (Godthelp et al., 1984). The TLC is calculated using the trigonometric method (van Winsum et al., 2000) where the road's curvature and the predicted vehicle trajectory are taken into account. By extracting data on the position, orientation and angular acceleration of the participants from the driving simulator and positioning this over the simulated road map, an estimate of the time to line crossing could be made. An increase in TLC represents increased safety margins.
- Perceived danger score (-). Participants graded the statement: "I experienced this vehicle as: Dangerous - Safe" on a five-point scale. The scores (see Appendix D) were mirrored in order to have a score of five represent dangerous.

2.7. Statistical Analyses

For each experimental trial, the dependent measures were retrieved, which resulted in a 32 x 5 matrix for each dependent measure (32 participants, 5 conditions). The mean, standard deviation (SD) and the corrected within-subject normalised confidence interval (CI) were calculated for each of the dependent measures and conditions. To determine the corrected within-subject normalised CI, as described in Morey et al. (2008), the data was normalised by subtracting the appropriate participant's mean of a specific dependent measure from each of the participant's observations and adding the grand mean to every observation before using the standard method for determining the 95% CI. The CI was then corrected, with a correction factor, according to the number of experimental conditions to account for the fact that the CIs are correlated. This type of CI facilitates the analysis of the within-subject variations between conditions i.e., an analysis of the average effect of driving with a different experimental condition on the different dependent measures.

Cumming and Finch (2005) showed that non overlapping CIs correspond to a p value smaller than 0.006. However, this p value was determined for non-overlapping CIs of equal size and non-paired data. Furthermore, they state that in the paired data case, these findings do not hold. We hypothesised that, because the within-subject CIs were corrected for the correlation between conditions, the determination by Cumming and Finch (2005) should hold. To test this hypothesis, a small simulation was run (see Appendix E) to estimate the p value for two non-overlapping CIs when having 5 experimental conditions. This simulation confirmed that with random data, 0.6% of the cases result in non-overlapping within-subject CIs. This is similar to what was found in the study of Cumming and Finch (2005).

In the current study five experimental conditions were tested and compared. This resulted in 10 comparisons for each dependent measure. The large number of comparisons and dependent measures increased the chance

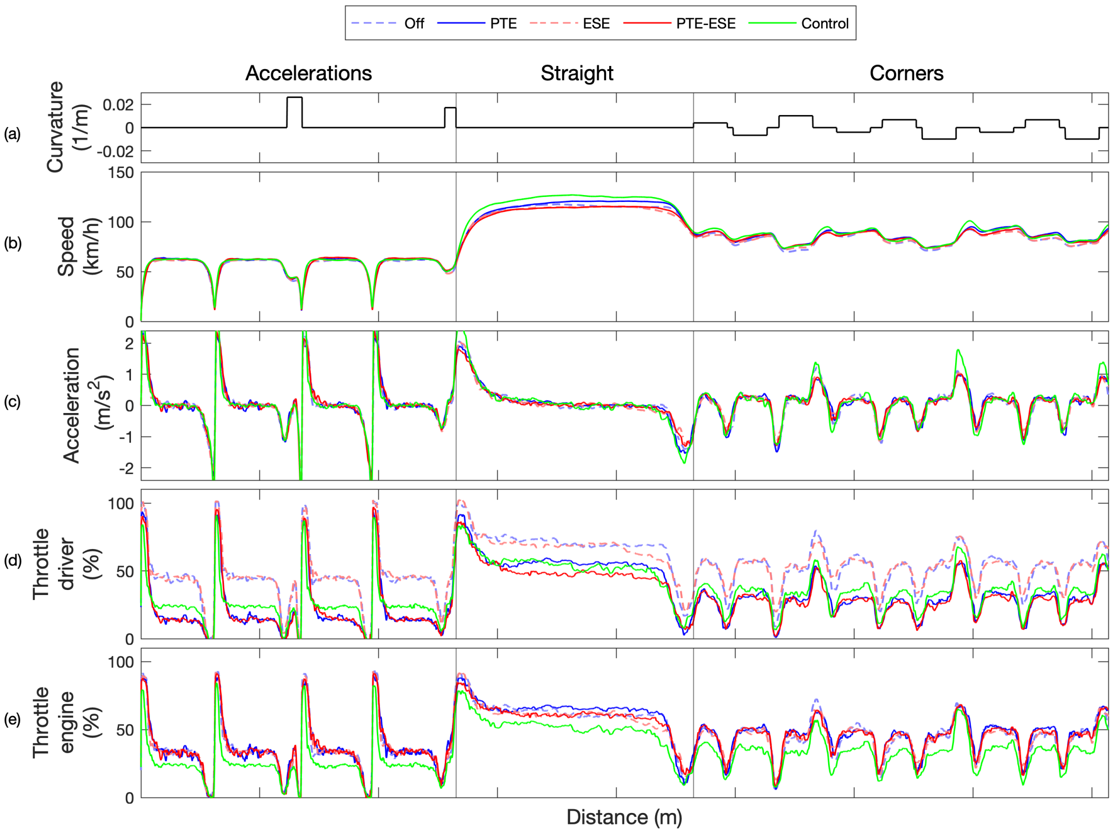

Fig. 4. The mean driving behaviour averaged over all 32 participants, with from top to bottom: (a) curvature (1/radius) of the road, (b) mean speed (m/s), (c) mean acceleration (m/s^2), (d) mean throttle driver or normalised accelerator pedal depression angle (%), (e) mean throttle engine or normalised requested engine torque (%). Means are per condition and over all participants. With the vertical lines indicating the transitions for the accelerations, straight and corners section.

of false positives. Therefore, as suggested by Benjamin et al. (2018) we applied a lower threshold for statistical significance than the commonly used p value of 0.05. Instead, we consider non-overlapping CIs, corresponding to approximately $p < 0.006$, to indicate statistical significance.

3. Results

To illustrate the driving behaviour of the participants while they experienced the five experimental conditions, Figure 4 shows the curvature of the road (a), speed (b), acceleration (c), throttle driver (d) and throttle engine (e), averaged over all participants and for the entire test track. This figure demonstrates that participants adopted a significantly different level of throttle driver with PTE and PTE-ESE compared to Off and ESE. Furthermore, Figure 4 shows other aspects of driving behaviour per road section were similar across the different conditions. It can be seen that participants accelerated to and decelerated from 60 km/h during the accelerations section, drove at a speed at which they felt comfortable during the straight section, and freely accelerated and decelerated during the corners section at the end of the test track. As discussed in the Section 2.6, the dependent measures and results have been divided into three categories: perceived sportiness, driving behaviour and safety.

3.1. Perceived Sportiness

Figure 5 shows the means, over all participants, of perceived sportiness (d) and perceived engine responsiveness (f) in combination with the within-subject 95% CIs and for each condition. Table 1 shows the mean, SD and a 95% CI comparison for all dependent measures.

Figure 5d shows that Control was rated the highest in terms of perceived sportiness followed by PTE-ESE, ESE, PTE and finally Off. Participants reported, on average, an increased perceived sportiness of 0.13 points for PTE, 1.06 points for ESE, 1.25 points for PTE-ESE and 2.19 points for Control compared to Off. Although the increased perceived sportiness of PTE was non-significant, these results suggest that the effects of PTE and ESE on perceived sportiness are interactive as the effect of PTE-ESE was larger than the summed effects of PTE and ESE

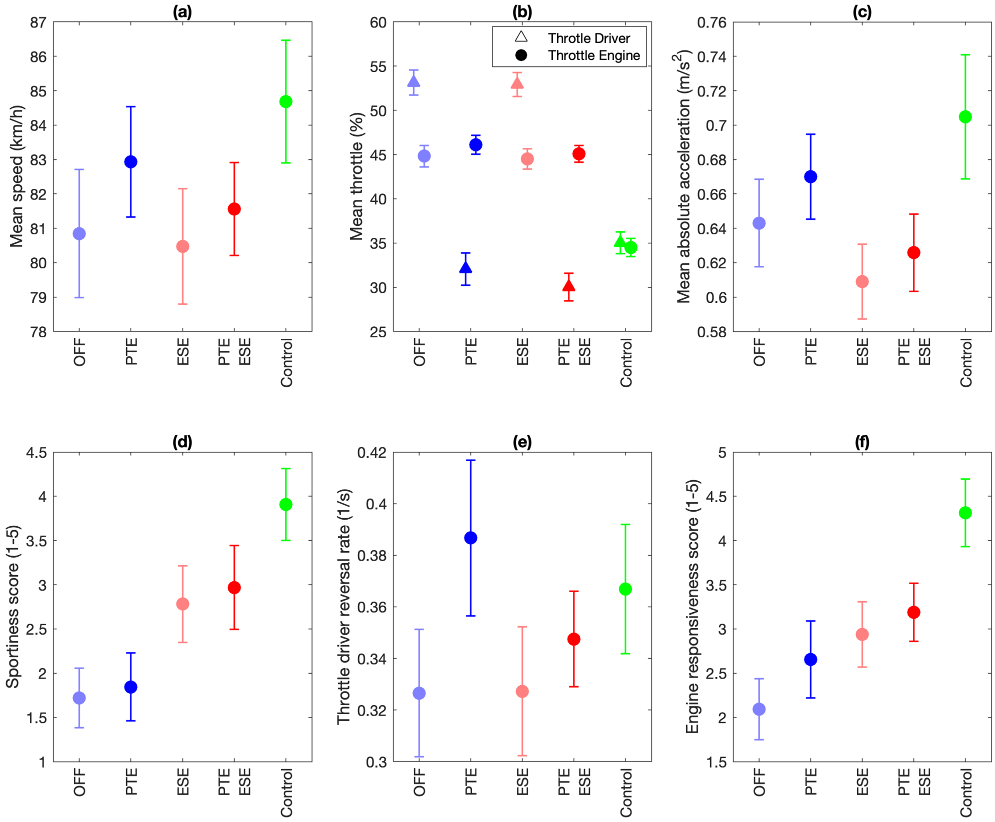

Fig. 5. A within-subject 95% CI analysis of selected dependent measures with (a) mean speed (km/h), (b) mean throttle driver and throttle engine (%), (c) mean absolute acceleration (m/s^2), (d) perceived sportiness (-), (e) throttle reversal rate (1/s), (f) perceived engine responsiveness (-). All dependent measures are per condition, over all participants and accompanied by their within-subject CI. Means are calculated over the entire test track.

compared to Off. The mean perceived sportiness of PTE-ESE approaches that of Control where the gap between the CIs is small.

Figure 5f shows that perceived engine responsiveness was strongly correlated with sportiness and led to similar results where Control was reported to have the highest increased perceived engine responsiveness (2.22 points) followed by PTE-ESE (1.09 points), ESE (0.84 points), PTE (0.56 points) compared to Off. PTE increased engine responsiveness in the lower accelerator pedal depression range; however, the mentioned increase in perceived engine responsiveness as a result of PTE was non-significant. The non-significant results suggest an interactive effect for PTE and ESE on perceived engine responsiveness as the effect of PTE-ESE was lower than the summed effects of PTE and ESE compared to Off.

Table 1 shows that participants reported an increased perceived engine sound of 1.84 points for Control, 1.59 for PTE-ESE, 1.34 for ESE and 0.03 for PTE compared to Off where the effect of PTE was non-significant. None of the conditions significantly affect perceived comfort.

3.2. Driving Behaviour

Figure 5 shows the means, over all participants, of the mean speed (a), mean throttle driver and throttle engine (b), mean absolute acceleration (c) and mean pedal reversal rate (e) in combination with the within-subject 95% CIs and for each condition. Table 1 shows the mean, SD and a 95% CI comparison for all dependent measures. Figure 6 shows (a) the mean acceleration over all participants during the first 1.5 seconds of the four 0-60 km/h acceleration trajectories (b) the mean acceleration over all participants over the first 1.5 seconds of the four 0-60 km/h acceleration trajectories together with their 95% CIs.

The results show that over the entire track, participants did not significantly change their mean speed (Figure 5a), mean throttle engine (Figure 5b), mean absolute acceleration (Figure 5c) and mean brake depression (Table 1) when driving with the enhancement conditions compared to Off. The control condition on the other hand, having increased power and sporty engine sound, resulted in increased speed (3.84 km/h), increased mean absolute acceleration (0.06 m/s^2), and decreased throttle engine (10.32 %) compared to Off.

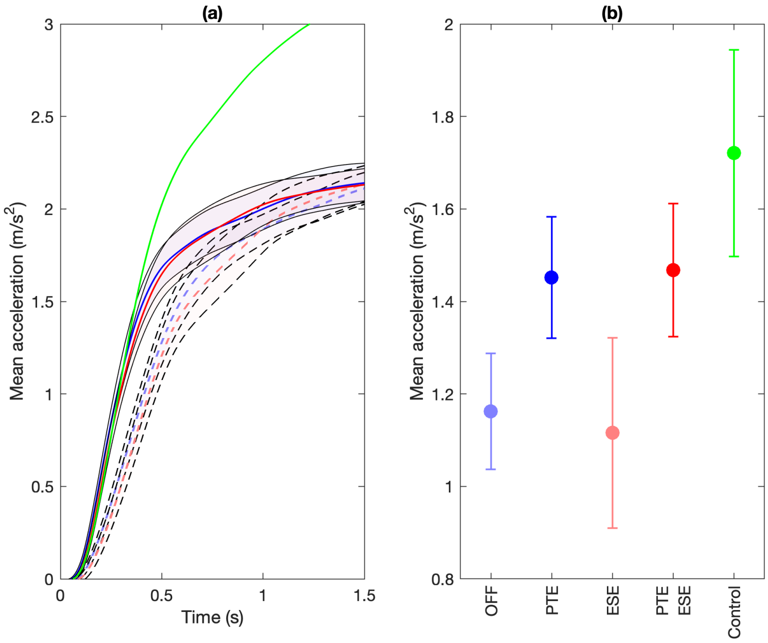

Fig. 6. A within-subject 95% CI analysis of the mean acceleration (m/s^2) during first 1.5 seconds of the four 0-60 km/h acceleration trajectories

The mean absolute acceleration over the total test track (Figure 5c) shows a decreasing but non-significant trend for ESE compared to Off and for PTE-ESE compared to PTE presumably indicating that ESE decreased the mean absolute acceleration. Furthermore, it can be seen that for PTE compared to Off and for PTE-ESE compared to ESE the mean absolute acceleration shows a non-significant positive trend presumably indicating that PTE increased the mean absolute acceleration. Figure 5b displays the working principle of PTE as it reports that participants changed the amount of throttle driver with a decrease of 21% for PTE and 23% for PTE-ESE compared to Off. In addition, Figure 6 shows that participants increased their acceleration during the first 1.5 seconds of the four acceleration trajectories with an increase of 0.29 m/s^2 for PTE and 0.30 m/s^2 for PTE-ESE compared to Off. The mean throttle reversal rate (Figure 5c) reports a significant increase of 0.06 reversals/s higher for PTE compared to Off indicating that participants adjusted the accelerator pedal position more actively with PTE. The significant differences in the pedal control behaviour (i.e., throttle driver and throttle reversal rate) did not lead to significant differences in mean throttle engine or other dependent measures over the total test track. For ESE we notice that participants did not significantly change their mean throttle driver and mean throttle reversal rate compared to Off.

No significant interactive effects on driving behaviour as a result of PTE and ESE combined were observed. However, where PTE resulted in a significant increase in the throttle reversal rate of 0.06 reversal/s and ESE had no effect, ESE-PTE resulted in a non-significant increase of 0.02 reversals/s. These results suggest the effects of PTE and ESE on the throttle reversal rate are interactive as the effect of PTE-ESE was smaller than the summed effects of PTE and ESE compared to Off.

3.3. Safety

PTE, ESE, PTE-ESE and the control condition had no significant effect on the 15th percentile TLC and participants did not report a difference in perceived danger. Therefore, the results do not show significant effects on safety as a result of PTE, ESE, PTE-ESE and Control.

3.4. Spearman Correlation Analysis

The Spearman correlation coefficients between perceived sportiness and engine responsiveness were 0.54, 0.56, 0.67, 0.51 and 0.52 for the Off, PTE, ESE, PTE-ESE and Control conditions, respectively (see Appendix F). This suggests that participants strongly associated sportiness with engine responsiveness. The Spearman correlation coefficients between perceived sportiness and comfort were 0.38, 0.27, 0.47, -0.02 and 0.47 for the Off, PTE, ESE, PTE-ESE and Control conditions, respectively (Appendix F). This suggest that participants did not relate increased sportiness to decreased comfort. Finally we see an unexpected positive correlation between perceived comfort and perceived danger where the Spearman correlation coefficients were 0.41, 0.64, 0.56, 0.43 and 0.32 for the Off, PTE, ESE, PTE-ESE and Control conditions, respectively (Appendix F).

Table 1. Mean and standard deviation for each dependent measure. With on the right a within-subject 95% confidence interval comparison where x indicates non-overlapping confidence intervals.

	Conditions					Confidence Interval Comparison (x=non-overlapping)									
	Off (1)	PTE (2)	ESE (3)	PTE-ESE (4)	Control (5)										
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
Perceived Sportiness															
Perceived sportiness (1-5)	1.72 (0.96)	1.84 (0.95)	2.78 (1.07)	2.97 (1.33)	3.91 (1.20)		x	x	x	x	x	x		x	x
Perceived engine responsiveness (1-5)	2.09 (1.06)	2.66 (1.29)	2.94 (1.01)	3.19 (1.06)	4.31 (0.82)		x	x	x			x		x	x
Perceived comfort (1-5)	3.19 (1.12)	3.13 (1.18)	3.38 (0.94)	3.06 (1.11)	3.34 (1.04)										
Perceived engine sound (1-5)	2.09 (1.23)	2.13 (1.04)	3.47 (0.98)	3.69 (0.78)	3.94 (1.24)		x	x	x	x	x	x			
Driving Behaviour															
Mean Speed (km/h)	80.85 (11.66)	82.93 (11.69)	80.47 (12.50)	81.56 (12.05)	84.69 (13.54)				x					x	
Mean absolute acceleration (m/s^2)	0.64 (0.14)	0.67 (0.10)	0.61 (0.12)	0.63 (0.12)	0.70 (0.20)				x					x	x
Mean throttle driver (%)	53.14 (7.11)	32.07 (11.57)	52.92 (6.76)	30.01 (10.58)	35.04 (8.16)	x		x	x	x			x	x	x
Mean throttle engine (%)	44.83 (7.45)	46.12 (7.58)	44.51 (7.61)	45.09 (7.34)	34.51 (7.24)				x			x		x	x
Mean throttle reversal rate (1/s)	0.33 (0.14)	0.39 (0.15)	0.33 (0.11)	0.35 (0.13)	0.37 (0.15)	x				x					
Mean brake depression (%)	1.15 (0.65)	1.04 (0.49)	1.00 (0.43)	1.00 (0.42)	1.10 (0.47)									x	
Safety															
15^{th} percentile TLC (s)	0.38 (0.16)	0.36 (0.15)	0.37 (0.18)	0.36 (0.14)	0.36 (0.16)										
Perceived danger (1-5)	3.59 (0.95)	3.53 (1.19)	3.41 (1.04)	3.34 (0.90)	2.97 (0.90)										

4. Discussion

4.1. Main Results

This study investigated the effect of Engine Sound Enhancement (ESE) and Power-Train Enhancement (PTE) on perceived sportiness and driving behaviour. In addition, their combination (PTE-ESE) was compared to the sum of the effects of PTE and ESE to determine if PTE-ESE resulted in interactive effects. Currently, little knowledge is available of the effect of these systems on perceived sportiness. For ESE, studies investigated perceived sportiness while participants listened to various original and manipulated engine sounds (Krüger et al., 2004; Kwon et al., 2018; Coen et al., 2004) but not while driving. In the case of PTE, previous studies did not investigate perceived sportiness (Achleitner et al., 2005; Melman et al., 2019). While sport modes usually activate a combination of systems, this study detached ESE and PTE and investigated their single and combined effect on perceived sportiness and driving behaviour.

The results showed that, compared to no enhancement (Off), ESE positively affected perceived sportiness while the effect of PTE was limited. PTE-ESE led to the greatest increase in perceived sportiness. However, the effect did not significantly differ from the effect of ESE. Furthermore, PTE did not significantly increase sportiness. These results suggest that the auditory sensations, caused by ESE, had a much larger effect than the changes in input behaviour due to PTE. PTE-ESE resulted in a perceived sportiness that approached the perceived sportiness of the Control condition, although the difference between them remained significant.

PTE resulted in increased accelerations during acceleration from standstill, increased throttle reversal rates and decreased throttle driver, whereas no effects were found for ESE. These results suggest that PTE led participants to significantly adapt their input behaviour (throttle driver and throttle reversal rate) to a point where the results do not show large differences in other facets of the driving behaviour (e.g. no differences in speed or safety margins). In addition, ESE did not significantly affect driving behaviour. Furthermore, PTE and ESE did not result in dangerous driving behaviour expressed in increased speeds, decreased safety margins and increased perceived danger. In contrast, Horswill and Coster (2002) showed that driving in more sporty cars with increased performance led to greater intended risk-taking of drivers. We found similar results with the Control condition resulting in a higher mean speed over all participants and some participants driving at very high speeds (see Appendix G).

The lack of an effect of PTE on perceived sportiness could be due to either participants not noticing the effects of PTE at all, or due to the effects of PTE not being effective at increasing perceived sportiness. The absence of an increase in perceived engine responsiveness for PTE compared to Off suggests that participants may indeed not have noticed the effects of PTE. This raises the question if the digital manipulation of the pedal-to-throttle mapping of PTE had any noticeable effect on the handling properties of the vehicle. Although participants did in fact utilise the more rapid increase of engine power, demonstrated by the higher acceleration during the accelerations from standstill for PTE, it might be possible that due to the lack of vestibular feedback they did not perceive it as increased engine responsiveness. Fischer et al. (2012) state that for the sensation of acceleration the visual sense is a contributor. However, as vision is a rather slow sense, they consider the vestibular system to be most important. In a fixed base simulator, instead of through vestibular forces, accelerations are sensed visually through a change in speed (Schmerler, 1976) where various visual factors, e.g., spatial frequency, contrast, declination angle and the field of view, influence the fidelity of the sense of speed (Diels and Parkes, 2010). Previous studies show that drivers which only have the visual system to perceive locomotion suffer from inferior speed perception (de Groot et al., 2011; Greenberg et al., 2003; Boer, 2000). To improve the perception of speed, this study provided extra visual stimuli in the form of a digital speed indicator and scenery next to the road. However, the threshold for the visual detection of acceleration seems to be large. Siegler et al. (2001) state that driving on the road typically results in sustained decelerations of 4 m/s^2 during braking while it is not uncommon to see decelerations of 6 or 7 m/s^2 in a fixed base simulator. Furthermore, Schmerler (1976) show that to visually detect if an object is accelerating during a short period of time (<2.6 seconds), an increase in speed between 79% to 105% is required. These studies show that in a simulator, accelerations are underestimated and need large differences in speed to be perceived. Therefore, it seems plausible that the detection of differences in acceleration as a result of PTE, which were mainly present during the first 1.5 seconds of the four acceleration trajectories, is difficult. If vestibular feedback would be introduced, the non-significant effects of PTE might see substantial amplification. Therefore, future studies on the perception of PTE should experiment with an actual vehicle to provide further insight into PTE's effectiveness.

In addition to perceived sportiness, ESE also increased perceived engine sound and perceived engine responsiveness compared to Off. Whereas an increased perceived engine sound is in line with expectations, the increase in perceived engine responsiveness was surprising as the vehicle behaviour, power-train, and all visual cues, remained unchanged with ESE. A possible explanation is that due to the more rapid change in the engine sound, vehicle acceleration is more easily noticed. Thomas (2007) state that temporal drift, which is the gradual change over time of the tempo of a sound, plays an important role in human perception of a change in velocity. In addition, Seifritz et al. (2002) state that acoustic change is an important cue for the perception of auditory motion. These findings show that human subjects are sensitive to changes in sound and associate this with motion. Therefore, the rate of change of the engine sound may play a vital role in the time it takes to detect a change in engine and vehicle speed. Presumably, an earlier registration of a change in engine speed led to an increase in perceived engine responsiveness.

The earlier detection of a change in speed may aid in the task of maintaining speed. Various studies (Merat and Jamson, 2011; Horswill and Plooy, 2008; Denjean et al., 2012) demonstrated the importance of sound feedback when controlling speed in a driving simulator study. In these studies drivers had to maintain speed with and without vehicle sound. The results were that drivers' ability to maintain speed was more variable in the absence of vehicle sound. As sound is important for maintaining speed, one could argue that it is easier to maintain speed while experiencing ESE. Because of the more rapid change of the engine sound when accelerating with ESE, changes in speed may be detected earlier. As a result of this, participants can react quicker to changes in speed which could explain the non-significant decrease in the mean absolute acceleration as a result of ESE compared to Off, and non-significant decrease in the mean absolute acceleration as a result of ESE-PTE compared to PTE. As driving behaviour was similar across conditions, the increased throttle reversal rate for PTE compared to OFF suggests that participants had to adjust the accelerator pedal more frequently to drive at a desired speed. In addition, the results suggest that the effects of PTE and ESE on the throttle reversal rate were interactive resulting in a decreased throttle reversal rate for PTE-ESE compared to the sum of the effect of PTE and ESE. It seems that with PTE-ESE the increased throttle reversal rate, as a result of PTE, was mitigated by ESE. Presumably ESE's better auditory feedback of the engine speed made it easier to maintain speed while driving with PTE-ESE resulting in a decrease in the throttle reversal rate compared to PTE.

Control significantly affected both perceived sportiness and driving behaviour. The results showed a significant increase in perceived sportiness, perceived engine responsiveness, perceived engine sound, mean speed and mean absolute accelerations for Control compared to Off. As ESE and PTE create the illusion of a sporty engine sound and increased engine power, the Control condition was the authors' representation of genuine increased engine power and a sporty engine sound. Active components designed to increase the vehicle's sportiness are generally expensive and require additional parts. However, PTE and ESE require limited to no additional parts and are therefore low-cost while the Control condition was representative of an actual sporty vehicle. The results show that these low-cost systems that created the illusion of increased sportiness can deliver results approaching a sporty car with increased engine power and a sporty engine sound, without significantly altering driving behaviour or instigating unsafe driving.

4.2. Strong Criteria For Significance

As discussed in Section 2.7 non-overlapping CIs indicate a p value smaller that 0.006 which is a strict criterion for statistical significance. This strict criterion was instated to limit the number of false positives, however it might have generated false negatives. The generally adopted default criterion for a single hypothesis test is p smaller than 0.05 which, according to Cumming and Finch (2005), corresponds to a proportional overlap of about half of the CIs. If the strict criterion were to be adjusted to the default criterion, the decrease in the mean absolute acceleration and throttle reversal rate (Figure 5c,e) with PTE-ESE compared to PTE would become significant. These findings would be in accordance with the theory that ESE mitigates the increased throttle reversal rate resulting from PTE.

4.3. Limitation: Order Effects

A within-subject experiment suffers from order effects (De Winter and Dodou, 2017). The participants were influenced by their previous experiences and learned quickly, which influenced the results of this study. For instance, on average, participants increased their speed by 1.5 km/h with every trail (see Appendix H.1). Furthermore, participants had to base their perception ratings of the simulated vehicle on their previously experienced vehicles. As a result, their choices for the first few trials were presumably based on real-world vehicles, whereas in the last trails, their choices may have been based on the simulated vehicles of previous trails. This may have resulted in the fact that, on average, the fourth trail's sportiness score was 0.94 points higher (see Appendix H.1) than first trails score. As the overlap of the CIs was often less than 1.5km/h for speed and 0.94 points for perceived sportiness, the significance of the results could have been influenced.

To mitigate the order effect, this study had a Latin square counterbalanced experimental design which, with a randomised and unique condition order for every participant (see Appendix H.2), spreads the order effects over the conditions. However, this study was not perfectly counterbalanced as 32 of the possible 120 condition orders were used.

4.4. Procedural Changes Suggested For Future Studies

Although participants were instructed to drive as they usually would, high speeds and various instances of line crossings (where part of the vehicle was outside the lane boundary) were recorded. The mean maximum speed for all participants was 124 km/h (SD 22 km/h) and seven of the 32 participants drove the vehicle's maximum possible speed during more than one of the four ESE/PTE conditions. On average participants drove 4% (SD 3.25%) of the total distance with a part of the vehicle outside the lane boundary, resulting in instances of a TLC of 0 seconds. Future studies could implement some visual or haptic indication of road departure to make participants more aware of their driving behaviour. Possibly, this reinforcement of safe driving will limit the number of times that the maximum vehicle speed and the lane width are reached.

To investigate PTE in an experimental setup with vistibular forces and to further investigate the effect of PTE and ESE on safety, future studies should conduct an experiment with a real vehicle. Driving in a real vehicle will make it easier for participants to perceive accelerations and will favor safe driving due to the additional physical risks. The current PTE implementation is easily translated to a real vehicle as it is based on a commercially available product that performs the same digital manipulation (DTE Systems, 2020). The ESE implementation in this study is less translatable as an artificial increase of the engine speed of the sound of an internal combustion engine (ICE), without actually increasing the engine speed, seems difficult. Vibrations of an ICE are often felt and heard throughout the vehicle making masking this sound with a sound related to a different engine speed seemingly difficult. On the other hand, electric vehicles (EVs) produce a meagre amount of motor sound which does not resemble the sound of an ICE. EVs could be implemented with an ESE sound similar to this study and studies have shown that, subjectively, the sound of an ICE is appropriate and most acceptable for EVs (Wogalter et al., 2001; Nyeste and Wogalter, 2008).

4.5. Future Work

The results of the driving simulator experiment showed that changing the sound of a vehicle, while all other aspects of the driving experience remain the same, is effective at increasing perceived sportiness. It would be interesting to investigate how other alterations of the cabin ambiance, e.g., adaptive gauge cluster (Petiot et al., 2015), affect perceived sportiness and driving behaviour. Furthermore, it would be interesting to investigate how alterations of the cabin ambiance compare to adaptable haptic interfaces, such as increased steering torques and increased centre point emphasis of the steering system (Fankem and Müller, 2014).

To investigate alterations of the cabin ambiance it may be enough to use an experimental setup similar to the one discussed in Gerber et al. (2019) where, in artificial reality, a simulated interior is superposed over a video of real-world driving. To investigate, for instance, the effects of an adaptable gauge cluster and ESE, this type of experiment seems adequate. As the current study investigated the effects of ESE while driving, for future studies to compare ESE with other active components, it may be sufficient to use an experimental setup where participants judge videos.

To generate a better understanding of the contribution of active components to the bigger picture of the sport mode, other studies can expand with different active components in the cabin ambience and/or vehicle dynamics. Furthermore, a greater understanding can be generated on the effect of sportiness enhancement on driving behaviour. With knowledge of active components' effectiveness, future sport modes can possibly be designed with increased efficiency and effectiveness.

4.6. Conclusions

In a driving simulator experiment, two driving enhancement systems, which supposedly increase perceived sportiness, were investigated to determine their relative and combined effects on perceived sportiness and driving behaviour. ESE and PTE do not mechanically alter the vehicle or increase engine power and can therefore be described as creating the illusion of increased sportiness of a vehicle. The effects of ESE and PTE were compared to those of an actual sporty vehicle with increased power and a sporty engine sound. From the results, it can be concluded that:

- As was hypothesised, a combination ESE and PTE was effective at increasing perceived sportiness and delivered comparable results to actually increasing the vehicle's sportiness.
- From our findings, it appears that ESE contributed significantly to perceived sportiness, whereas PTE did not.
- ESE had a positive effect on perceived engine responsiveness, more so than PTE.
- ESE did not seem to affect driving behaviour as no significant differences were found in terms of speed, acceleration, brake and accelerator pedal depression.
- PTE resulted in increased acceleration during acceleration from standstill and a more active use of the accelerator pedal.

The results suggest that, synthetically providing engine sounds associated with increased engine speeds is an effective method to increase perceived sportiness while not affecting driving behaviour. Furthermore, in a fixed base driving simulator, changing the pedal-to-throttle mapping to be more sensitive in the lower depression range does not seem to produce the desired effects. Future studies could investigate different alterations of engine sound to discover what sound adaptation is most effective for ESE. Furthermore, PTE should be further explored with an experimental setup that provides vestibular feedback.

References

Achleitner, A., Glück, H., Hähle, R., Krickelberg, T., Morbitzer, U., and Schätzle, M. (2005). The new porsche 911 carrera. *ATZ worldwide*, 107(1):15–19.

Benjamin, D. J., Berger, J. O., Johannesson, M., Nosek, B. A., Wagenmakers, E.-J., Berk, R., Bollen, K. A., Brembs, B., Brown, L., Camerer, C., et al. (2018). Redefine statistical significance. *Nature human behaviour*, 2(1):6–10.

BMW (2020). Technical features bmw 7 series. https://www.press.bmwgroup.com/netherlands/tv-footage/detail/PF0002596/the-new-bmw-7-series-technical-features.

Boer, E. R. (2000). Experiencing the same road twice: A driver centered comparison between simulation and reality. In *DSC2000 (Driving Simulation Conference), Paris, France*.

Bruinsma, Denarié, Kuppers, and Schouten (2020). Effects of multiple adaptive throttle response systems on driving performance and system acceptance.

CARLA Simulator (2020). Carla is an open-source autonomous driving simulator. `carla.readthedocs.io`. Accessed: 09-12-2020.

Coen, T., Jans, N., Van de Ponseele, P., Goethals, I., De Baerdemaeker, J., and De Moor, B. (2004). Modelling the relationship between human perception and sound quality parameters using ls-svms. In *Proceeding of the International Conference on Modal Analysis Noise and Vibration Engineering (ISMA 2004)*, pages 3749–3763.

Cumming, G. and Finch, S. (2005). Inference by eye: confidence intervals and how to read pictures of data. *American psychologist*, 60(2):170.

de Groot, S., de Winter, J. C., Mulder, M., and Wieringa, P. A. (2011). Nonvestibular motion cueing in a fixed-base driving simulator: Effects on driver braking and cornering performance. *Presence: Teleoperators and Virtual Environments*, 20(2):117–142.

De Winter, J. C. and Dodou, D. (2017). *Human subject research for engineers: A practical guide*. Springer.

Delft University (2020). Joan simulator. `joan.readthedocs.io`. Accessed: 09-12-2020.

Denjean, S., Roussarie, V., Kronland-Martinet, R., Ystad, S., and Velay, J.-L. (2012). How does interior car noise alter driver's perception of motion? multisensory integration in speed perception. In *Acoustics 2012*.

Diels, C. and Parkes, A. (2010). Geometric field of view manipulations affect perceived speed in driving simulators. *Annual Research*, page 55.

DTE Systems (2020). The pedalbox: The throttle response. `https://www.pedalbox.com/en/product/response`. Accessed: 06-12-2020.

Fankem, S. and Müller, S. (2014). A new model to compute the desired steering torque for steer-by-wire vehicles and driving simulators. *Vehicle System Dynamics*, 52(sup1):251–271.

Fischer, M., Eriksson, L., and Oeltze, K. (2012). Evaluation of methods for measuring speed perception in a driving simulator. In *Driving Simulation Conference*, page 16.

Fu, Y., Zhang, W. G., Lei, Y. L., and Liu, H. B. (2013). Research for cornering gearshift strategy of automatic transmission vehicles based on fuzzy inference. In *Applied Mechanics and Materials*, volume 336, pages 1234–1240. Trans Tech Publ.

Gerber, M. A., Schroeter, R., and Vehns, J. (2019). A video-based automated driving simulator for automotive ui prototyping, ux and behaviour research. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pages 14–23.

Godthelp, H., Milgram, P., and Blaauw, G. J. (1984). The development of a time-related measure to describe driving strategy. *Human factors*, 26(3):257–268.

Green, P. (1984). Subjective evaluation of steering effort levels. final report. Technical report.

Greenberg, J., Artz, B., and Cathey, L. (2003). The effect of lateral motion cues during simulated driving. *Proceedings of DSC North America*, pages 8–10.

Havelka, F. and Musil, M. (2014). Multi-objective optimization of vehicle suspension parameters considering various road classes. *Scientific Proceedings Faculty of Mechanical Engineering*, 22(1):26–31.

Hellier, E., Naweed, A., Walker, G., Husband, P., and Edworthy, J. (2011). The influence of auditory feedback on speed choice, violations and comfort in a driving simulation game. *Transportation research part F: traffic psychology and behaviour*, 14(6):591–599.

Horswill, M. S. and Coster, M. E. (2002). The effect of vehicle characteristics on drivers' risk-taking behaviour. *Ergonomics*, 45(2):85–104.

Horswill, M. S. and McKenna, F. P. (1999). The development, validation, and application of a video-based technique for measuring an everyday risk-taking behavior: Drivers' speed choice. *Journal of Applied psychology*, 84(6):977.

Horswill, M. S. and Plooy, A. M. (2008). Auditory feedback influences perceived driving speeds. *Perception*, 37(7):1037–1043.

Hosoda, M. (2010). Power train for a new compact sporty hybrid vehicle. Technical report, SAE Technical Paper.

Jackson, A. P. (2013). A comparison between active and passive approaches to the sound quality tuning of a high performance vehicle. Technical report, SAE Technical Paper.

Kroes, R. (2019). The impact of steering ratio variability to road profiles on driver acceptance and driving behaviour.

Krüger, J., Castor, F., and Müller, A. (2004). Psychoacoustic investigation on sport sound of automotive tailpipe noise. *Fortschritte der Akustik–DAGA*, pages 233–234.

Kwon, G., Jo, H., and Kang, Y. J. (2018). Model of psychoacoustic sportiness for vehicle interior sound: Excluding loudness. *Applied Acoustics*, 136:16–25.

Leith, D., Leithead, W., and Vilaplana, M. (2005). Robust lateral controller for 4-wheel steer cars with actuator constraints. In *Proceedings of the 44th IEEE Conference on Decision and Control*, pages 5101–5106. IEEE.

McLane, R. C. and Wierwille, W. W. (1975). The influence of motion and audio cues on driver performance in an automobile simulator. *Human Factors*, 17(5):488–501.

Melman, T., de Winter, J., Mouton, X., Tapus, A., and Abbink, D. (2019). How do driving modes affect the vehicles dynamic behaviour? comparing renaults multi-sense sport and comfort modes during on-road naturalistic driving. *Vehicle System Dynamics*, pages 1–19.

Merat, N. and Jamson, H. (2011). A driving simulator study to examine the role of vehicle acoustics on drivers speed perception.

Mercedes-Benz (2020). Mercedes-benz eqc: Eq driving modes. `https://www.mercedes-benz.co.uk/passengercars/mercedes-benz-cars/models/eqc/charging-and-range.pi.html/mercedes-benz-cars/models/eqc/charging-and-range/intelligent-energy/eq-modes`.

Morey, R. D. et al. (2008). Confidence intervals from normalized data: A correction to cousineau (2005). *reason*, 4(2):61–64.

Nyeste, P. and Wogalter, M. S. (2008). On adding sound to quiet vehicles. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 52, pages 1747–1750. Sage Publications Sage CA: Los Angeles, CA.

Petiot, J.-F., Francisco, C. C., Ludivine, B., et al. (2015). A comparison of conjoint analysis and interactive genetic algorithms for the study of product semantics. In *DS 80-5 Proceedings of the 20th International Conference on Engineering Design (ICED 15) Vol 5: Design Methods and Tools-Part 1, Milan, Italy, 27-30.07. 15*, pages 011–020.

Porsche (2020). Porsche sport mode - porsche usa. https://www.porsche.com/usa/models/panamera/panamera-e-hybrid-models/drive-chassis/sport-mode/. Accessed: 18-12-2020.

Renault (2020). E-tech plug- in hybrid - technology explained. https://www.renaultsport.com/-e-tech-plug-in-technology-explained-.html.

Russell, H. B. E. (2015). *Driver adaptation to changes in automobile handling properties*. PhD thesis, Stanford University.

Schmerler, J. (1976). The visual perception of accelerated motion. *Perception*, 5(2):167–185.

Seifritz, E., Neuhoff, J. G., Bilecen, D., Scheffler, K., Mustovic, H., Schächinger, H., Elefante, R., and Di Salle, F. (2002). Neural processing of auditory looming in the human brain. *Current Biology*, 12(24):2147–2151.

Sharp, R. and Crolla, D. (1987). Road vehicle suspension system design-a review. *Vehicle system dynamics*, 16(3):167–192.

Siegler, I., Reymond, G., Kemeny, A., and Berthoz, A. (2001). Sensorimotor integration in a driving simulator: contributions of motion cueing in elementary driving tasks. In *Proceedings of driving simulation conference*, pages 21–32.

Thomas, K. (2007). Just noticeable difference and tempo change. *Journal of Scientific Psychology*, 2:14–20.

Uselmann, A., Krüger, K., Bittner, C., and Rivera, G. (2015). Innovative software functions to operate electric power steering systems in sports cars–unterstützungskraftregelung (ukr). In *6th International Munich Chassis Symposium 2015*, pages 423–441. Springer.

van Winsum, W., Brookhuis, K. A., and de Waard, D. (2000). A comparison of different ways to approximate time-to-line crossing (tlc) during car driving. *Accident Analysis & Prevention*, 32(1):47–56.

Volvo (2020a). V90 cross country, 2020 driving modes. https://www.volvocars.com/en-th/support/manuals/v90-cross-country/2019w17/starting-and-driving/drive-modes/drive-modes.

Volvo (2020b). Volvo. https://www.volvocars.com/ie/support/manuals/v90/2020w46/driver-support/electronic-stability-control/activating-and-deactivating-sport-mode-for-electronic-stability-control. Accessed: 18-12-2020.

Wehbi, K., Bestle, D., and Beilharz, J. (2017). Automatic calibration process for optimal control of clutch engagement during launch. *Mechanics Based Design of Structures and Machines*, 45(4):507–522.

Wogalter, M. S., Ornan, R. N., Lim, R. W., and Chipley, M. R. (2001). On the risk of quiet vehicles to pedestrians and drivers. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 45, pages 1685–1688. SAGE Publications Sage CA: Los Angeles, CA.

Appendix A: Informed consent

Informed Consent Form in a driving simulator study

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This document describes the purpose, procedures, benefits, risks and possible discomforts of a driving simulator study. It also describes the right to withdraw from the study at any time in any case. Before agreeing to participate in this study, it is important that the information provided in this document is fully read and understood.

Location of the experiment:
TU Delft, Faculty of Mechanical, Maritime and Material Engineering
Department of Cognitive Robotics
Mekelweg 2, 2628 CD, Delft.

Prevention of the spread of covid-19:
If you:

- Are over the age of 70
- have underlying ailments that could be seen as a risk factor for COVI-19 infection
- have any complaints or symptoms that could be indicative of a COVID-19 infection
- have been in contact with a COVID-19 patient within 14 days prior to today
- are not enabled to travel outside of rush hours to and from the research location

You **cannot** take part in this study.

Purpose of the study: The purpose of this driving-simulator study is to investigate driving behavior and the subjective experience of different driving-experience enhancement systems. The results will be statistically analysed and published in a Master thesis. Possibly in a scientific publication as well.

Procedure: You will be requested to take a seat in the driving simulator (a fixed-base driving simulator) and will be briefed on how to operate it. The simulated vehicle has a gearbox with one gear. Therefore, you do not have to use the clutch or shift gears. Moreover, you are requested to keep both hands on the steering wheel in a ten-to-two position at all time.

The experiment consists of 5 trials on a rural road. A trial will last approximately 6 minutes. Each trial will be supported by a different set of driving-experience enhancement conditions. Prior to each trail you will engage in a 3-minute training run where you are asked to familiarise yourself with that particular driving-experience enhancement condition. You are asked to try and notice what makes each condition different by accelerating, decelerating and steering the vehicle.

During the trials you are asked to drive as you normally would and to adhere to traffic rules which can be identified by road signs. After each trail you are requested to get out of the simulator and fill out two questionnaires.

The road signs you will encounter are: Speed limit 60 km/h, stop, and end of speed limit. After the end of speed limit sign there is no speed limit to adhere to.

Task instructions: To stress this one more time. **During the entire track you are requested to drive as you normally would and to adhere to traffic rules.**

Duration: The total experiment, including filling out questionnaires, will approximately take 1 hour.

Risk and discomforts: Virtual environments like driving-simulators can cause different types of sicknesses: visuomotor dysfunctions (eyestrain, blurred vision, difficulty focusing), nausea, drowsiness, fatigue, or headache. These symptoms are similar to motion sickness. If you feel uncomfortable in any way, you are advised to stop the experiment or rest for several minutes. As mentioned above, you can stop the experiment and withdraw at any time, without negative consequences. If you do not feel well, then please take sufficient rest before leaving the laboratory.

Confidentiality: The collected data in this experiment is kept anonymous and will be used for human factors research purposes only. Throughout the study you will only be identified by a subject number.

Right to refuse or withdraw: Your participation is strictly voluntary and you may withdraw or stop the experiment at any time without negative consequences.

Questions: If you have any question regarding this experiment, feel free to contact P.J.D. Visser (details are provided at the top of this document).

I have read and understood the information provided above
I give permission to process the data for the purpose described above
I voluntarily agree to participate in this study
I agree that <u>none</u> of the COVID-19 statements mentioned above apply to me

Name of participant:

Signature: **date:**

Fig. A.1. The informed consent form was signed by all participants.

Appendix B: Generic characteristics questionnaire

A driving simulator study

How nice of you to want to sign up! Please read the informed consent form and answer the following questions.
Thank you!

*Vereist

1. I have read the Consent Form: https://drive.google.com/file/d/1TzYkb-WYvBcRJEEODZuO3twvgAaonQw9/view?usp=sharing *

   Markeer slechts één ovaal.

   - Yes
   - I will do so now

2. I have signed up for a specific time slot: https://docs.google.com/spreadsheets/d/19VMdWRxvvCmRhWIU6EU8VQOW0K-_5eVe8DgaOwSzuQ4/edit?usp=sharing *

   Markeer slechts één ovaal.

   - Yes
   - I will do so now

3. First name + Surname *

4. E-mail address *

5. What is your age? *

6. What is your gender? *

   Markeer slechts één ovaal.

   - Female
   - Male
   - I prefer not to answer

7. What is your primary mode of transportation? *

   Markeer slechts één ovaal.

   - Private automobile
   - Private motorcycle
   - Public transport
   - Human powered transportation (e.g. walking, cycling)
   - I prefer not to answer
   - Anders: ____________

8. At which age did you obtain your first driver's licence? *

9. On average, how often did you drive a vehicle in the last months? *

Markeer slechts één ovaal.

- Every day
- 4 to 6 days a week
- 1 to 3 days a week
- Once a month to once a week
- Less than once a week
- Less than once a month
- Never
- I prefer not to answer

10. Roughly how many kilometers did you drive in the last 12 months? *

Markeer slechts één ovaal.

- 0
- 1-1.000
- 1.001-5.000
- 5.001-10.000
- 10.001-15.000
- 15.001-20.000
- 20.001-25.000
- 25.001-35.000
- 35.001-50.000
- 50.001-100.000
- More than 100.000
- I prefer not to answer

11. Have you ever heard of a sport mode in vehicles? *

Markeer slechts één ovaal.

- Yes
- No
- I prefer not to answer

12. How many accidents were you involved in when driving a car in the last three years? *

Markeer slechts één ovaal.

- 0
- 1
- 2
- 3
- 4
- 5
- more than 5
- I prefer not to answer

13. How often do you do the following? Sounding your horn to indicate your annoyance with another road user. *

Markeer slechts één ovaal.

- Never
- Hardly ever
- Occasionally
- Quite often
- Frequently
- Nearly all the time
- I prefer not to answer

14. How often do you do the following? Disregarding the speed limit on a residential road. *

Markeer slechts één ovaal.

- Never
- Hardly ever
- Occasionally
- Quite often
- Frequently
- Nearly all the time
- I prefer not to answer

15. How often do you do the following? Using a mobile phone without a hands free kit. *

Markeer slechts één ovaal.

- Never
- Hardly ever
- Occasionally
- Quite often
- Frequently
- Nearly all the time
- I prefer not to answer

16. How often do you do the following? Becoming angered by a particular type of driver, and indicating your hostility by whatever means you can. *

Markeer slechts één ovaal.

- Never
- Hardly ever
- Occasionally
- Quite often
- Frequently
- Nearly all the time
- I prefer not to answer

17. How often do you do the following? Racing away from traffic lights with the intention of beating the driver next to you. *

Markeer slechts één ovaal.

- Never
- Hardly ever
- Occasionally
- Quite often
- Frequently
- Nearly all the time
- I prefer not to answer

18. How often do you do the following? Driving so close to the car in front that it would be difficult to stop in an emergency. *

Markeer slechts één ovaal.

- Never
- Hardly ever
- Occasionally
- Quite often
- Frequently
- Nearly all the time
- I prefer not to answer

19. How often do you do the following? Disregarding the speed limit on a motorway. *

Markeer slechts één ovaal.

- Never
- Hardly ever
- Occasionally
- Quite often
- Frequently
- Nearly all the time
- I prefer not to answer

Appendix C: Questionnaire

Name:

Participant nr.:

Condition nr.:

Complete the survey by ticking a box on every line.

How much effort did it take you to:

1 Brake	Low						High
2 Steer	Low						High
3 Accelerate	Low						High
4 Maintain speed	Low						High

The vehicle that I just drove had:

5 Low engine responsiveness						High engine responsiveness
6 High brake responsiveness						Low brake responsiveness
7 High engine sound						Low engine sound

I experienced this vehicle as:

8 Sporty						Not sporty
9 Dangerous						Safe
10 Comfortable						Not comfortable
11 Undesirable						Desirable
12 Raising Alertness						Sleep-inducing
13 Irritating						Likeable
14 Sluggish						Quick

Fig. C.1. The questionnaire that was filled out after driving with each condition.

Appendix D: Questionnaire results

The questionnaire results of every participant with on the third row the question number from Appendix C. The number represents the n^{th} square on the form. The responses for questions 7, 8, 9 and 10 seen in these tables are mirrored from the original responses i.e. five equals one, four equals two and so on.

Appendix D.1: No enhancement

Table D.1. The questionnaire results for no enhancement

	Questionnaire questions													
	Effort				Vehicle			Driving experience						
Participant nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	2	1	4	2	4	5	1	2	3	4	2	2	2	1
2	3	4	3	4	1	3	5	2	2	2	2	4	3	1
3	2	5	5	5	3	3	1	1	2	3	2	4	2	2
4	5	4	5	4	2	2	2	1	3	2	2	2	2	1
5	3	3	2	2	3	2	2	2	3	3	2	4	2	2
6	3	3	3	3	3	4	1	1	2	2	2	5	2	2
7	3	3	4	3	2	2	4	1	4	2	3	4	2	2
8	5	3	4	3	1	1	1	1	5	3	2	4	2	1
9	4	4	4	4	2	2	1	1	3	2	4	3	3	3
10	2	2	4	2	1	3	1	1	4	3	4	3	3	2
11	4	2	1	2	4	2	2	4	4	4	5	2	4	5
12	5	3	3	3	2	2	3	2	4	5	3	3	4	3
13	5	2	5	1	1	1	1	1	5	5	4	5	3	1
14	2	2	2	2	3	3	2	1	4	4	3	5	3	1
15	3	3	4	3	1	3	4	2	4	4	2	3	2	2
16	2	2	2	2	2	3	3	3	4	4	3	3	4	3
17	3	1	2	1	2	1	2	2	5	3	2	4	3	1
18	3	3	2	2	3	4	3	3	4	3	3	3	2	2
19	3	2	2	2	4	3	2	3	3	4	4	3	4	4
20	2	4	4	2	1	3	2	1	4	5	4	4	4	2
21	5	5	4	1	1	1	1	1	3	2	1	1	2	1
22	2	4	4	3	3	4	1	1	4	4	4	4	4	2
23	4	5	5	3	2	3	2	2	3	3	3	4	3	2
24	2	2	2	2	4	4	3	4	4	4	4	3	4	4
25	4	2	5	2	1	2	1	1	5	4	3	4	4	2
26	4	1	4	2	2	4	2	3	4	4	4	5	4	2
27	4	3	4	4	1	2	4	1	2	1	1	2	1	1
28	5	4	5	2	1	2	5	1	2	2	1	4	2	2
29	4	3	3	3	2	2	2	3	3	4	2	5	2	2
30	5	2	5	2	1	2	1	1	5	1	1	5	1	1
31	4	2	4	2	3	2	1	1	4	4	3	4	3	3
32	4	2	4	2	1	2	1	1	4	2	1	5	2	2

Appendix D.2: Power-train enhancement

Table D.2. The questionnaire results for power-train enhancement

	Questionnaire questions													
	Effort				Vehicle			Driving experience						
Participant nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	3	5	3	4	4	3	2	1	1	1	1	2	2	2
2	4	2	3	1	4	1	3	2	2	2	3	4	3	1
3	3	3	4	4	2	2	3	1	4	4	3	3	4	3
4	4	4	4	4	2	2	2	3	5	4	4	2	2	2
5	4	4	2	2	4	2	2	2	4	2	2	3	2	3
6	5	4	2	2	3	1	1	1	2	2	2	3	2	2
7	5	4	5	4	2	1	1	1	2	1	1	5	1	1
8	4	4	4	2	1	4	2	1	5	4	3	4	3	3
9	4	3	1	2	4	2	1	3	4	4	4	3	4	3
10	4	3	4	4	1	2	1	1	3	2	2	4	2	1
11	5	1	1	4	5	2	1	4	3	4	4	5	4	4
12	2	1	5	2	1	3	1	1	5	5	4	5	4	2
13	3	1	5	4	1	3	1	1	5	2	2	5	2	1
14	4	3	4	4	1	4	3	2	2	2	2	4	2	1
15	4	2	2	2	4	2	5	1	5	4	3	4	3	2
16	3	1	2	3	4	2	2	2	4	4	3	3	4	4
17	2	4	5	4	2	4	2	1	4	4	1	4	1	2
18	3	4	4	2	2	3	4	2	4	3	2	4	3	2
19	5	5	4	4	1	1	1	2	3	1	2	2	2	3
20	1	1	5	2	2	5	1	1	5	5	3	4	3	1
21	5	5	4	4	2	1	1	1	2	3	1	2	2	2
22	3	4	4	4	4	4	3	2	4	4	4	3	4	2
23	3	5	5	5	2	3	1	2	4	2	3	4	2	3
24	4	4	3	3	2	2	3	1	3	2	1	2	2	3
25	4	4	4	3	1	2	3	1	4	4	2	4	4	2
26	4	1	4	4	2	4	3	2	3	3	3	3	3	2
27	4	2	2	2	4	4	3	4	4	4	4	2	4	4
28	4	3	4	4	2	2	3	2	5	3	2	4	2	2
29	3	2	2	3	4	4	2	4	3	4	4	3	4	4
30	4	3	2	2	4	2	2	2	2	3	3	3	3	2
31	1	2	2	2	4	5	3	3	5	5	5	3	5	3
32	4	4	2	5	4	2	2	2	2	3	2	3	2	3

Appendix D.3: Engine sound enhancement

Table D.3. The questionnaire results for engine sound enhancement

	Questionnaire questions													
	Effort				Vehicle			Driving experience						
Participant nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	2	2	4	5	5	5	4	3	4	4	1	4	5
2	4	3	4	5	2	2	4	1	3	2	2	3	2	1
3	4	3	2	2	3	1	2	2	2	3	2	2	3	2
4	4	4	3	2	2	4	3	1	3	3	2	2	2	2
5	2	1	2	1	4	4	4	4	4	4	3	4	3	2
6	2	2	2	1	4	4	4	5	2	4	5	2	5	4
7	1	1	1	1	4	3	3	4	4	4	4	3	4	4
8	2	3	2	3	3	4	3	3	4	3	3	3	3	3
9	4	4	3	2	3	2	2	2	2	2	2	2	2	3
10	2	2	3	2	2	2	4	1	4	4	4	3	4	3
11	4	5	4	1	2	1	5	2	2	4	1	2	3	2
12	3	3	4	3	3	2	4	4	4	4	4	2	4	4
13	4	4	2	1	4	3	3	3	5	4	4	4	4	3
14	4	3	4	3	4	2	3	2	3	3	3	4	3	2
15	3	2	3	2	3	3	4	3	4	4	4	3	1	3
16	2	2	4	3	1	3	4	3	3	3	3	4	2	2
17	4	4	4	1	2	3	2	2	4	4	4	5	2	3
18	3	2	3	3	3	3	3	2	4	2	3	3	3	2
19	5	3	4	2	2	2	1	2	4	4	2	4	2	2
20	3	2	2	2	3	2	3	4	5	4	5	2	5	4
21	1	1	2	2	5	5	5	4	5	5	4	4	5	5
22	3	3	4	2	2	3	2	2	4	4	2	3	4	3
23	3	2	5	1	2	3	5	2	2	4	3	5	2	2
24	4	2	3	1	3	3	4	3	3	2	3	2	3	3
25	4	4	5	2	2	2	4	3	3	2	2	5	2	2
26	4	4	2	3	2	2	3	2	2	2	3	2	2	2
27	4	4	4	3	2	4	3	2	4	3	3	4	3	2
28	3	2	2	2	4	3	3	4	4	4	2	3	4	4
29	4	4	4	2	2	4	4	2	3	2	3	4	3	2
30	3	3	2	2	4	3	4	3	1	2	2	4	2	3
31	3	2	2	1	3	2	4	4	4	4	4	3	4	3
32	2	2	2	1	4	2	4	4	5	5	4	2	4	4

Appendix D.4: Engine sound and power-train enhancement

Table D.4. The questionnaire results for engine sound and power-train enhancement

	Questionnaire questions													
	Effort				Vehicle			Driving experience						
Participant nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	2	4	2	3	4	4	4	3	3	2	2	2	2	3
2	3	4	3	4	3	2	4	3	4	3	3	4	3	3
3	2	2	2	2	4	3	4	2	4	3	4	2	4	4
4	3	2	3	2	2	3	3	3	3	4	4	3	3	3
5	2	2	2	2	4	2	4	4	4	4	4	3	3	3
6	4	3	3	3	4	4	4	2	4	4	3	4	3	3
7	1	3	1	1	3	4	4	1	3	3	3	4	2	2
8	2	5	2	2	4	4	4	3	5	5	4	3	4	4
9	3	3	4	3	4	3	5	5	3	4	3	2	3	4
10	2	3	2	4	3	3	4	3	3	4	3	3	3	3
11	1	2	4	2	3	2	3	2	5	4	4	4	3	2
12	3	2	4	3	3	3	4	3	3	4	4	2	3	4
13	4	2	4	4	2	4	4	4	2	2	2	2	2	4
14	2	2	3	5	2	4	3	4	2	1	2	2	2	2
15	4	4	5	3	1	1	3	2	4	2	2	4	3	2
16	4	2	2	3	3	3	4	1	4	3	2	4	3	2
17	3	2	3	2	2	3	2	2	5	5	4	3	3	2
18	2	2	2	2	4	2	3	5	3	4	4	2	5	4
19	5	1	4	2	2	1	2	1	4	3	3	4	2	2
20	4	2	3	4	3	1	5	3	3	2	2	3	2	3
21	2	1	1	4	4	4	5	5	4	4	4	2	4	5
22	3	4	4	3	4	3	3	2	3	3	3	3	2	2
23	4	2	1	5	5	2	4	4	4	1	3	4	2	4
24	4	2	1	5	5	3	4	4	3	1	1	2	1	4
25	4	4	4	2	2	2	3	4	4	4	4	2	3	3
26	3	4	4	1	3	2	3	4	2	2	2	1	2	4
27	4	4	4	4	2	4	4	1	2	2	2	5	2	2
28	3	2	4	4	2	2	3	1	2	3	3	4	3	2
29	4	3	4	2	2	4	3	1	3	3	1	3	2	2
30	3	3	2	2	4	3	4	4	2	4	4	2	4	3
31	3	2	3	3	5	4	4	5	3	3	5	2	4	4
32	4	2	3	4	4	2	5	4	4	2	4	2	2	4

Appendix D.5: Control condition

Table D.5. The questionnaire results for the Control condition

	Questionnaire questions													
	Effort				Vehicle			Driving experience						
Participant nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	4	4	1	5	5	2	5	4	2	3	3	1	2	4
2	2	2	2	3	4	4	5	4	3	4	4	2	5	4
3	2	1	1	2	5	3	4	3	5	4	5	1	5	5
4	4	2	2	2	5	4	5	4	4	1	2	2	4	4
5	2	2	2	4	4	3	5	4	4	4	4	2	4	4
6	4	3	1	2	4	2	3	4	4	4	3	2	4	4
7	4	2	1	2	5	2	5	5	4	4	5	1	4	5
8	2	2	1	2	5	4	5	5	2	4	5	1	5	5
9	5	4	5	4	5	5	5	5	4	4	3	3	4	5
10	5	3	2	2	4	5	3	2	2	2	4	4	3	3
11	4	2	2	1	4	2	5	4	3	2	2	5	3	2
12	2	3	2	3	4	4	1	5	3	4	5	2	5	4
13	4	1	1	1	5	4	4	5	4	5	5	2	5	5
14	5	2	2	4	4	1	4	4	3	3	3	3	4	4
15	3	1	2	2	4	2	1	5	2	3	4	1	4	5
16	2	1	1	2	5	4	3	5	3	5	5	1	5	5
17	2	2	1	3	5	4	5	4	4	4	4	1	4	4
18	2	2	1	4	5	1	1	5	2	4	5	2	5	5
19	4	4	2	3	5	2	4	4	2	3	4	2	5	5
20	2	4	1	5	5	4	4	5	3	4	5	2	5	5
21	5	2	3	3	2	1	4	1	1	3	2	2	2	2
22	3	2	2	4	4	3	4	4	2	3	2	3	2	4
23	4	4	5	4	5	2	5	5	3	3	3	1	2	5
24	4	2	3	3	3	2	5	3	3	1	2	2	2	4
25	3	3	3	4	4	3	4	3	3	4	3	3	3	3
26	1	4	1	2	4	4	5	5	3	4	3	4	4	4
27	4	4	1	3	4	2	3	2	2	2	2	3	2	3
28	2	2	1	2	5	3	2	1	3	2	5	4	4	5
29	4	2	1	4	4	4	5	5	3	4	4	2	5	5
30	2	2	2	3	5	4	4	4	2	2	3	2	2	3
31	5	1	2	3	2	1	4	2	3	4	4	4	3	2
32	2	2	2	5	4	4	4	4	4	4	4	2	4	4

Appendix E: Simulation to determine p-value for non-overlapping, within-subject CIs

Provided by Joost de Winter and checked and amended by Peter Visser

```
clear all;close all;clc
reps=10^5;
hci=zeros(reps,1);
ht=NaN(reps,1);
pt=NaN(reps,1);

for i=1:reps
    X=randn(10,5);
    CI=within_subject_ci(X);
    CIhigh=mean(X)+CI;
    CIlow=mean(X)-CI;
    if CIhigh(1)<CIlow(2) || CIlow(1)>CIhigh(2)
        hci(i)=1;
    end
    [ht,pt(i)]=ttest(X(:,1),X(:,2));
end

disp([mean(hci==1) max(pt(hci==1))])

function CI = within_subject_ci(X)
X=X-repmat(nanmean(X')',1,size(X,2)); % subtract participant mean
[~,~,ci]=ttest(X); % calculate confidence interval assuming a normal distribution
CI=diff(ci)/2*sqrt(size(X,2)/(size(X,2)-1)); % Correction factor as described in Morey (2008)
end
% CI is half of the confidence interval; so it should be plotted from mean-CI to mean+CI
% Morey, R. D. (2008). Confidence intervals from normalized data: A correction to Cousineau (2005). Reason, 4, 61-64.
```

This simulation estimates the chance that two set of results produce non-overlapping CIs while they are not significantly different. The results show that this chance is smaller than 0.6%.

Appendix F: Correlation tables

The Spearman correlation was calculated between all dependent measures for each condition. In addition the mileage in km/year of the participants was added.

Appendix F.1: No enhancement

Table F.1. Spearman correlation matrix for the **No enhancement** condition.

	Perceived sportiness	Perceived engine responsiveness	Perceived comfort	Sound	Mean speed	Mean absolute acceleration	Mean throttle driver	Mean throttle engine	Mean throttle reversal rate	Mean brake depression	15^{th} percentile TLC	Perceived danger	Mileage
Perceived sportiness	1.00	0.54	0.38	0.27	-0.02	-0.11	0.03	-0.01	-0.15	0.18	0.00	0.05	-0.11
Perceived engine responsiveness	0.54	1.00	0.31	-0.16	-0.10	-0.10	-0.14	-0.12	0.12	0.14	0.01	-0.15	-0.14
Perceived comfort	0.38	0.31	1.00	-0.15	0.10	0.27	0.13	0.14	-0.02	0.44	-0.06	0.41	0.37
Sound	0.27	-0.16	-0.15	1.00	-0.38	-0.26	-0.35	-0.37	-0.05	-0.06	0.34	-0.33	0.02
Speed	-0.02	-0.10	0.10	-0.38	1.00	0.75	0.93	0.98	0.10	0.10	-0.88	0.26	-0.04
Acceleration	-0.11	-0.10	0.27	-0.26	0.75	1.00	0.71	0.75	0.34	0.11	-0.65	0.08	-0.05
Throttle driver	0.03	-0.14	0.13	-0.35	0.93	0.71	1.00	0.98	0.01	0.18	-0.80	0.27	-0.06
Throttle engine	-0.01	-0.12	0.14	-0.37	0.98	0.75	0.98	1.00	0.07	0.15	-0.85	0.27	-0.05
Throttle reversal rate	-0.15	0.12	-0.02	-0.05	0.10	0.34	0.01	0.07	1.00	0.17	-0.20	-0.26	-0.01
Brake depression	0.18	0.14	0.44	-0.06	0.10	0.11	0.18	0.15	0.17	1.00	-0.12	0.19	0.30
15^{th} percentile TLC	0.00	0.01	-0.06	0.34	-0.88	-0.65	-0.80	-0.85	-0.20	-0.12	1.00	-0.10	-0.07
Perceived danger	0.05	-0.15	0.41	-0.33	0.26	0.08	0.27	0.27	-0.26	0.19	-0.10	1.00	0.21
Mileage	-0.11	-0.14	0.37	0.02	-0.04	-0.05	-0.06	-0.05	-0.01	0.30	-0.07	0.21	1.00

Appendix F.2: Power-train enhancement

Table F.2. Spearman correlation matrix for the **Power-train enhancement** condition.

	Perceived sportiness	Perceived engine responsiveness	Perceived comfort	Sound	Mean speed	Mean absolute acceleration	Mean throttle driver	Mean throttle engine	Mean throttle reversal rate	Mean brake depression	15^{th} percentile TLC	Perceived danger	Mileage
Perceived sportiness	1.00	0.56	0.27	0.05	0.23	0.23	0.17	0.18	0.32	-0.14	-0.15	0.05	-0.27
Perceived engine responsiveness	0.56	1.00	0.18	0.18	-0.14	-0.04	-0.14	-0.16	0.05	0.15	0.16	-0.21	-0.21
Perceived comfort	0.27	0.18	1.00	0.20	0.16	-0.02	0.11	0.13	0.06	0.21	-0.05	0.64	0.33
Sound	0.05	0.18	0.20	1.00	-0.02	0.12	0.06	0.01	-0.10	0.52	0.25	0.18	-0.02
Speed	0.23	-0.14	0.16	-0.02	1.00	0.66	0.92	0.97	0.34	0.17	-0.84	0.14	-0.13
Acceleration	0.23	-0.04	-0.02	0.12	0.66	1.00	0.79	0.74	0.52	0.29	-0.52	0.00	-0.24
Throttle driver	0.17	-0.14	0.11	0.06	0.92	0.79	1.00	0.99	0.37	0.26	-0.72	0.08	-0.16
Throttle engine	0.18	-0.16	0.13	0.01	0.97	0.74	0.99	1.00	0.38	0.22	-0.78	0.10	-0.13
Throttle reversal rate	0.32	0.05	0.06	-0.10	0.34	0.52	0.37	0.38	1.00	0.15	-0.38	-0.01	-0.15
Brake depression	-0.14	0.15	0.21	0.52	0.17	0.29	0.26	0.22	0.15	1.00	-0.04	0.12	0.12
15^{th} percentile TLC	-0.15	0.16	-0.05	0.25	-0.84	-0.52	-0.72	-0.78	-0.38	-0.04	1.00	0.01	-0.04
Perceived danger	0.05	-0.21	0.64	0.18	0.14	0.00	0.08	0.10	-0.01	0.12	0.01	1.00	0.43
Mileage	-0.27	-0.21	0.33	-0.02	-0.13	-0.24	-0.16	-0.13	-0.15	0.12	-0.04	0.43	1.00

Appendix F.3: Engine sound enhancement

Table F.3. Spearman correlation matrix for the **Engine sound enhancement** condition.

	Perceived sportiness	Perceived engine responsiveness	Perceived comfort	Sound	Mean speed	Mean absolute acceleration	Mean throttle driver	Mean throttle engine	Mean throttle reversal rate	Mean brake depression	15^{th} percentile TLC	Perceived danger	Mileage
Perceived sportiness	1.00	0.67	0.47	0.32	-0.01	-0.08	-0.04	-0.05	-0.04	-0.03	-0.16	0.28	0.28
Perceived engine responsiveness	0.67	1.00	0.36	0.22	-0.20	-0.27	-0.23	-0.24	-0.02	-0.19	0.00	0.21	0.01
Perceived comfort	0.47	0.36	1.00	0.15	0.11	0.14	-0.01	0.03	-0.06	-0.25	-0.33	0.56	0.08
Sound	0.32	0.22	0.15	1.00	-0.09	-0.04	-0.08	-0.10	-0.18	-0.14	0.09	-0.13	-0.19
Speed	-0.01	-0.20	0.11	-0.09	1.00	0.76	0.95	0.97	0.28	0.37	-0.77	0.13	0.15
Acceleration	-0.08	-0.27	0.14	-0.04	0.76	1.00	0.78	0.79	0.44	0.28	-0.51	0.24	0.09
Throttle driver	-0.04	-0.23	-0.01	-0.08	0.95	0.78	1.00	0.99	0.31	0.49	-0.68	0.11	0.13
Throttle engine	-0.05	-0.24	0.03	-0.10	0.97	0.79	0.99	1.00	0.29	0.42	-0.71	0.13	0.15
Throttle reversal rate	-0.04	-0.02	-0.06	-0.18	0.28	0.44	0.31	0.29	1.00	0.39	-0.31	0.00	-0.02
Brake depression	-0.03	-0.19	-0.25	-0.14	0.37	0.28	0.49	0.42	0.39	1.00	-0.41	-0.07	0.28
15^{th} percentile TLC	-0.16	0.00	-0.33	0.09	-0.77	-0.51	-0.68	-0.71	-0.31	-0.41	1.00	-0.26	-0.23
Perceived danger	0.28	0.21	0.56	-0.13	0.13	0.24	0.11	0.13	0.00	-0.07	-0.26	1.00	0.36
Mileage	0.28	0.01	0.08	-0.19	0.15	0.09	0.13	0.15	-0.02	0.28	-0.23	0.36	1.00

Appendix F.4: Engine sound and power-train enhancement

Table F.4. Spearman correlation matrix for the **Engine sound and Power-train enhancement** condition.

	Perceived sportiness	Perceived engine responsiveness	Perceived comfort	Sound	Mean speed	Mean absolute acceleration	Mean throttle driver	Mean throttle engine	Mean throttle reversal rate	Mean brake depression	15^{th} percentile TLC	Perceived danger	Mileage
Perceived sportiness	1.00	0.51	-0.02	0.39	0.14	0.09	0.20	0.19	-0.13	0.06	-0.06	-0.13	0.00
Perceived engine responsiveness	0.51	1.00	-0.01	0.54	0.15	-0.04	0.07	0.10	-0.07	0.08	-0.12	0.13	0.07
Perceived comfort	-0.02	-0.01	1.00	-0.13	0.06	-0.08	-0.12	-0.05	0.12	-0.43	0.03	0.43	-0.11
Sound	0.39	0.54	-0.13	1.00	0.00	-0.11	0.01	0.01	-0.03	0.07	0.02	-0.07	0.16
Speed	0.14	0.15	0.06	0.00	1.00	0.65	0.93	0.97	0.36	-0.13	-0.88	-0.16	0.01
Acceleration	0.09	-0.04	-0.08	-0.11	0.65	1.00	0.72	0.68	0.56	-0.01	-0.58	-0.19	-0.08
Throttle driver	0.20	0.07	-0.12	0.01	0.93	0.72	1.00	0.98	0.34	-0.07	-0.79	-0.16	-0.03
Throttle engine	0.19	0.10	-0.05	0.01	0.97	0.68	0.98	1.00	0.35	-0.09	-0.85	-0.17	-0.01
Throttle reversal rate	-0.13	-0.07	0.12	-0.03	0.36	0.56	0.34	0.35	1.00	0.15	-0.34	-0.10	0.07
Brake depression	0.06	0.08	-0.43	0.07	-0.13	-0.01	-0.07	-0.09	0.15	1.00	-0.04	-0.25	0.45
15^{th} percentile TLC	-0.06	-0.12	0.03	0.02	-0.88	-0.58	-0.79	-0.85	-0.34	-0.04	1.00	0.21	0.00
Perceived danger	-0.13	0.13	0.43	-0.07	-0.16	-0.19	-0.16	-0.17	-0.10	-0.25	0.21	1.00	-0.09
Mileage	0.00	0.07	-0.11	0.16	0.01	-0.08	-0.03	-0.01	0.07	0.45	0.00	-0.09	1.00

Appendix F.5: Control condition

Table F.5. Spearman correlation matrix for the **Control** condition.

	Perceived sportiness	Perceived engine responsiveness	Perceived comfort	Sound	Mean speed	Mean absolute acceleration	Mean throttle driver	Mean throttle engine	Mean throttle reversal rate	Mean brake depression	15^{th} percentile TLC	Perceived danger	Mileage
Perceived sportiness	1.00	0.52	0.47	0.10	-0.20	-0.12	-0.18	-0.19	-0.18	-0.19	0.24	0.24	0.02
Perceived engine responsiveness	0.52	1.00	0.14	0.02	-0.19	-0.21	-0.23	-0.22	0.02	-0.13	0.22	0.28	0.06
Perceived comfort	0.47	0.14	1.00	-0.03	0.14	0.16	0.19	0.18	0.05	-0.08	-0.07	0.32	0.02
Sound	0.10	0.02	-0.03	1.00	0.01	0.08	0.07	0.05	0.03	0.12	-0.13	0.29	0.03
Speed	-0.20	-0.19	0.14	0.01	1.00	0.80	0.96	0.98	0.41	0.44	-0.85	-0.08	0.04
Acceleration	-0.12	-0.21	0.16	0.08	0.80	1.00	0.87	0.86	0.48	0.42	-0.65	-0.07	-0.10
Throttle driver	-0.18	-0.23	0.19	0.07	0.96	0.87	1.00	0.99	0.36	0.47	-0.76	-0.02	-0.01
Throttle engine	-0.19	-0.22	0.18	0.05	0.98	0.86	0.99	1.00	0.36	0.44	-0.79	-0.04	0.00
Throttle reversal rate	-0.18	0.02	0.05	0.03	0.41	0.48	0.36	0.36	1.00	0.62	-0.39	-0.12	0.06
Brake depression	-0.19	-0.13	-0.08	0.12	0.44	0.42	0.47	0.44	0.62	1.00	-0.41	-0.06	0.00
15^{th} percentile TLC	0.24	0.22	-0.07	-0.13	-0.85	-0.65	-0.76	-0.79	-0.39	-0.41	1.00	0.13	-0.23
Perceived danger	0.24	0.28	0.32	0.29	-0.08	-0.07	-0.02	-0.04	-0.12	-0.06	0.13	1.00	-0.04
Mileage	0.02	0.06	0.02	0.03	0.04	-0.10	-0.01	0.00	0.06	0.00	-0.23	-0.04	1.00

Appendix G: Maximum speed analysis

Table G.1. The maximum, mean and standard deviation of the maximum speed over all participants and for each condition.

	Off	PTE	ESE	PTE ESE	Control
Maximum maximum speed (km/h)	149	149	149	149	203
Mean maximum speed (km/h)	122	124	121	119	136
SD maximum speed (km/h)	21	20	22	21	33

Appendix H: Order effects

Appendix H.1: A selection of metrics calculated for each trail

Table H.1. An analysis of the order effects for various dependent measures and additional metrics.

	Trail 1	Trail 2	Trail 3	Trail 4	Trail 5
Mean Speed (km/h)	78.26	80.08	82.68	85.19	84.28
STD Speed (km/h)	11.36	10.86	13.61	12.48	12.13
Mean perceived sportiness (-)	2.19	2.75	2.88	3.13	2.28
STD perceived sportiness (-)	1.00	1.44	1.34	1.43	1.40
Mean maximum speed (km/h)	120.17	120.55	124.32	129.95	126.19
STD maximum speed (km/h)	28.66	20.45	25.31	26.46	20.90
Mean Time Off-Road (%)	3.83	3.67	3.87	4.21	4.42
STD Time Off-Road (%)	3.28	3.49	3.20	3.61	4.36

Appendix H.2: The order of Condition per participant

Table H.2. The order in which each participant experienced the conditions.

Par. nr.	Trail 1	Trail 2	Trail 3	Trail 4	Trail 5
1	Off	PTE	ESE	PTE-ESE	Control condition
2	ESE	Control condition	Off	PTE-ESE	PTE
3	PTE	ESE	PTE-ESE	Control condition	Off
4	PTE	PTE-ESE	ESE	Off	Control condition
5	Off	ESE	Control condition	PTE-ESE	PTE
6	Control condition	ESE	PTE-ESE	PTE	Off
7	PTE-ESE	PTE	Off	Control condition	ESE
8	Off	PTE	PTE-ESE	Control condition	ESE
9	ESE	PTE-ESE	Control condition	PTE	Off
10	Control condition	PTE	ESE	Off	PTE-ESE
11	PTE-ESE	Off	PTE	ESE	Control condition
12	Off	PTE-ESE	PTE	Control condition	ESE
13	PTE	PTE-ESE	Control condition	ESE	Off
14	Control condition	Off	PTE-ESE	ESE	PTE
15	PTE	ESE	Control condition	PTE-ESE	Off
16	ESE	PTE-ESE	Off	PTE	Control condition
17	Off	Control condition	ESE	PTE-ESE	PTE
18	ESE	PTE-ESE	PTE	Off	Control condition
19	PTE	ESE	Off	Control condition	PTE-ESE
20	PTE-ESE	Off	PTE	Control condition	ESE
21	Control condition	Off	PTE-ESE	PTE	ESE
22	Control condition	PTE	PTE-ESE	Off	ESE
23	PTE-ESE	Control condition	PTE	ESE	Off
24	ESE	Control condition	PTE	Off	PTE-ESE
25	ESE	Control condition	PTE-ESE	PTE	Off
26	PTE	ESE	Control condition	Off	PTE-ESE
27	Control condition	Off	PTE	ESE	PTE-ESE
28	PTE-ESE	PTE	ESE	Off	Control condition
29	PTE-ESE	ESE	Off	Control condition	PTE
30	ESE	PTE-ESE	Control condition	Off	PTE
31	Control condition	PTE	Off	PTE-ESE	ESE
32	Control condition	Off	ESE	PTE-ESE	PTE

Appendix I: Speed on straight section

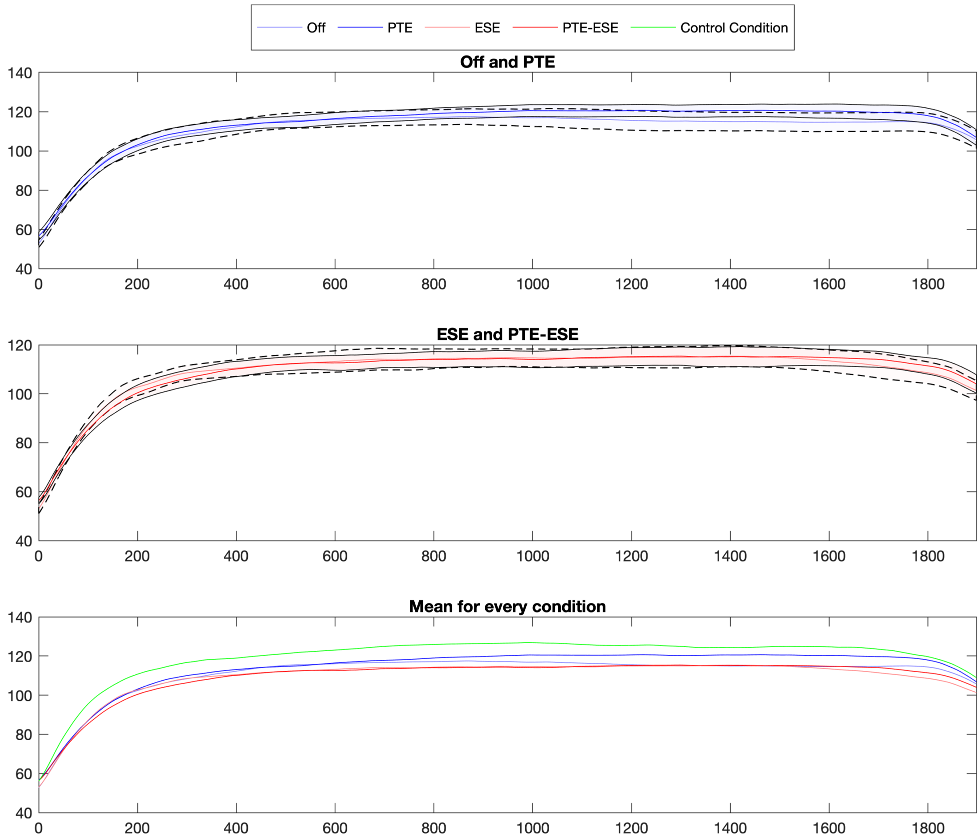


Fig. I.1. Average speed during the straight section per condition and with the within-subject 95% CI. The CIs were calculated for every 20 cm of the straight section by taking the mean speed for each participants and for each condition, creating a 5x32 matrix for each road point and calculating the within-subject CIs for that point.

Appendix J: Speed through corners

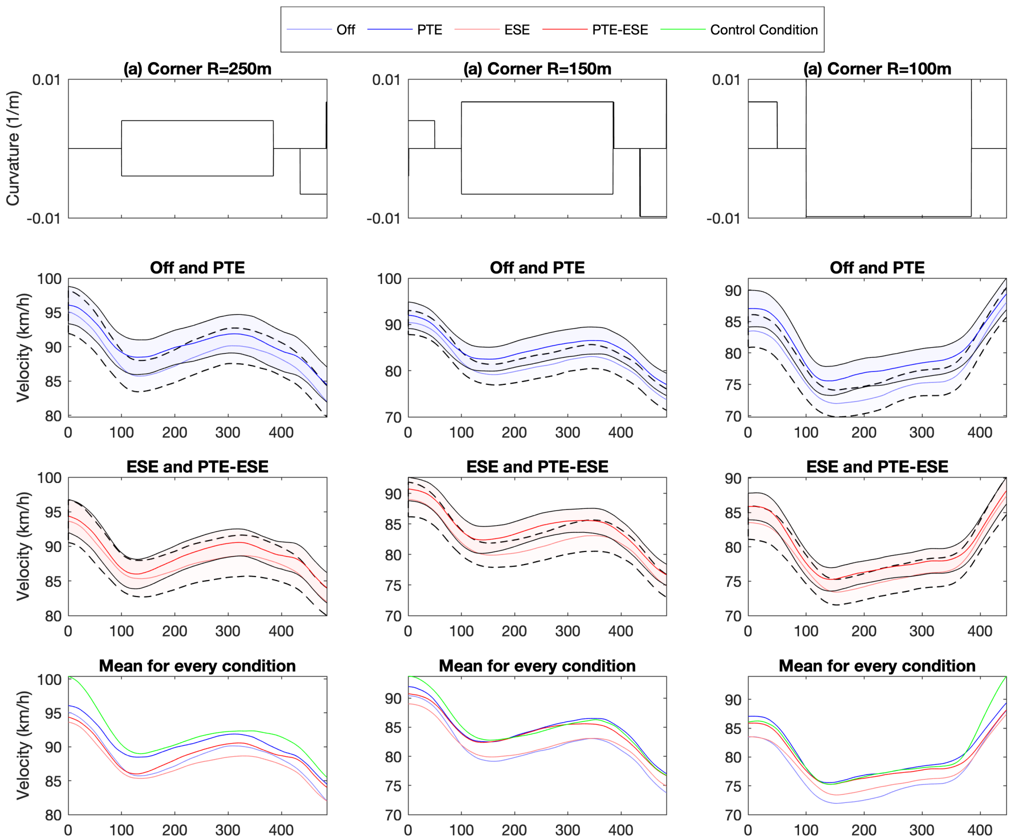
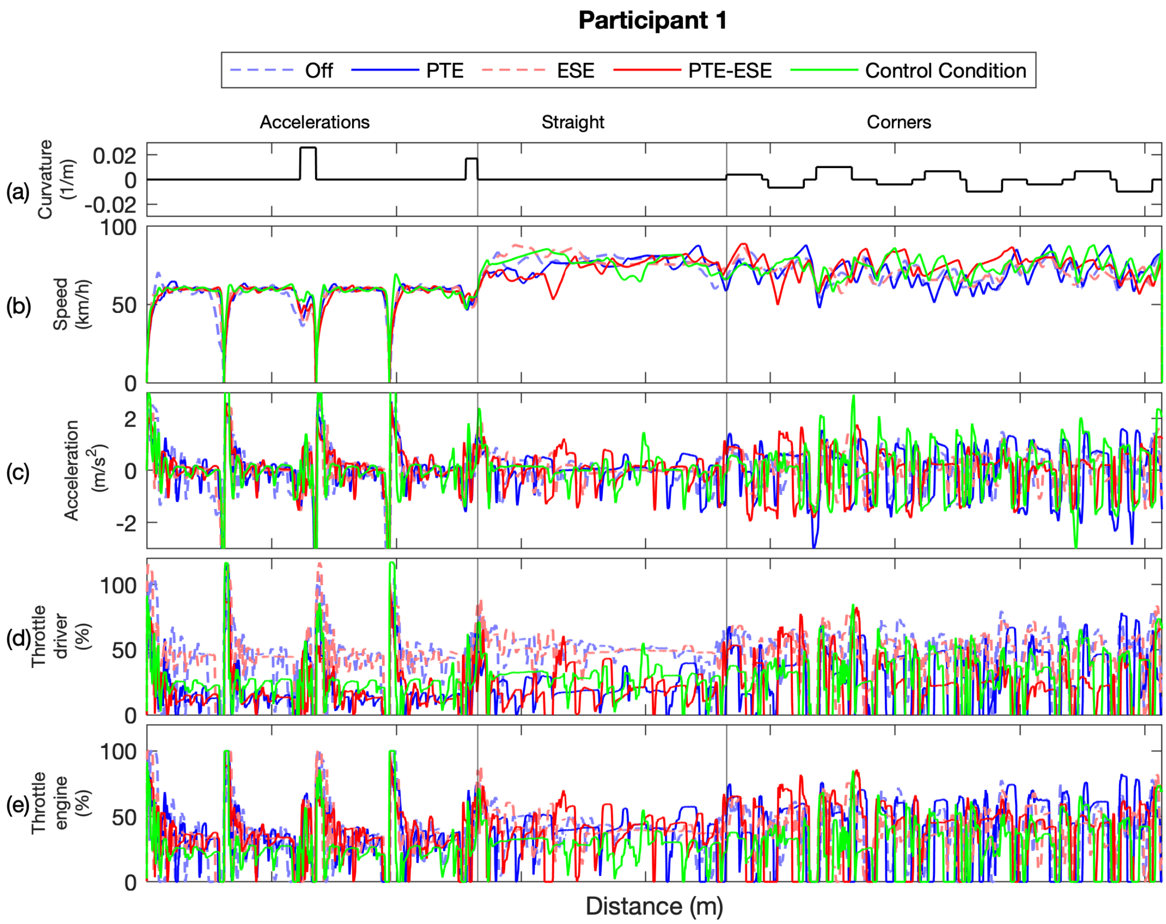
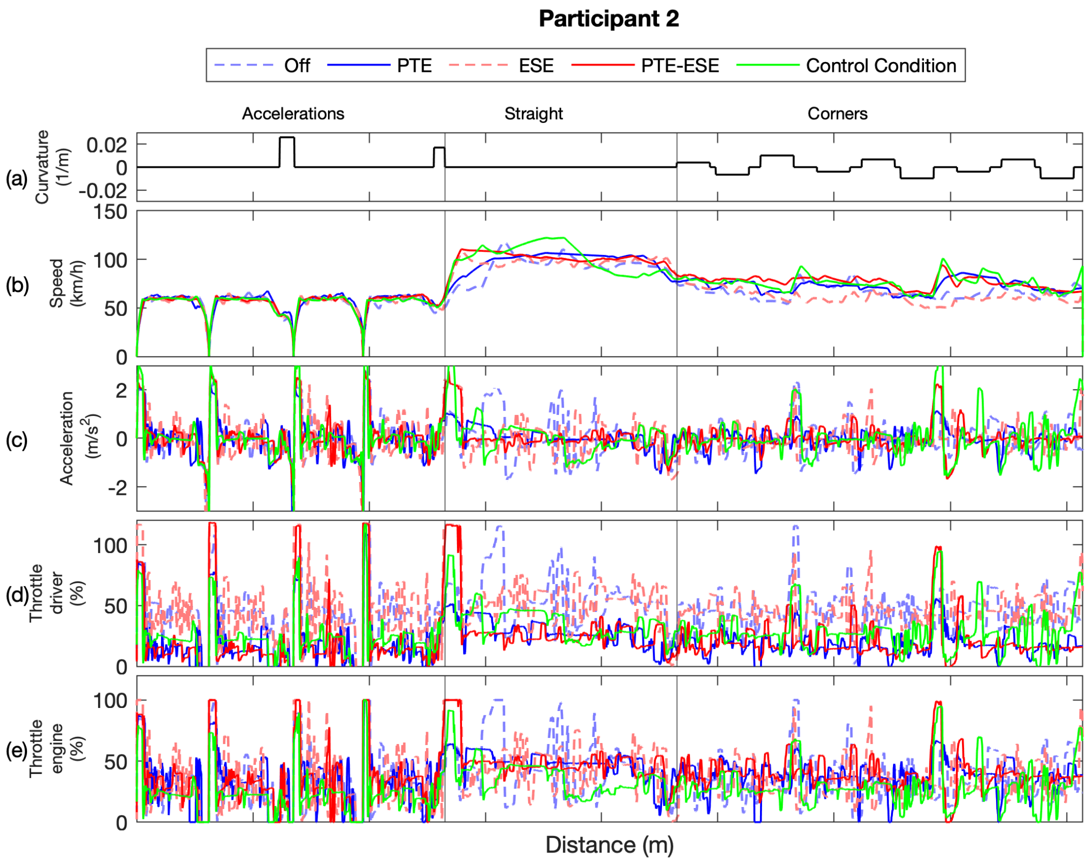


Fig. J.1. Average speed for each of the three corner types per condition and with the within-subject 95% CI. The CI were calculated for every 20 cm of the corner by taking the mean speed for each participants over the three corner instances (every corner type, with the same radius, occurred three times) and for each condition, creating a 5x32 matrix and calculating the within-subject CIs.

Appendix K: Figure 4 from paper for every participant

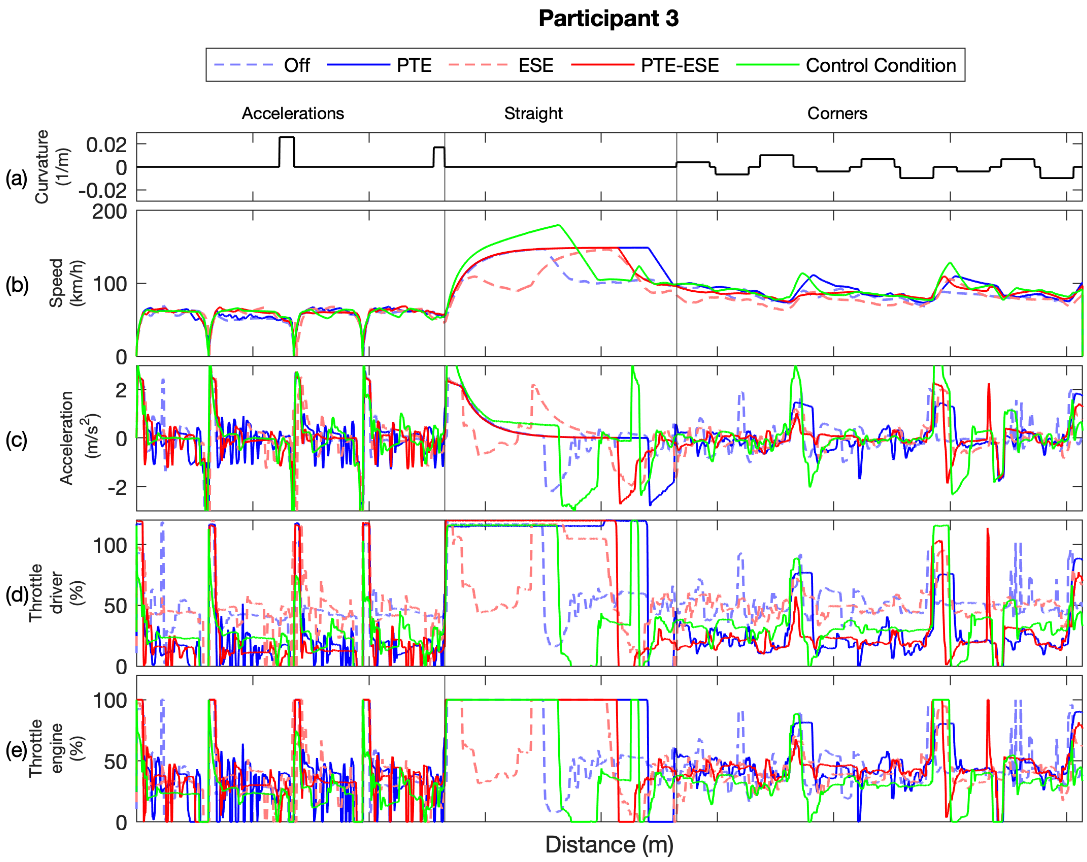
Appendix K.1: Participant 1 and 2

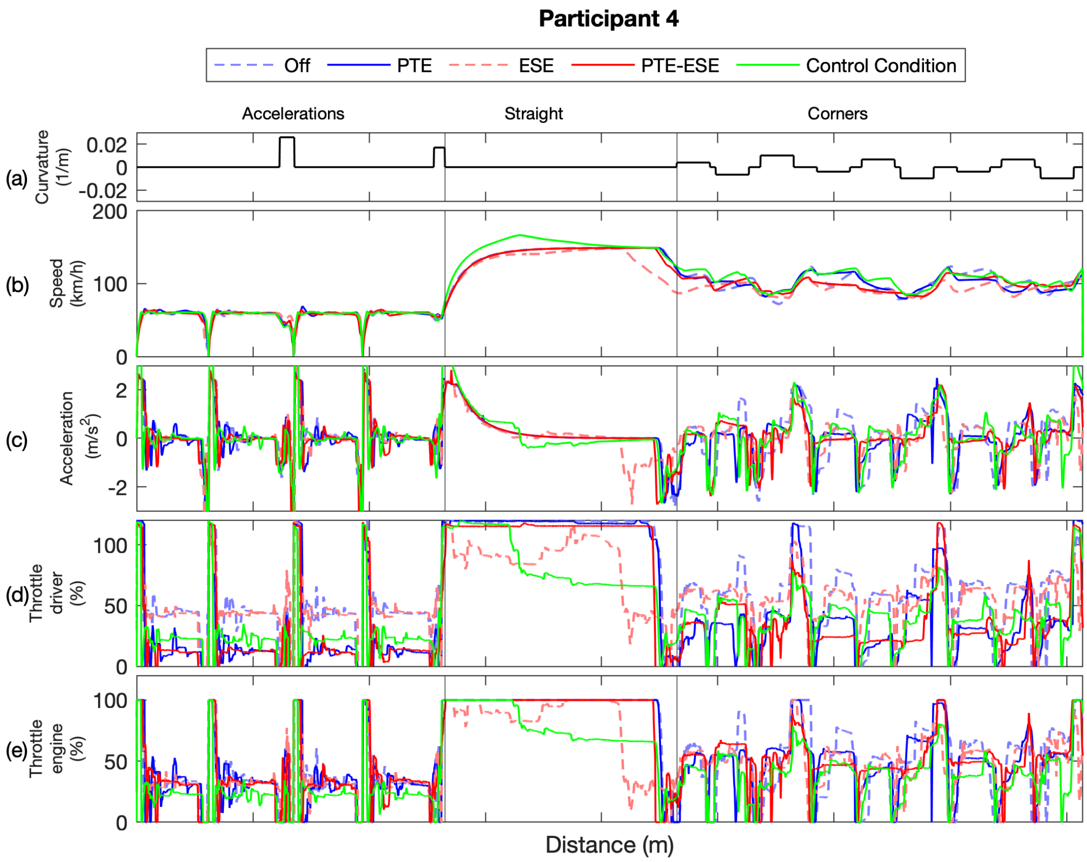




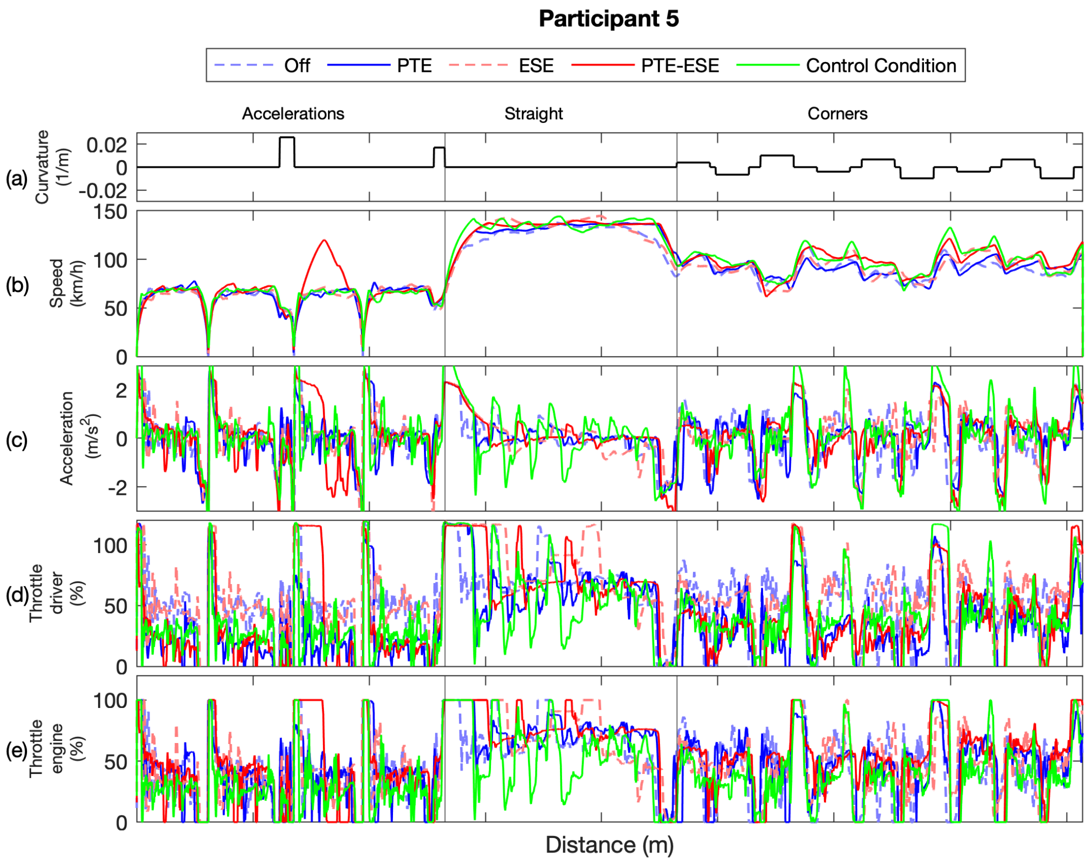
Participant 2
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
150
100
50
0
(c)
Acceleration (m/s^2)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

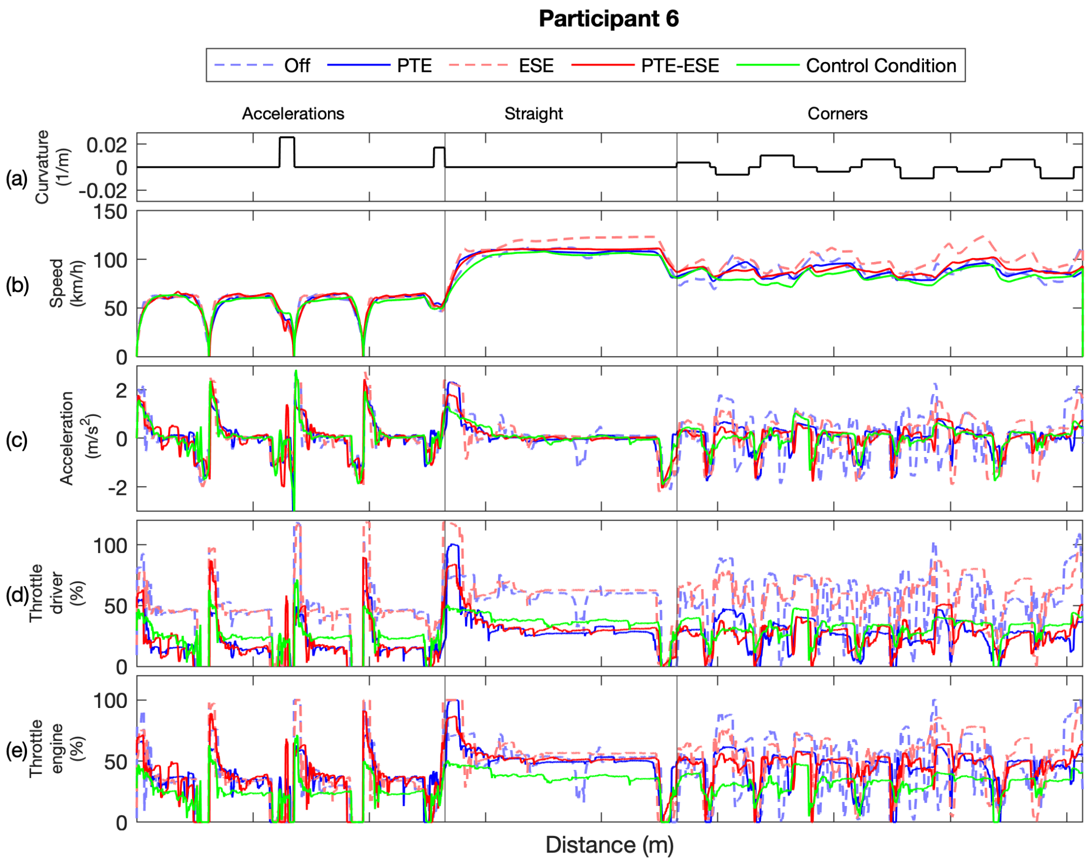
Appendix K.3: Participant 3 and 4



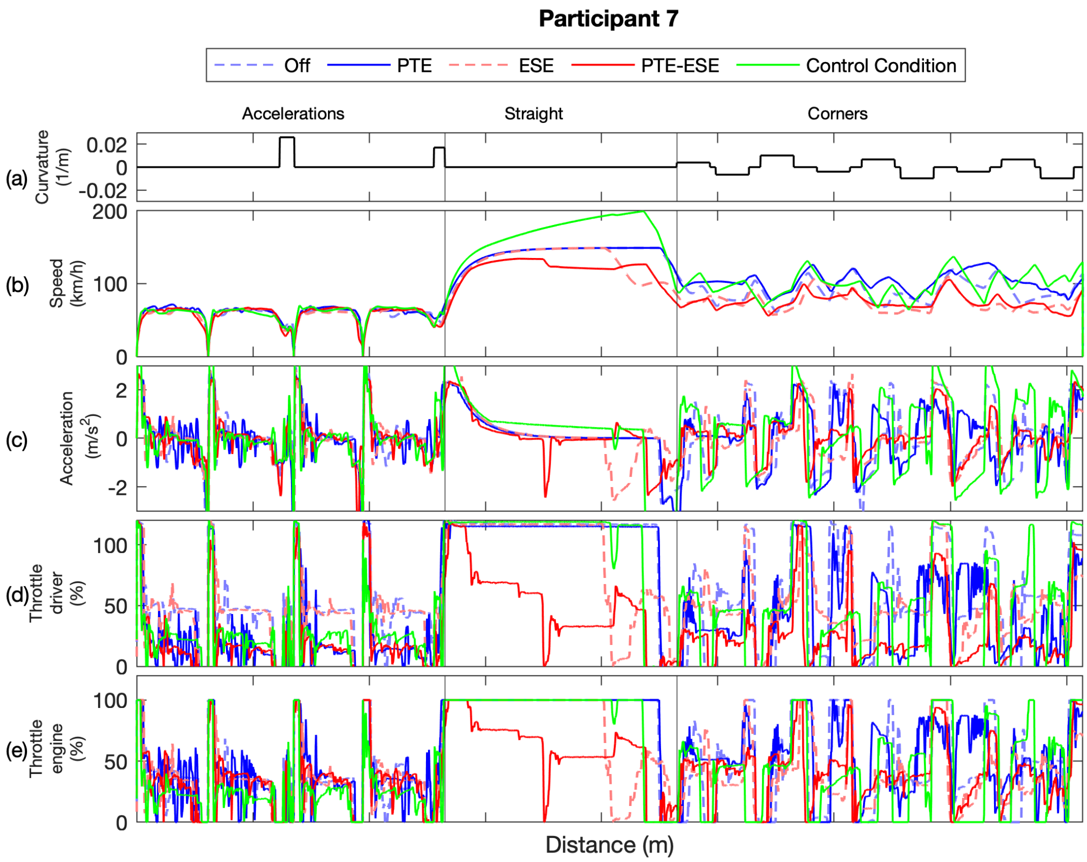

Participant 4
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
200
100
0
(c)
Acceleration (m/s²)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

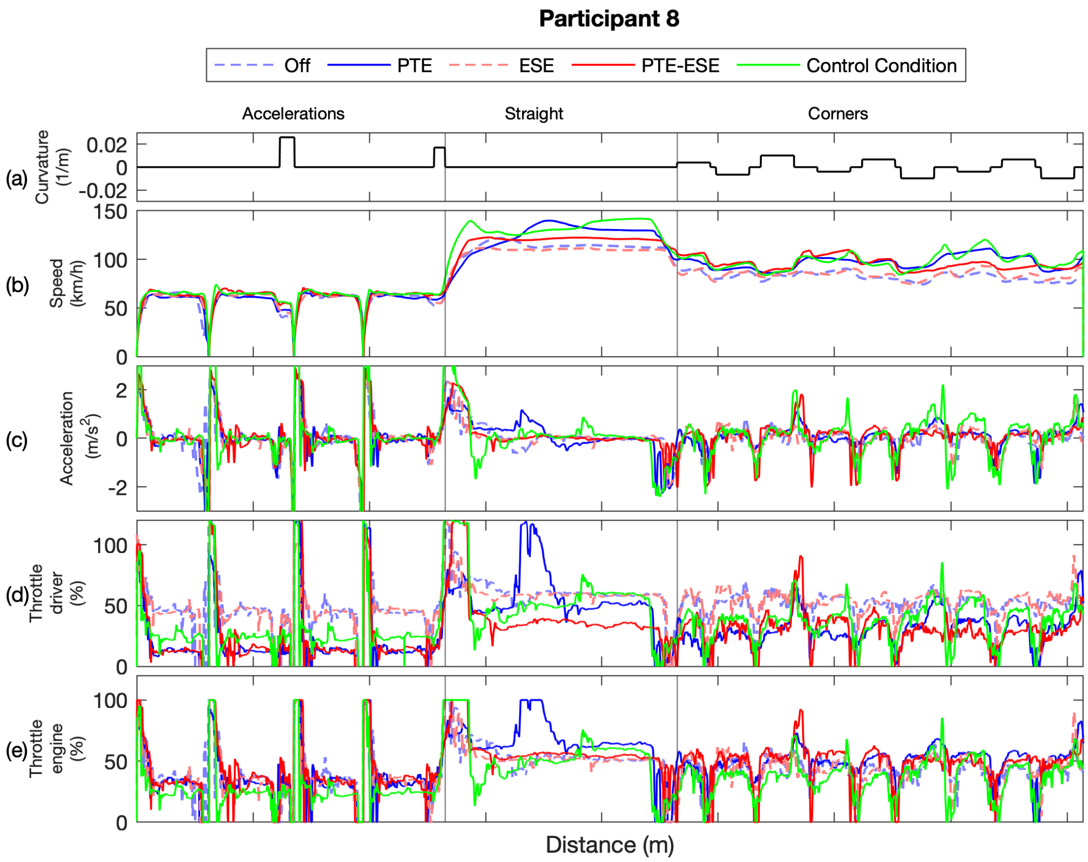
Appendix K.5: Participant 5 and 6




Participant 6
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
150
100
50
0
(c)
Acceleration (m/s^2)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

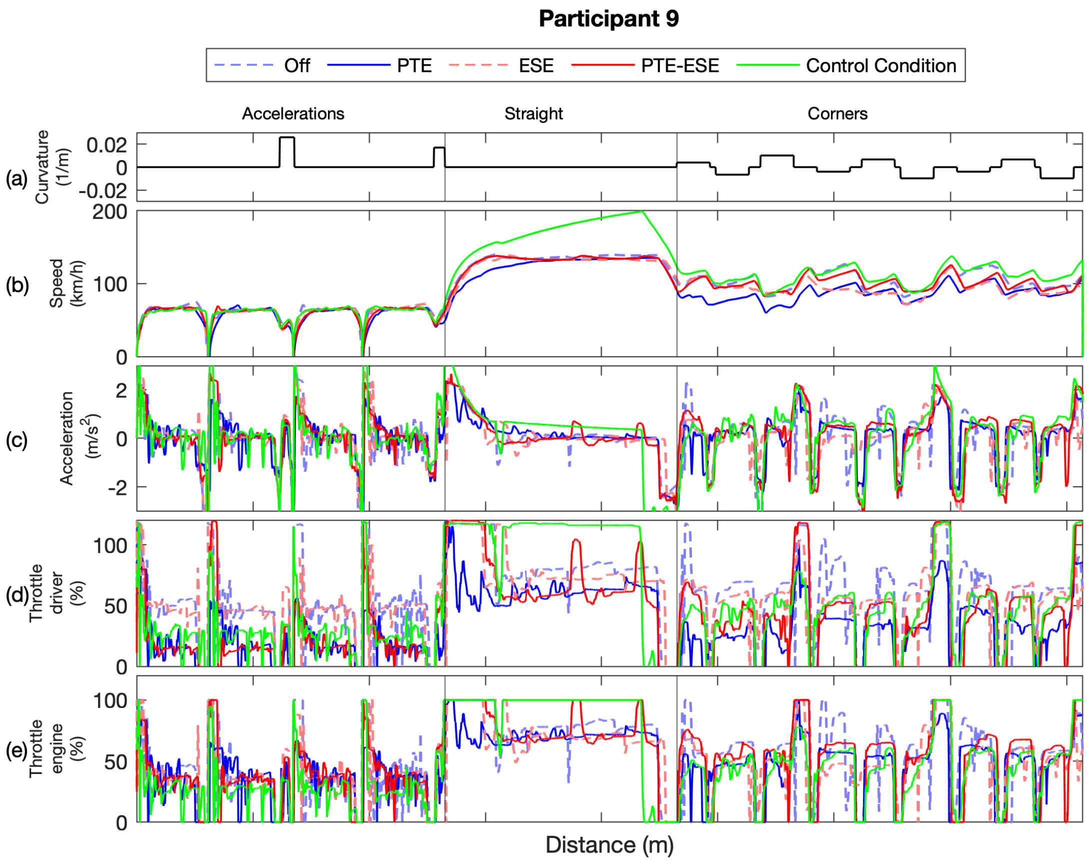
Appendix K.7: Participant 7 and 8

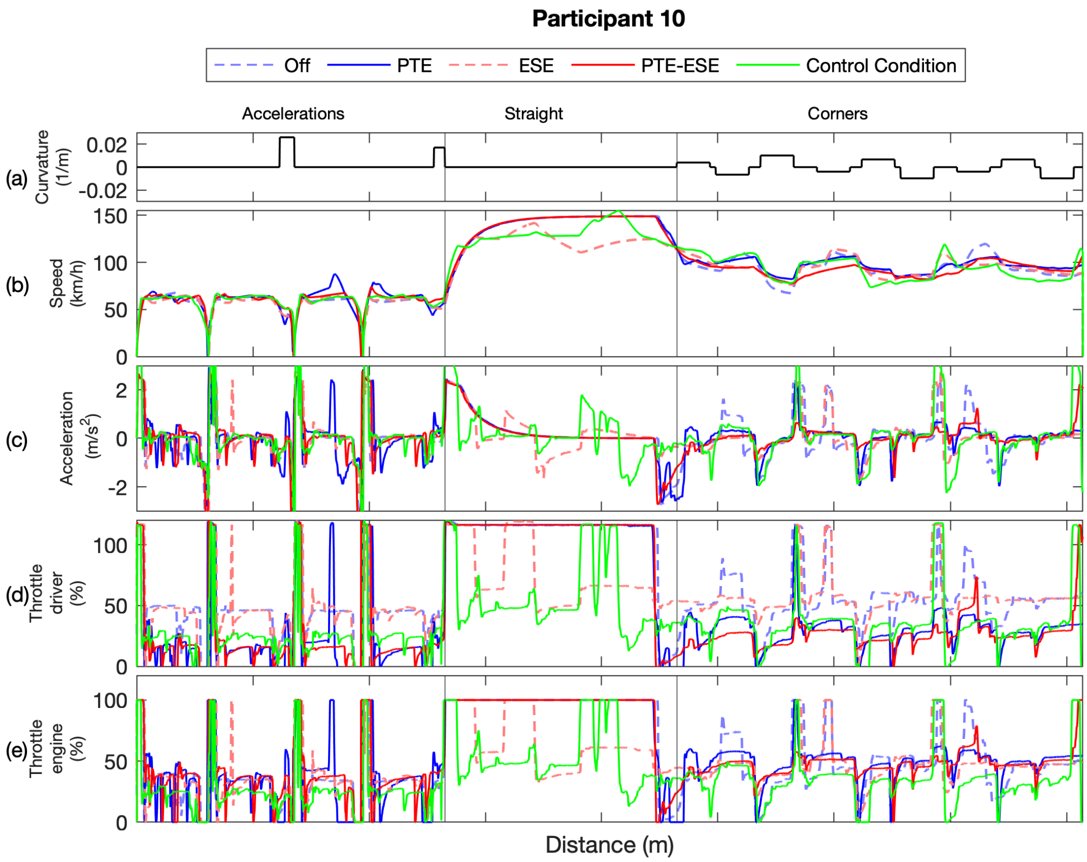




Participant 8
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
150
100
50
0
(c)
Acceleration (m/s^2)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

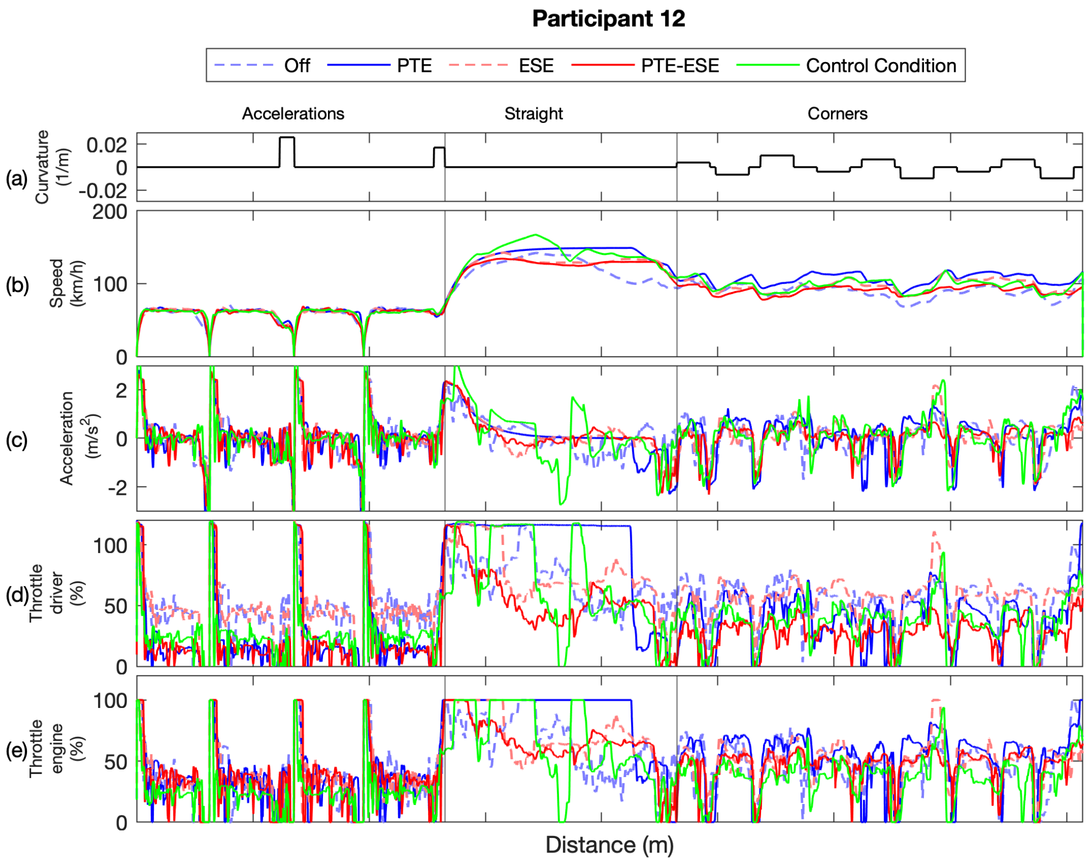
Appendix K.9: Participant 9 and 10





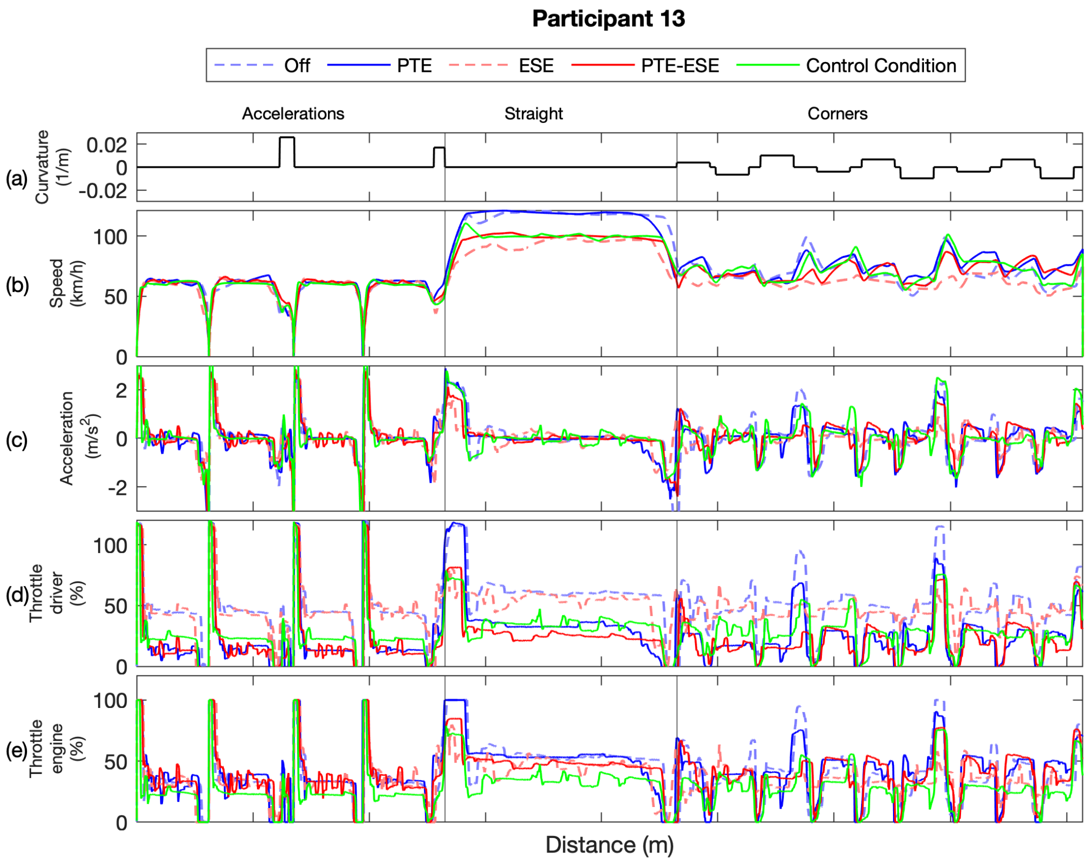
Participant 10
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
150
100
50
0
(c)
Acceleration (m/s²)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

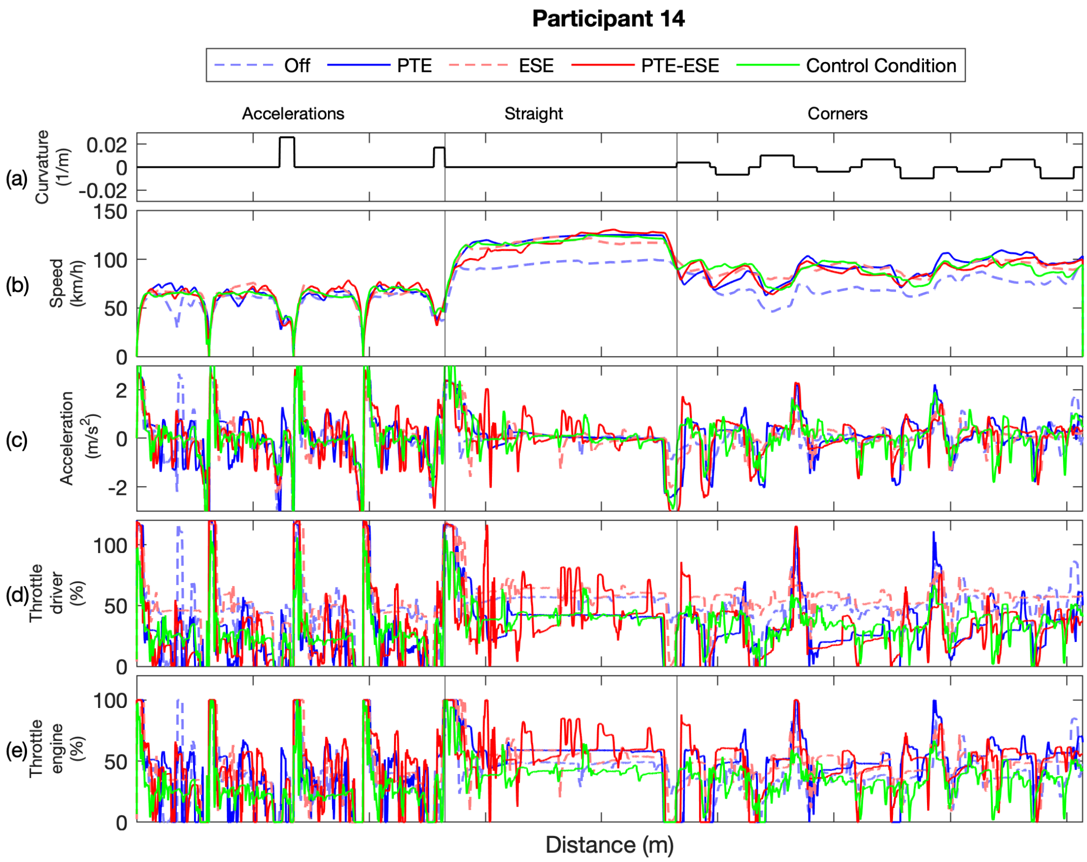
Appendix K.11: Participant 11 and 12



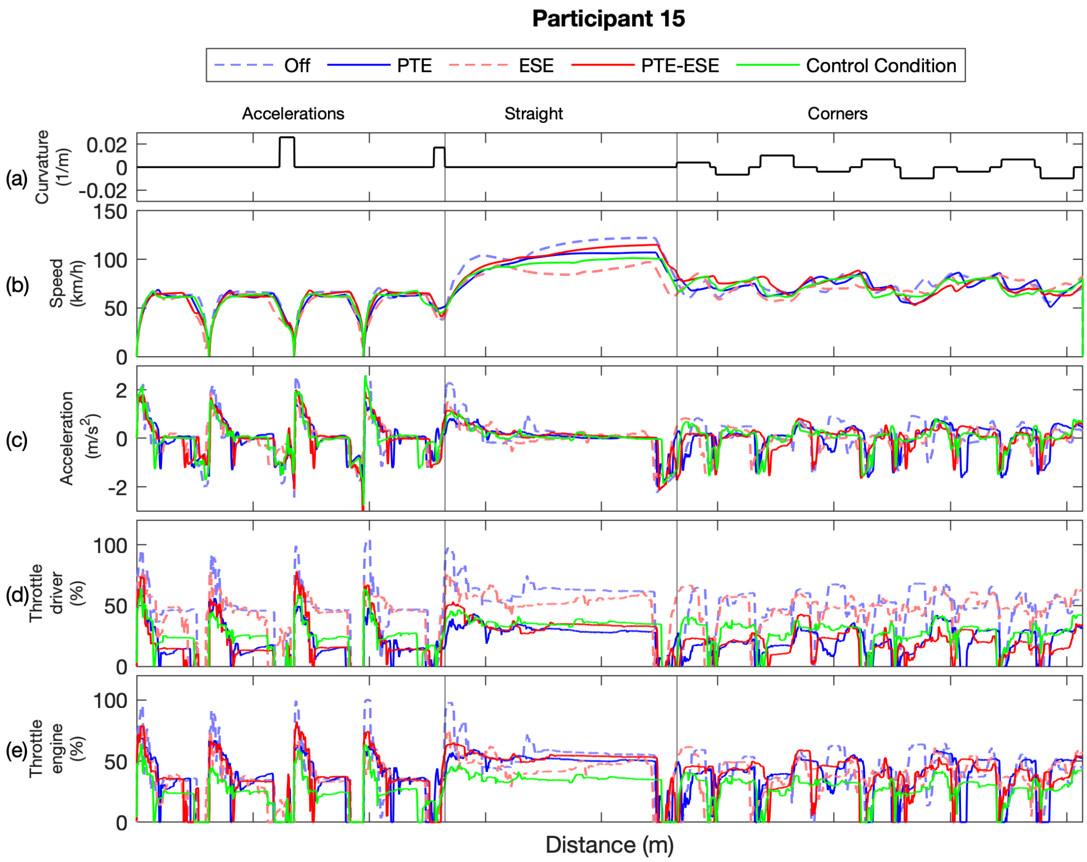
Participant 12
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
200
100
0
(c)
Acceleration (m/s2)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

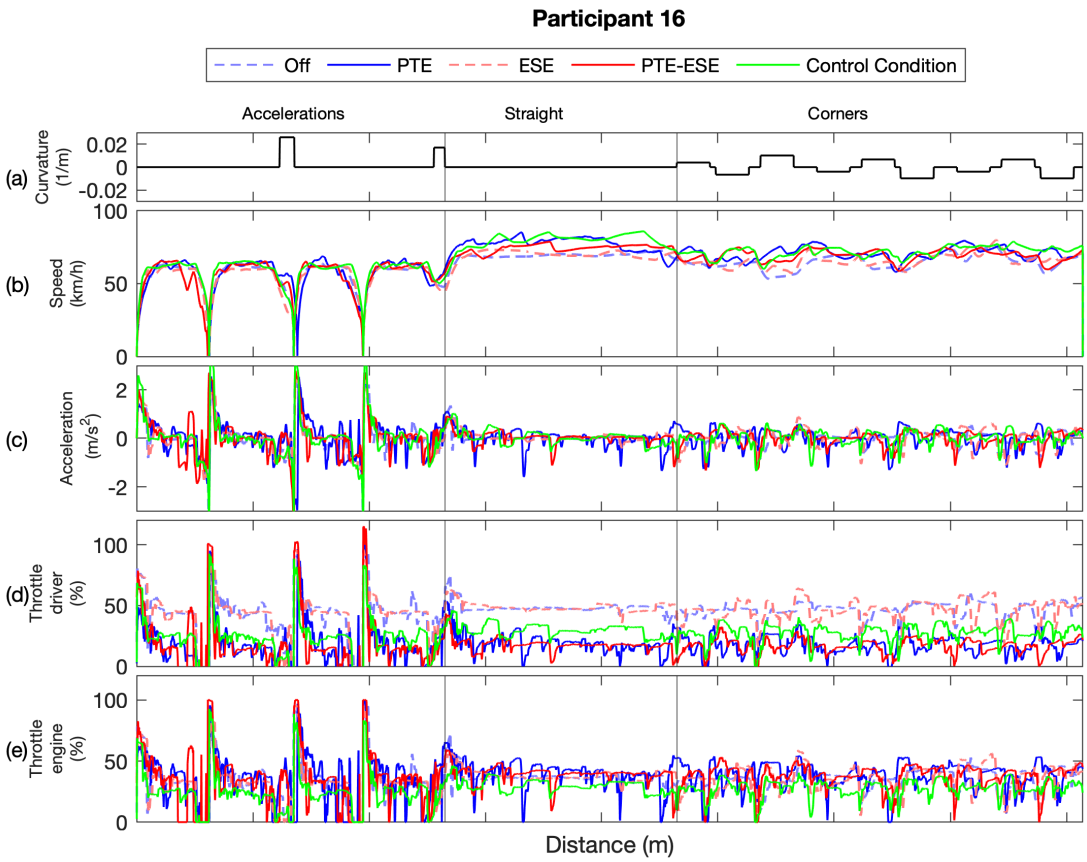
Appendix K.13: Participant 13 and 14



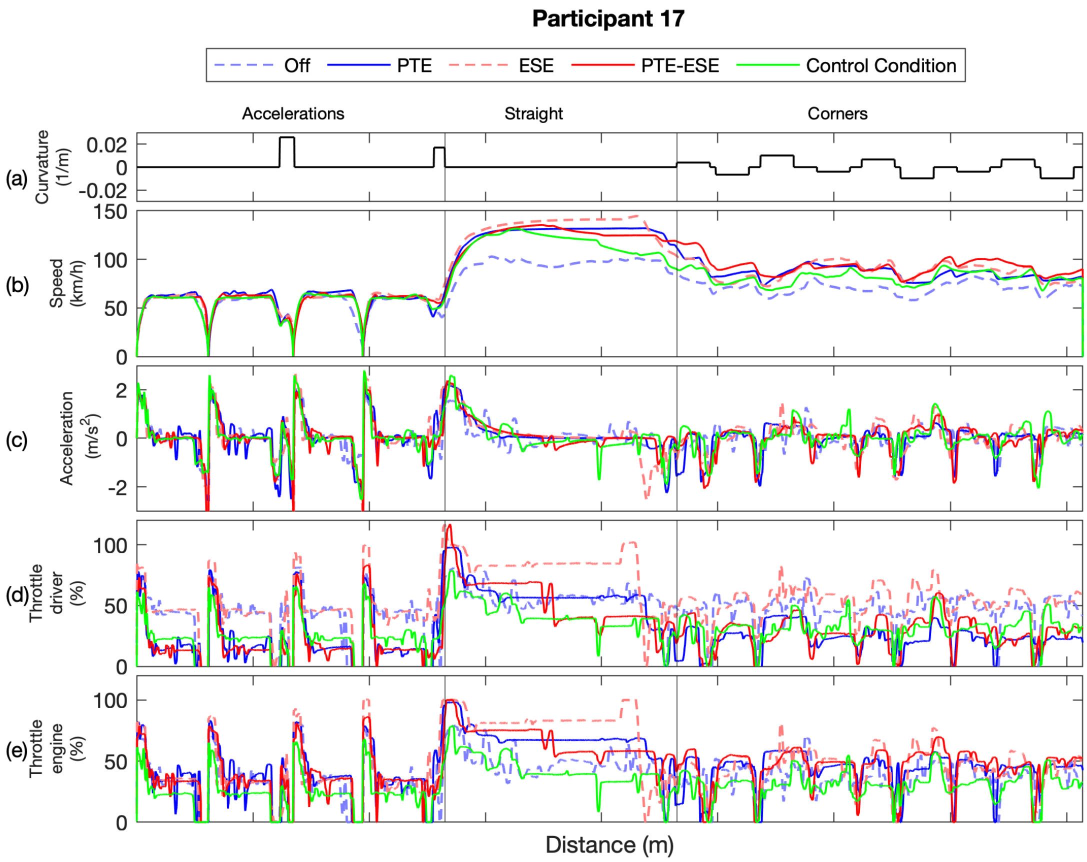

Participant 14
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
150
100
50
0
(c)
Acceleration (m/s^2)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

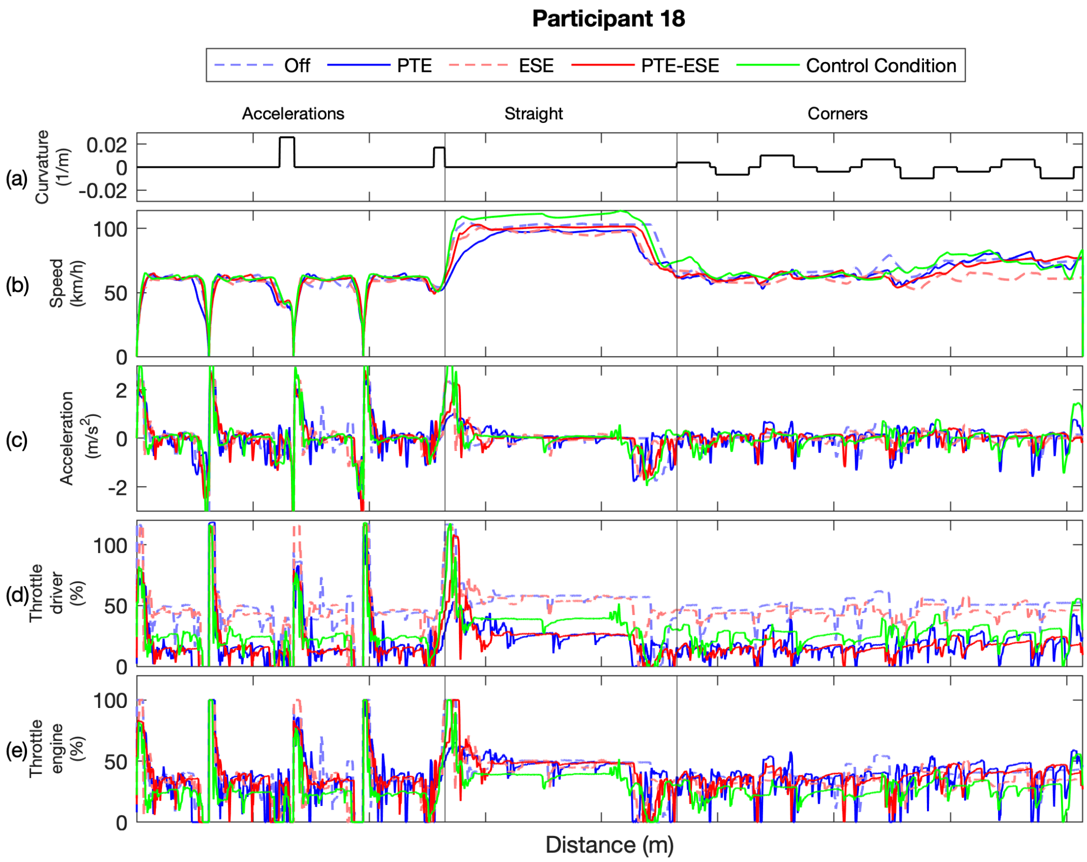
Appendix K.15: Participant 15 and 16




Participant 16
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
100
50
0
(c)
Acceleration (m/s²)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

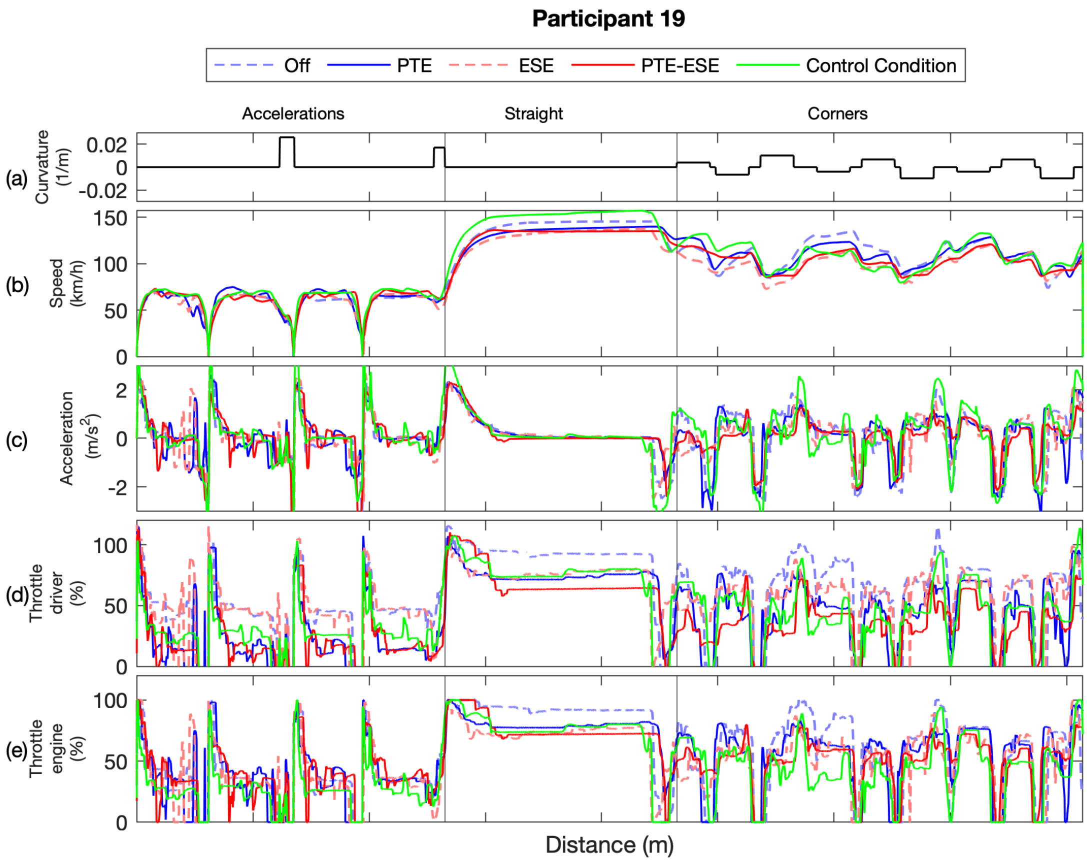
Appendix K.17: Participant 17 and 18

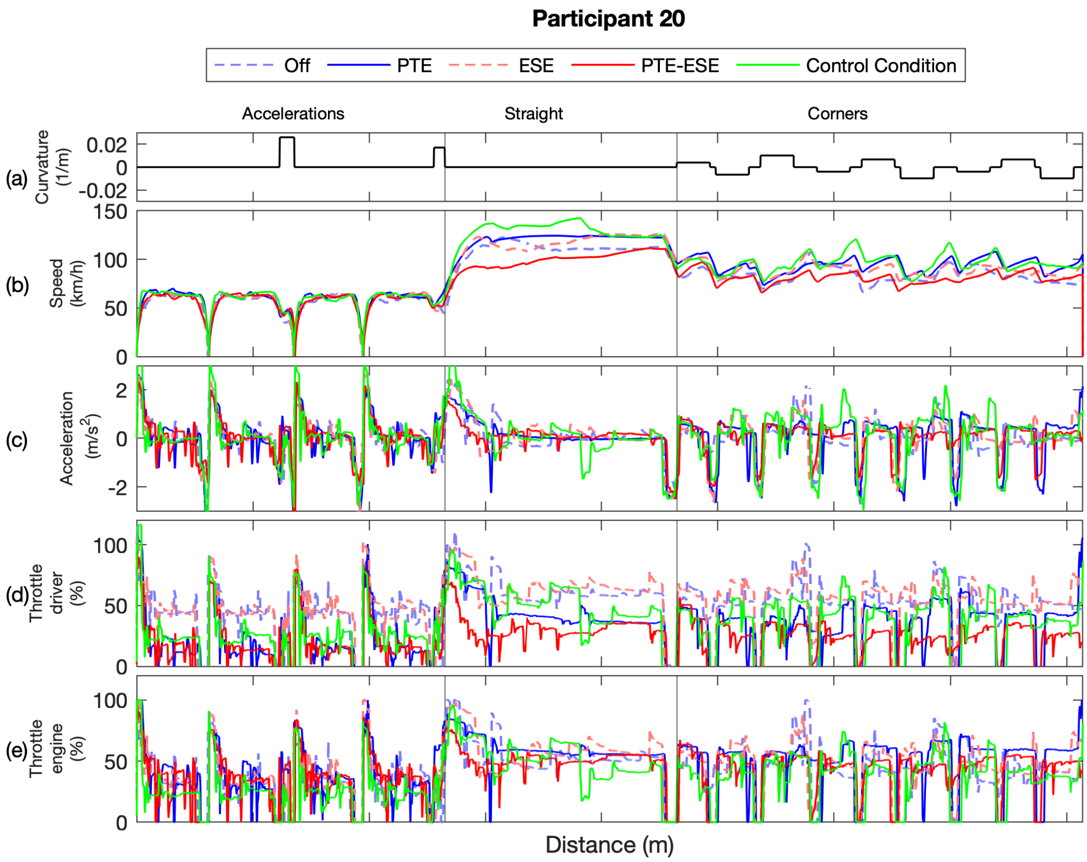




Participant 18
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
100
50
0
(c)
Acceleration (m/s²)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

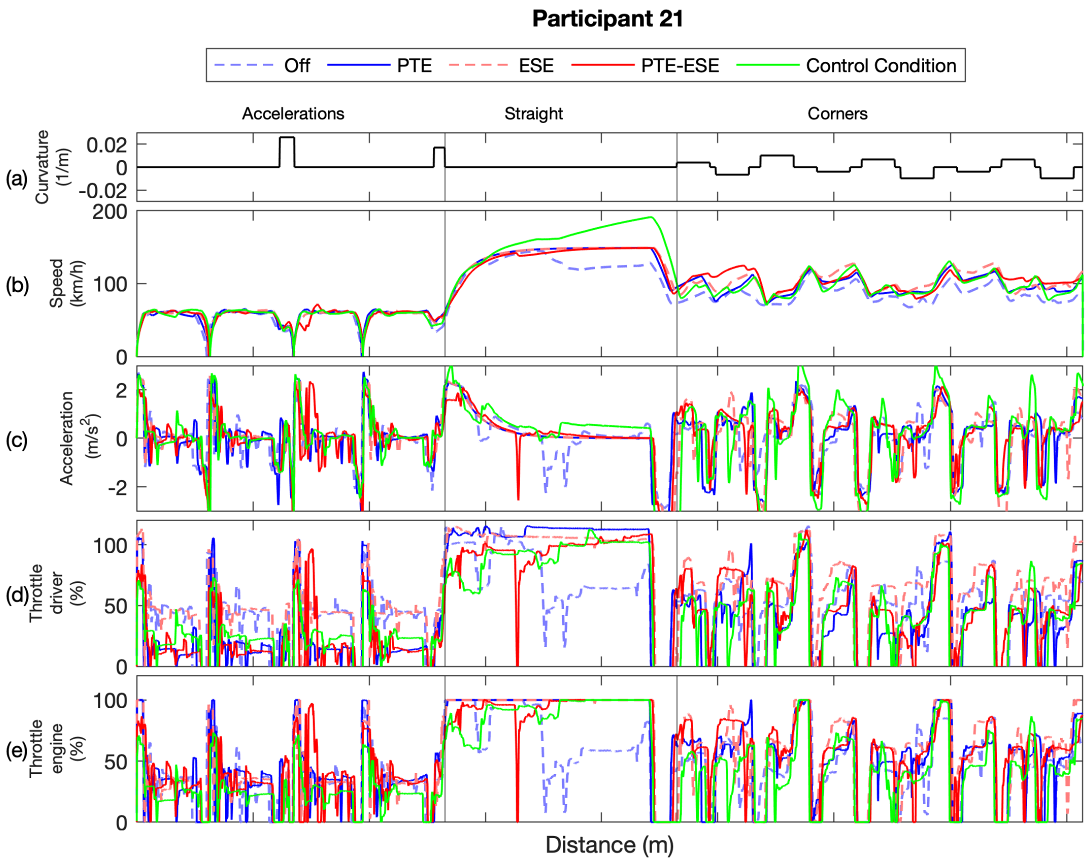
Appendix K.19: Participant 19 and 20

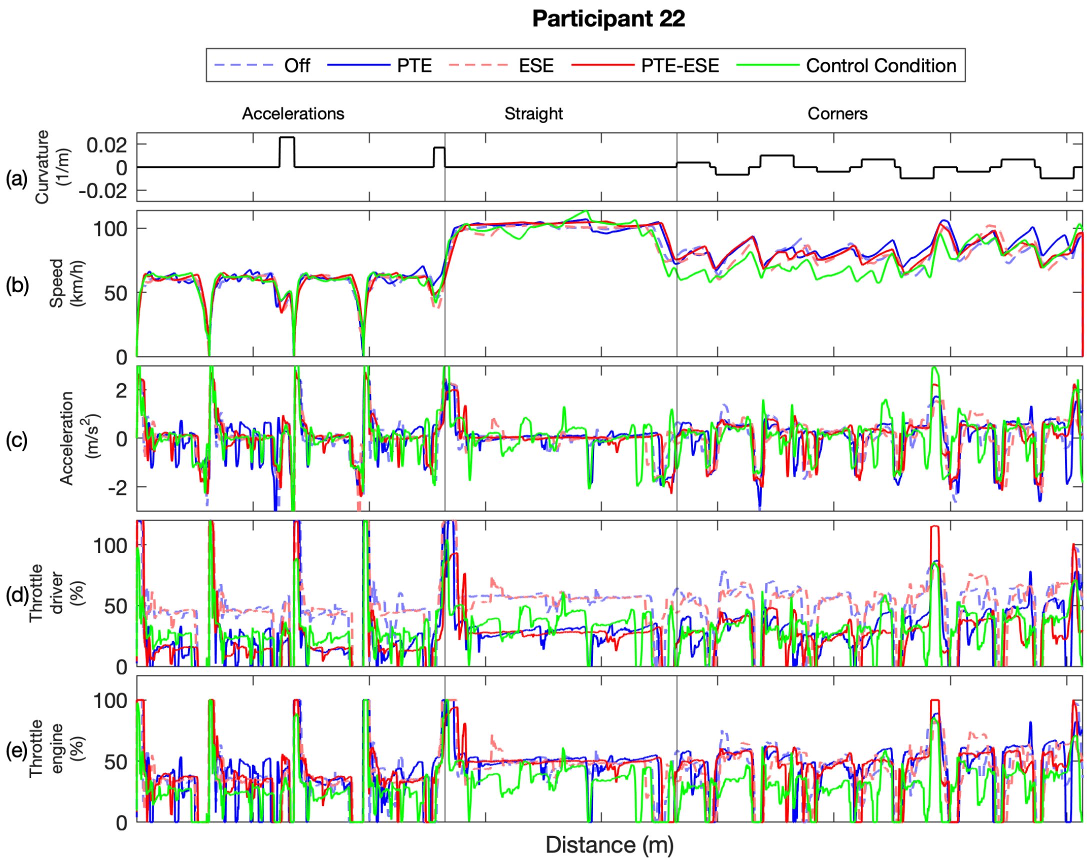




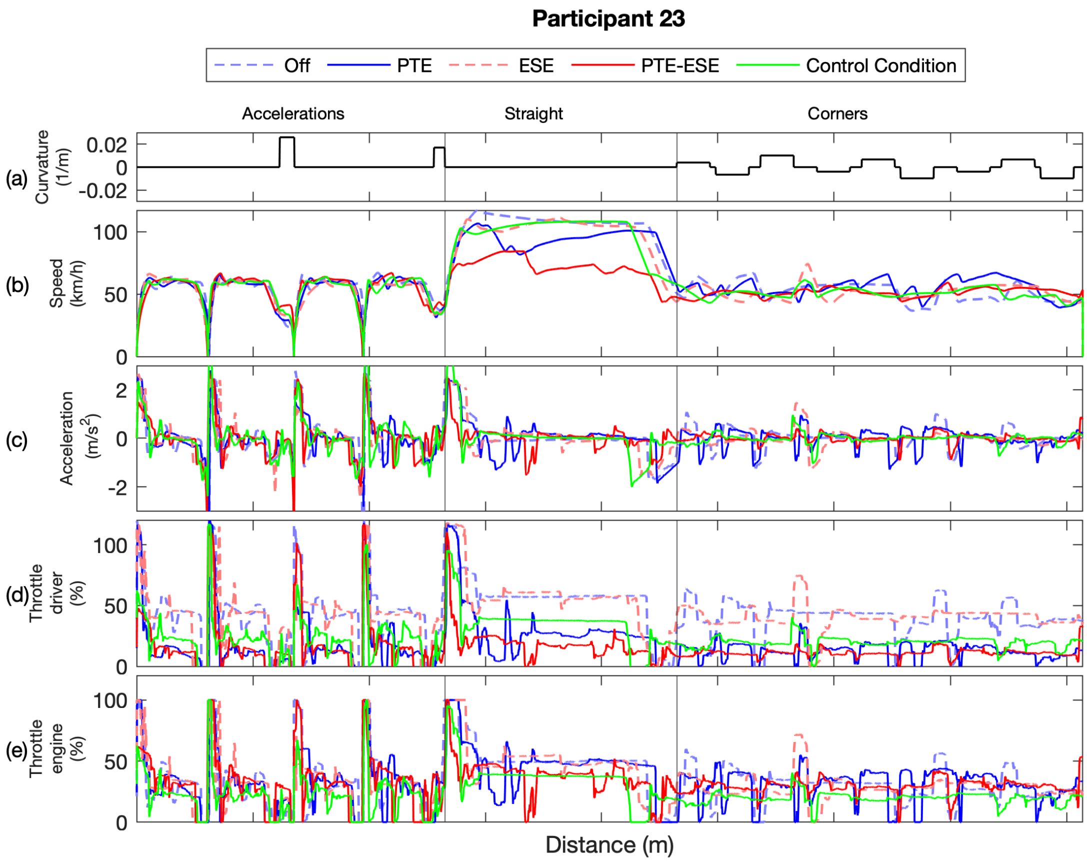
Participant 20
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
150
100
50
0
(c)
Acceleration (m/s²)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

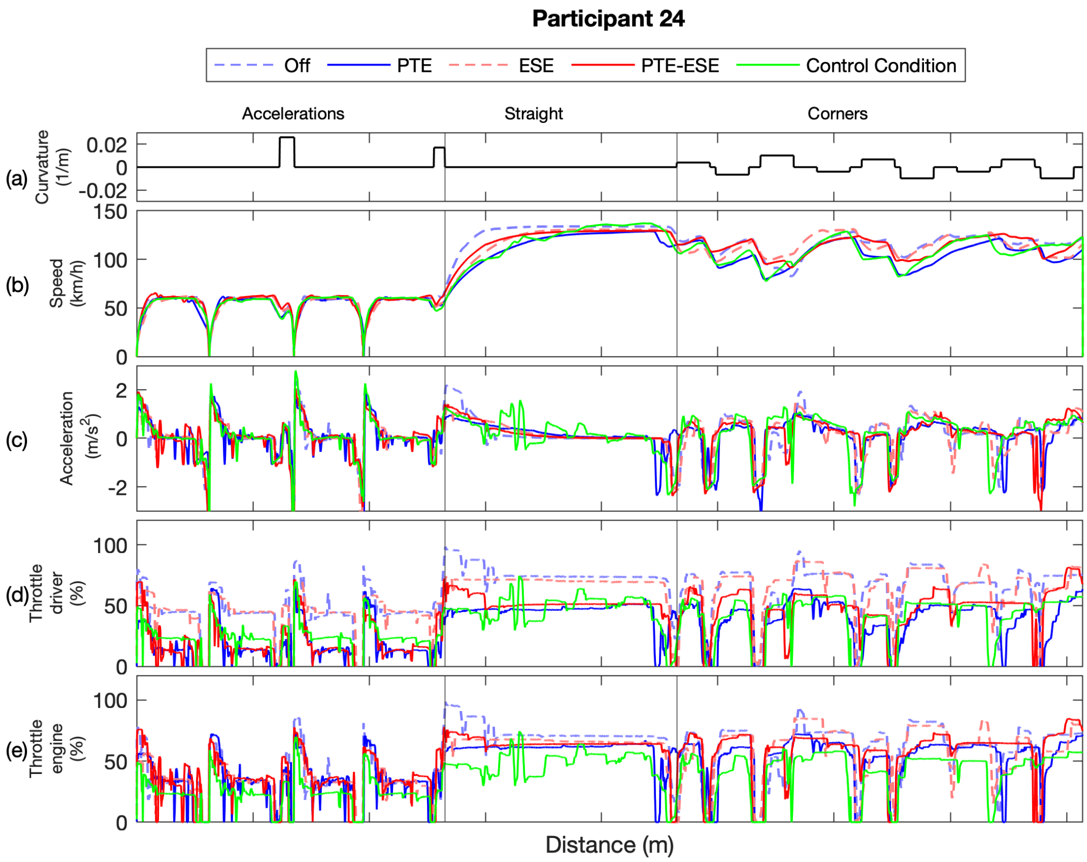
Appendix K.21: Participant 21 and 22




Participant 22
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
100
50
0
(c)
Acceleration (m/s2)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

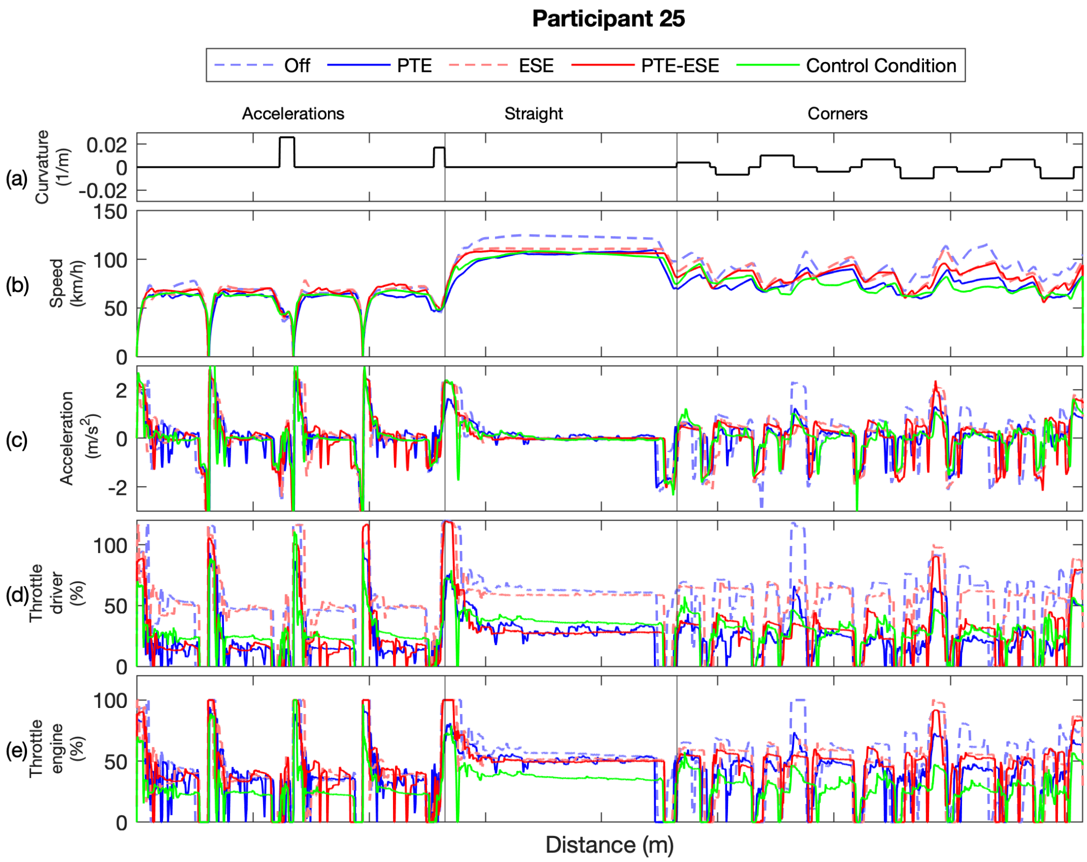
Appendix K.23: Participant 23 and 24

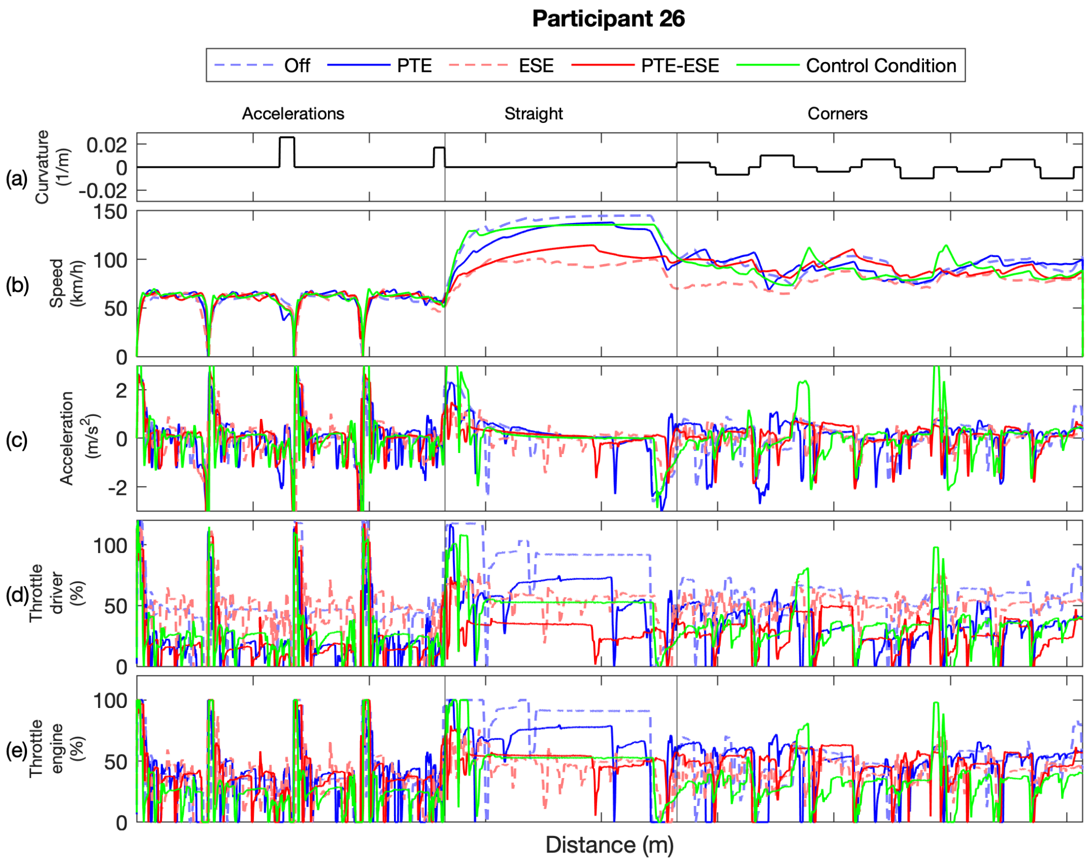




Participant 24
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
150
100
50
0
(c)
Acceleration (m/s2)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

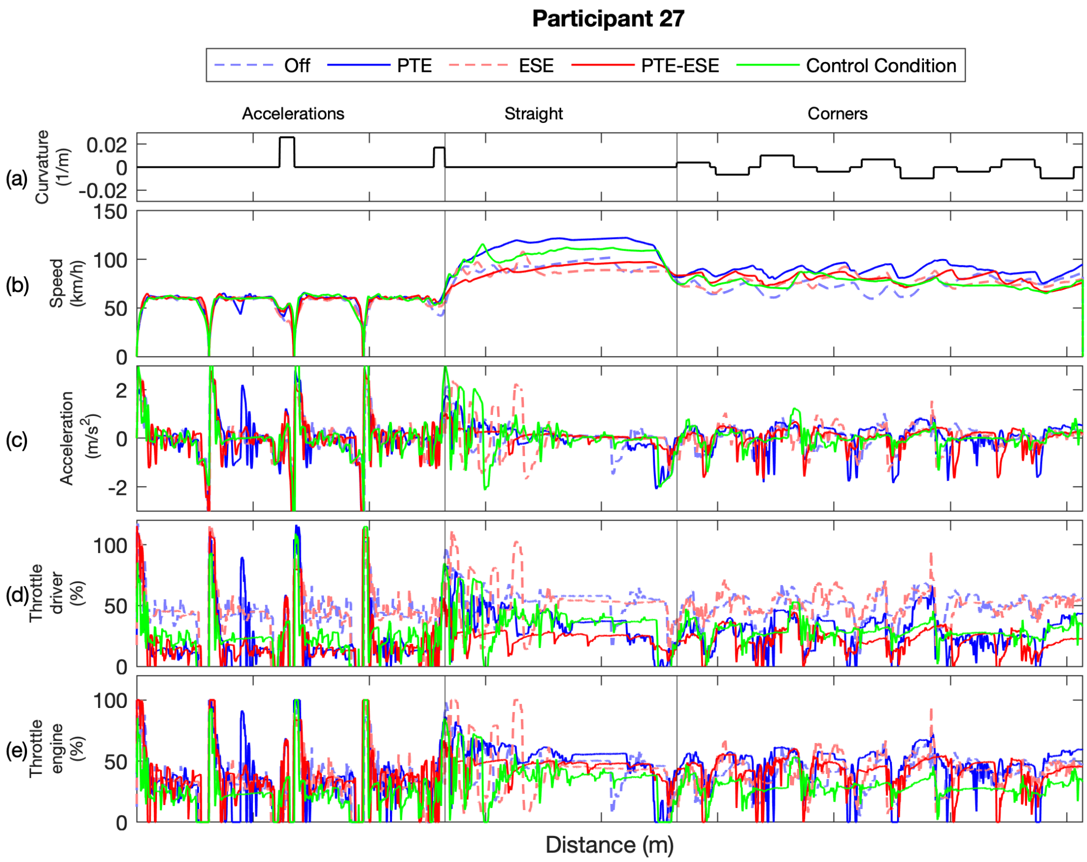
Appendix K.25: Participant 25 and 26

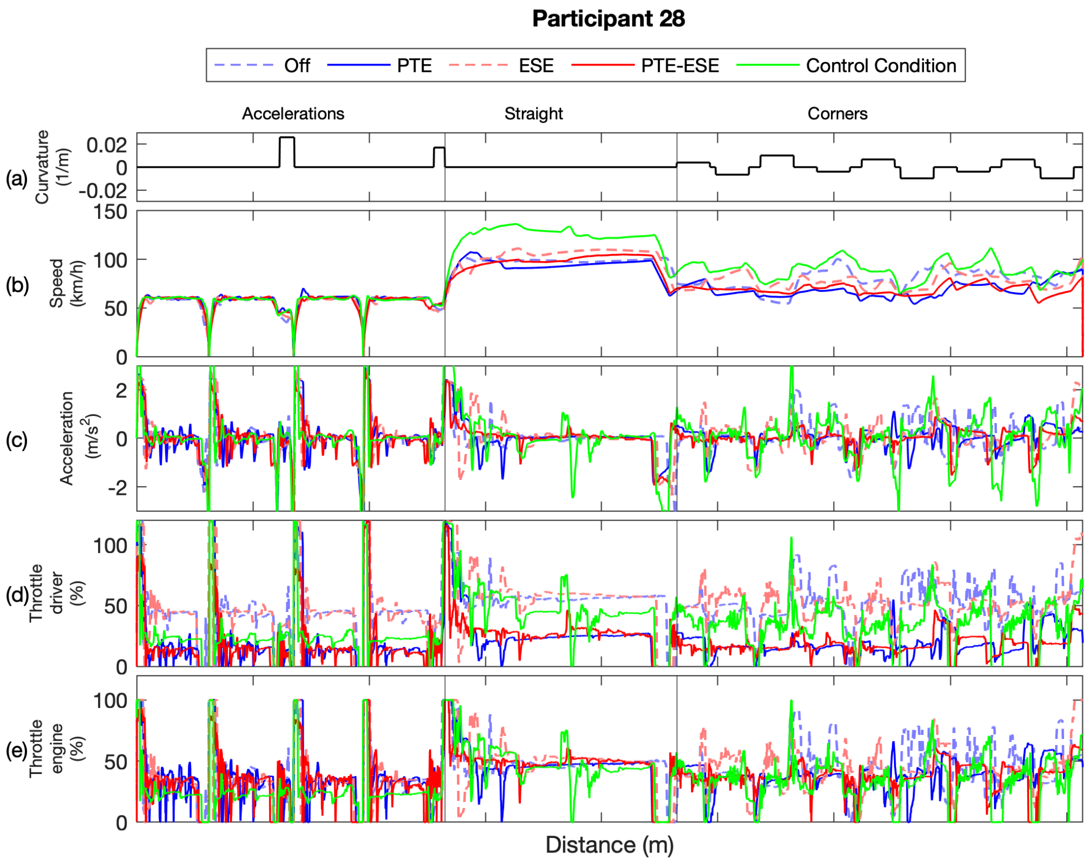




Participant 26
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
150
100
50
0
(c)
Acceleration (m/s^2)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

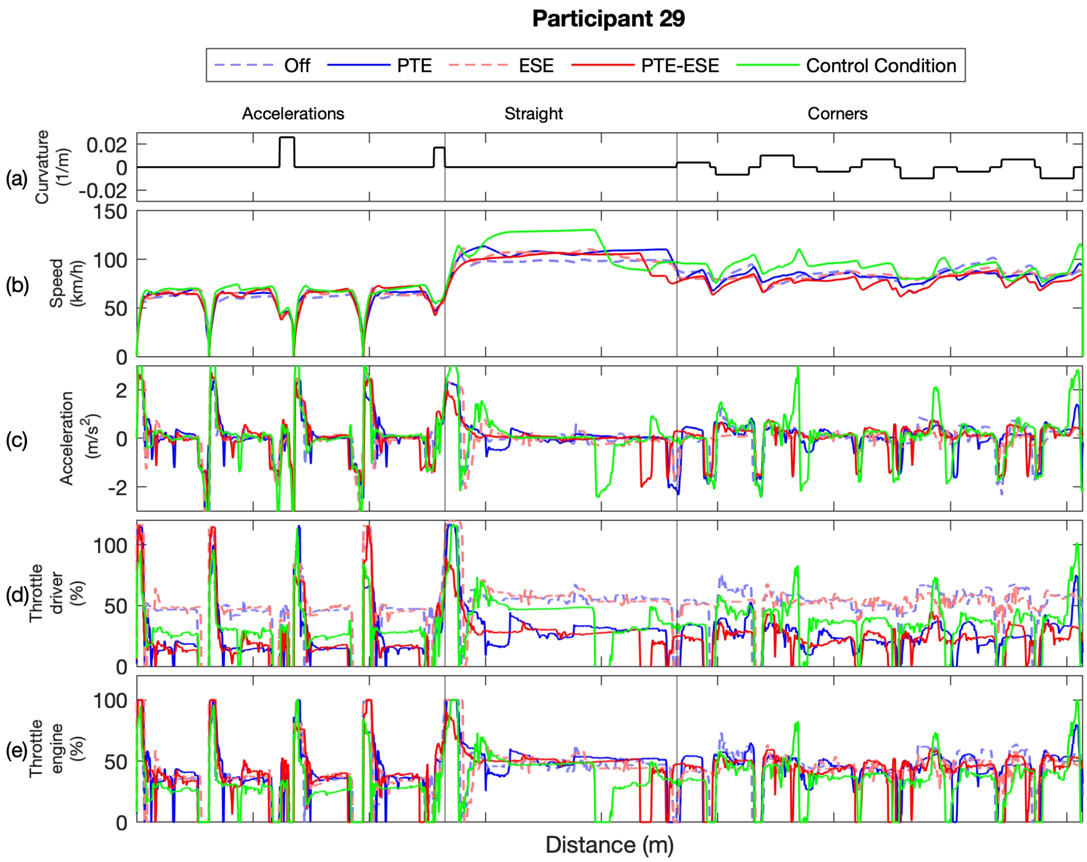
Appendix K.27: Participant 27 and 28

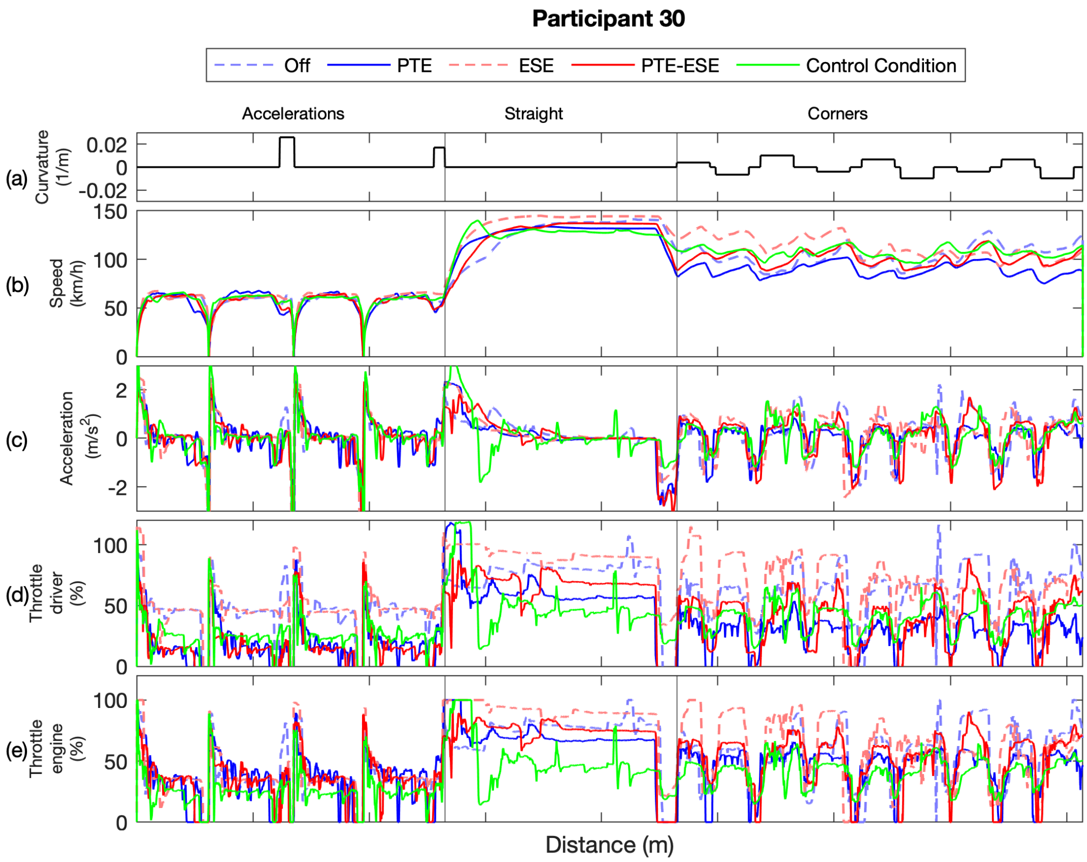




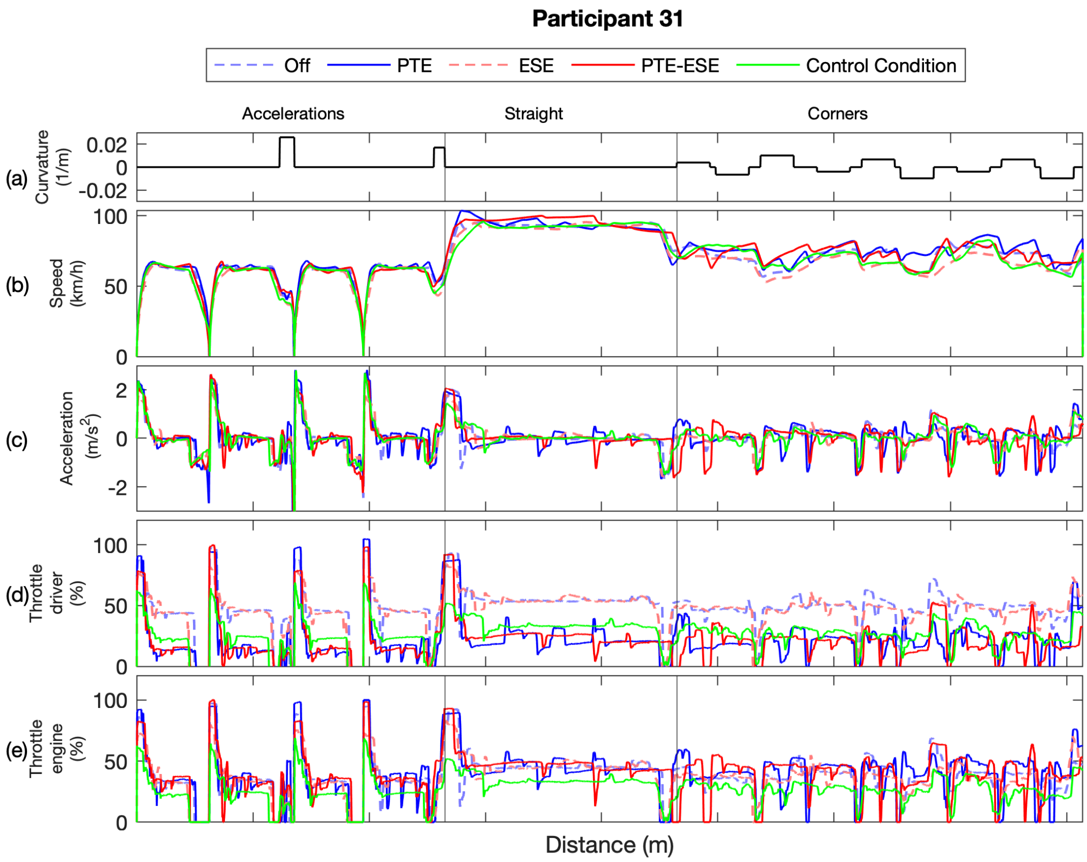
Participant 28
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
150
100
50
0
(c)
Acceleration (m/s^2)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

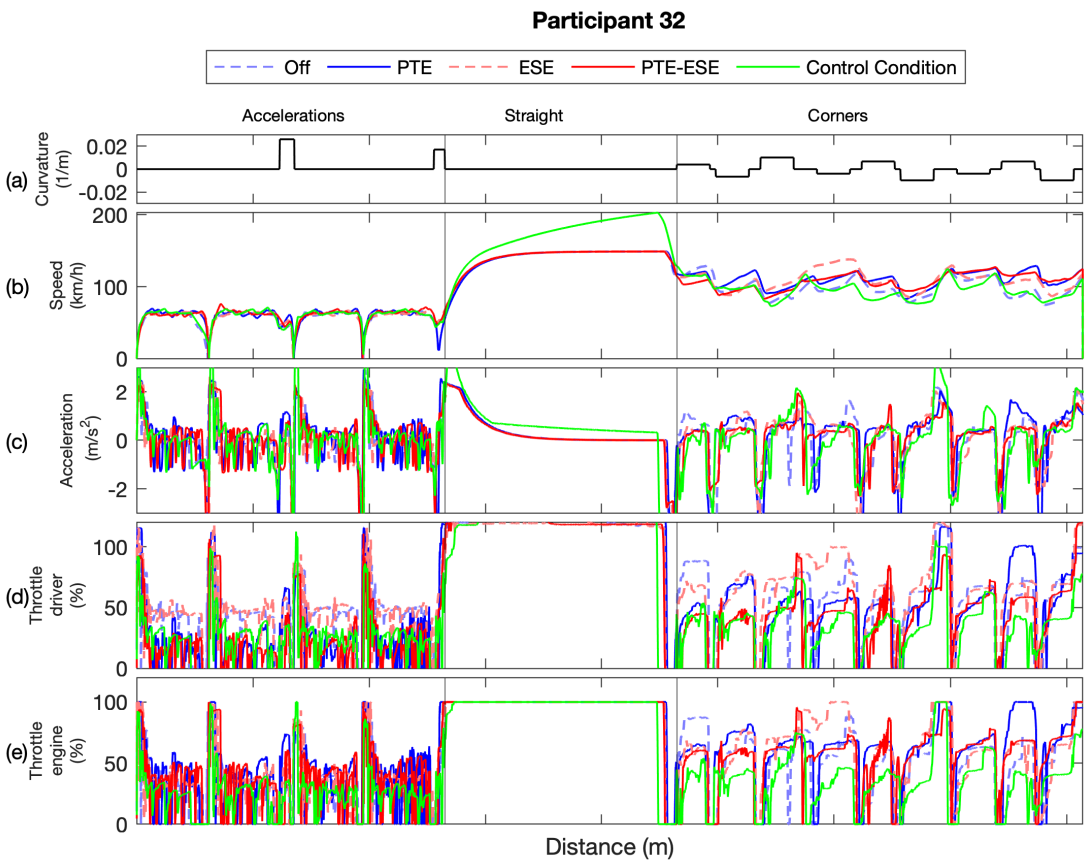
Appendix K.29: Participant 29 and 30




Participant 30
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
150
100
50
0
(c)
Acceleration (m/s^2)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)

Appendix K.31: Participant 31 and 32





Participant 32
Off
PTE
ESE
PTE-ESE
Control Condition
Accelerations
Straight
Corners
(a)
Curvature (1/m)
0.02
0
-0.02
(b)
Speed (km/h)
200
100
0
(c)
Acceleration (m/s^2)
2
0
-2
(d)
Throttle driver (%)
100
50
0
(e)
Throttle engine (%)
100
50
0
Distance (m)