Department for Transport

The Great Self-Driving Exploration

Understanding emotional responses to self-driving vehicles: Findings from the EEG study

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1. Executive summary

The UK is reaching a transition point in the emergence of self-driving vehicles with early uses approaching commercialisation. These new technologies have the potential to introduce a range of economic and societal benefits and it is government's role to understand how these could be realised while ensuring the safety and security of self-driving technology. Public understanding and acceptability of the technology as well as its governance will be vital for meeting these goals, including enabling the development and implementation of the required policies. Equally, it is necessary to understand what end users need from transport so that self-driving vehicles can be developed and deployed in a way that provides for those societal needs.

In 2022, DfT conducted in partnership with Thinks Insight & Strategy, University College London (UCL) and Aurrigo a series of large-scale public engagement events, held in areas of the country where little, or no, engagement had occurred to date, to provide an opportunity to increase exposure to and experience of SDVs. The aim of this research was to provide an opportunity to increase exposure to and experience of SDVs among the public, in turn enabling DfT to bring together two key elements of CCAV's engagement priorities: understanding public perceptions towards, and requirements for, SDV technologies; and increasing public awareness and understanding of aspects of the technology. This included providing a set of quantitative data on physiological responses to self-driving technology. To do so, electroencephalography (EEG) data was collected to assess the emotional state of participants whilst using a SDV. This study is the first of its kind to monitor the emotional responses of participants on a self-driving vehicle in real-time, and the data collection has resulted in a sizeable quantitative dataset on physiological responses to self-driving technology.

This report presents the findings from the EEG strand of the Great Self-Driving Exploration project. The EEG method is an electrophysiological process to record electrical activity from the brain. This electrical activity can be classified into real-time emotional states. This EEG data was collected for the shuttle and pod rides that took place during the in-person workshops, meaning that EEG data was collected in an uncontrolled setting. To allow for comparison baseline EEG readings were taken in a controlled setting prior to participants riding in the SDV. Additionally, pre- and post journey surveys on the reported emotional state of participants and video footage of the vehicle kinematics were gathered to help contextualise the EEG data. A total of he data collection led to 94 EEG recordings were obtained from 82 individuals. Of these, 63 EEG recordings were collected from the shuttle rides and 31 from the pod rides. The data was analysed based on six Performance

Metrics: 'Engagement', 'Excitement', 'Focus', 'Interest', 'Stress' and 'Relaxation' (for more detail on the Performance Metrics please see section 3) .

Based on the Performance Metrics, the main findings from the EEG data are as follows:

- Participants have medium to high levels of Engagement, Excitement and Interest, which suggests that participants, to a degree, are alert and immersed in the moment, have a degree of affinity with the task and tended to have more positive emotional responses to the technology.
- Participants have lower scores for Focus, Stress and Relaxation, suggesting that participants were not fixing their attention to a single task and were relatively comfortable with the experience despite its novelty. It also suggests that the experience of riding in a self-driving vehicle did not cause adverse emotions.
- Levels of Engagement and Excitement vary significantly between participants and these differences can be related to socio-economic status, age, gender and the specific vehicle route adopted.
- For instance, for the shuttle ride males have higher levels of Excitement compared to females, whilst participants in younger age categories and higher socio-economic status have lower levels of Excitement compared with participants in older age categories.
- Interestingly, for the pod ride, females have higher levels of Excitement and Interest relative to males, suggesting that the pod ride was more positively received by females. These gender differences could be explained by the characteristics of the vehicles themselves as well as attitudinal differences that were observed throughout the broader research programme
- For both pod and shuttle ride, Excitement levels are much higher during the pod and shuttle rides compared to the initial baseline EEG reading. This is in line with the patterns from the pre- and post-trial surveys, whereby there is a shift towards more positive self-reported emotional states.

Further analysis was focused on assessing how emotional states change during the ride on the shuttle. Based on this, the following findings were obtained:

- Participants have higher levels of Excitement during the first five minutes of the ride, after which this effect subsides.
- This effect is stronger for males relative to females.
- For females Focus and Stress levels slightly subside, suggesting that they feel more comfortable as the ride progresses.
- The same effect is found for participants with a higher socio-economic status.
- These findings suggest that as participants become more familiar with the technology the more immediate and emotional reactions, both positive or negative subside. Findings that are in line with dual processing theories (Epstein, 1994) whereby as participants trialled the technology for the first time their responses tended to be led by the more spontaneous route, but it is possible that as they became more familiar with the technology these emotions subsided allowing them to start to move towards the more systematic processing.

Subsequent analysis focused on the impact of vehicle kinematics on the emotional state during the shuttle ride. The main findings are as follows:

- Acceleration and turning events are associated with somewhat higher levels of Excitement, particularly for males.
- For the first two seconds of a vehicle kinematic event, Excitement is generally higher for turning and acceleration events, whilst the opposite effect is found for deceleration events.
- Stress levels are generally more confined during the later stage of the event in case of turning and accelerating events, particularly for females, though still generally low.
- This finding for females is in line with what was found for how the emotional state changes during the ride, namely that females perhaps feel more comfortable as events during the ride progress.
- These findings are in line with the observed changes in emotional state throughout a journey and provide further support that as participants become more familiar with the technology the more immediate and emotional reactions, both positive or negative, subside.

Finally, the pre-and post-trial surveys were analysed to explore how the EEG readings related to participants self-reported emotional state. The main findings are as follows:

- Post-trial surveys demonstrate higher levels of agreement with positive emotional states compared to pre-trial surveys.
- The increase in Excitement between the baseline EEG and shuttle EEG readings, as well as the pre-and post-trial survey demonstrate a trend towards more positive feelings. The EEG findings and pre-and post-trial surveys are thus in line with each other.

The findings demonstrate that participants respond in a positive way to the experience of riding in a self-driving vehicle and that feelings of anxiousness and/or stress were generally low. There are differences between groups in the emotional state experienced during the journey and how these emotional states develop throughout the ride or under the influence of vehicle kinematics, particularly based on gender. These differences will have implications on both engineering and policy choices to help mitigate certain emotional states if self-driving vehicles become more widespread. The changes in emotional state observed throughout a journey also suggest the value of providing members of the public with the opportunity to trial the technology. This should be done with a diverse representation of the public both to address concerns and normalise the idea of self-driving technology as well as provide opportunities for participants to progress from more automatic, or emotion led reactions, to more deliberated or informed views that can be embedded into the design and development of future self-driving vehicles.

2. Introduction

This report aims to present the findings from the electroencephalography (EEG) strand of the Great Self-Driving Exploration project which aimed to provide a set of quantitative data on physiological responses to the self-driving technology. To do so, electroencephalography (EEG) data was collected to assess the emotional state of participants whilst using a SDV.

The EEG technology

EEG is an electrophysiological process to record electrical activity from the brain. This method relies on the measurement of voltage changes, which comes from ionic current within and between some brain cells, called neurons. Dedicated EEG headsets can measure this electrical activity, by placing electrodes on the scalp of participants, which pick up and record the electrical activitiy. The analysis of these electric signals can be used to study cognitive processes. EEG data is recorded in real-time and for this report thus provides insight into how participants experienced a journey on a self driving vehicle, and how this experience changes, or is influenced by events, in real-time throughout the journey..

The EEG data was collected using the EMOTIV Insight 2.0, a light weight and non-invasive mobile EEG headset, containing five semi-dry electrodes. The collected data was processed by the EMOTIV software in real-time to classify the emotional state of participants into six Performance Metrics (Stress, Relaxation, Engagement, Excitement, Interest, Focus) through a machine learning algorithm. Since data is collected incredibly frequently, with roughly 120 observations per second, EEG data can be linked with events that are happening in real time while the vehicle is on the move. For this, the EEG data was enriched with events based data on the vehicle kinematics by collecting video data from the vehicle trajectory and the inside of the vehicle. Participants also completed a pre- and post ride survey on their emotional state, which was used to contextualise the collected EEG data. Unlike many other EEG studies which take place in controlled settings, such as laboratories, this study took place in an uncontrolled setting. Since EEG data is prone to distortions (e.g., due to participants' movements), collecting EEG data in an uncontrolled setting inevitably means that challenges arise with the processing of the EEG signals. Because of this data cleaning resulted in discarding part of the observations.

In total, the data collection resulted in 94 EEG recordings from 82 unique participants. Of these, 63 were collected from the shuttle ride and 31 from participants as they rode in the pod or whilst walking in the same environment as the pod was operating. For the shuttle, 23 of these EEG recordings were in the city, 25 in the rural location and 15 in the town. For the pod, 17 of these EEG recordings were in the city and 14 in the town.

The novelty of this study is that it is the first of its kind to monitor the emotional responses of participants on a self-driving vehicle in real-time, and the data collection has resulted in a sizeable quantitative dataset on physiological responses to self-driving technology.

The remainder of this report is structured as follows:

- Section 3: Methodology. This chapter outlines the methodology used for both the EEG data collection and analysis.
- Section 4: Analysis results. This outlines the data analysis undertaken for the shuttle, pod and pre-and post-trial surveys
- Section 5: Conclusion and Implications. This outlines the conclusions and overall implications of the research

3. Methodology

This section outlines the steps required and undertaken to conduct the EEG data collection.. First, the EEG data collection procedures are described. After this, data contents and equipment are discussed. Finally, data cleaning procedures and data analysis procedures are presented.

Description of the EEG data collection

The EEG data collection took place in three locations. All participants from the core deliberative strand (see The Great Self-Driving Exploration: A citizen view of self-driving technology in future transport systems report for the detail on sampling) were invited to take part. Participants were recruited prior to the first research event starting and were asked to provide their informed consent for the EEG experiment (see Section 6 Appendix for the Information sheet/consent form). It was made clear to participants that no loss of benefit would occur if they did not wish to participate in the EEG experiment. Participants had to agree to be monitored with the EEG headset and to be filmed whilst inside the vehicle. Furthermore, it was pointed out that their data would be linked with survey data from the pre-and post-trial survey. Only participants that provided their written consent were eligible for the experiment.

During each of the three workshops, a group of participants were invited to wear the EEG headsets whilst riding on both the self-driving shuttle and the pod. On the shuttle, participants experienced a 15-minute ride whilst the vehicle was driving on public roads, interacting with other vehicles, pedestrians and obstacles in the three different locations. For the pod, rides were roughly 5 to 10 minutes in a pedestrianised environment, whereby the pod drove on a pre-programmed route and interacted with pedestrians, cyclists and other obstacles.

To enable the EEG experiment, five people from UCL were on-site to fit the EEG headsets on the participants and to set-up the collection of video footage from the rides. For the rural and urban locations participants experienced the shuttle ride first followed by the pod ride. In the town location the order was reversed. Due to resources (e.g., number of headsets, set up time) EEG data was not collected for all journeys. For journeys where data was collected the number of EEG participants per ride varied between two and five. Before the ride, each participant completed a pre-trial survey to collect self-reported data on their emotional state. The findings obtained from the pre-and post-trial survey will be discussed in Chapter 4.

Before equipping participants with the EEG headset, these were prepared by attaching all the semi-dry sensors to the headset and a saline solution was applied to enable proper contact quality with the scalp to ensure the best EEG signal quality. EEG headsets were connected by Bluetooth to a laptop, on which the EMOTIV PRO software was installed to record and store the EEG data. It was reiterated to participants at this stage that if they felt at any time uncomfortable, they could take the EEG headset off.

Following fitting the quality of the EEG signal was assessed. This was done through assessing the contact quality between the sensor and the scalp, and subsequently the quality of the EEG signal coming through the sensor. When satisfactory EEG quality was obtained, a recording was started. Participants were each assigned a unique ID to enable retrospective matches with the other datasets gathered.

The first 40 seconds of the EEG recording were used to take a baseline measurement of participant's emotional state. For this, participants were asked to relax with their eyes opened for 15 seconds and subsequently with their eyes closed for 15 seconds. This is the only part of the EEG experiment that can be seen as data collected within a controlled setting and is used for validation purposes. After this, the participants were seated and waited until a ride on the shuttle or pod became available.

During the ride, both the shuttle and pod were equipped with two cameras, one capturing the inside of the vehicle and one capturing the vehicle trajectory. Video data was collected for all three locations but could only be used for the city and town environments. Whilst departure and arrival times were derived from the video footage these were also noted down for each participant to facilitate the allocation of EEG datasets to a particular shuttle or pod ride.

After the ride was completed, the EEG headsets were immediately collected from the participants and switched off to ensure the recording was stopped. The EEG headsets were thoroughly cleaned and prepared for the next participants. After this, participants completed a post-trial survey on their emotional state. This could be completed either via their mobile phones or a paper copy.

Ultimately, EEG data was collected from six shuttle rides in the city and five in the town, ten pod rides in the city and nine pod rides in the town. This resulted in 94 EEG recordings from 82 unique participants. Furthermore, video recordings were obtained for all shuttle and pod rides as well as departure and arrival times. Finally, pre-and post-trial surveys on the emotional state were completed by all participants.

Datasets contents

The data collection efforts resulted in the following datasets:

- EEG data
- Video data of vehicle trajectory
- Video data of inside of the vehicle
- Departure and arrival timestamps
- Pre-and post-trial survey on emotional state

EEG data

The EEG data was collected using the EMOTIV Insight 2.0, a light weight and non-invasive mobile EEG headset, containing five semi-dry sensors. These sensors measure EEG signals (electric signals from the brain, measured in microvoltages) from five channels, **AF3**, **AF4**, **T7**, **T8** and **Pz** (see Figure 1**)** in very small time increments (the potential is for over 8.000 EEG observations per minute).

The EEG datasets generated through the EMOTIV PRO software contain raw processed EEG data, whereby raw EEG data is transformed using *Fast Fourier transformation* into frequency bandpowers (**Theta**, **Alpha**, **Beta low**, **Beta high** and **Gamma**). The strength of these bandpowers relates to emotional states, and subsequently results in six Performance Metrics **Stress**, **Engagement**, **Interest**, **Excitement**, **Focus** and **Relaxation** devised by EMOTIV. The Performance Metrics will be the main focus of analysis in this report.

During the data collection, the EEG headsets were each connected through Bluetooth with the EMOTIV PRO software on the laptops. This software stores and processes the raw EEG data collected through the headsets and generates EEG datasets for each participant, which was subsequently exported to a csv file and securely stored within UCL's IT system.

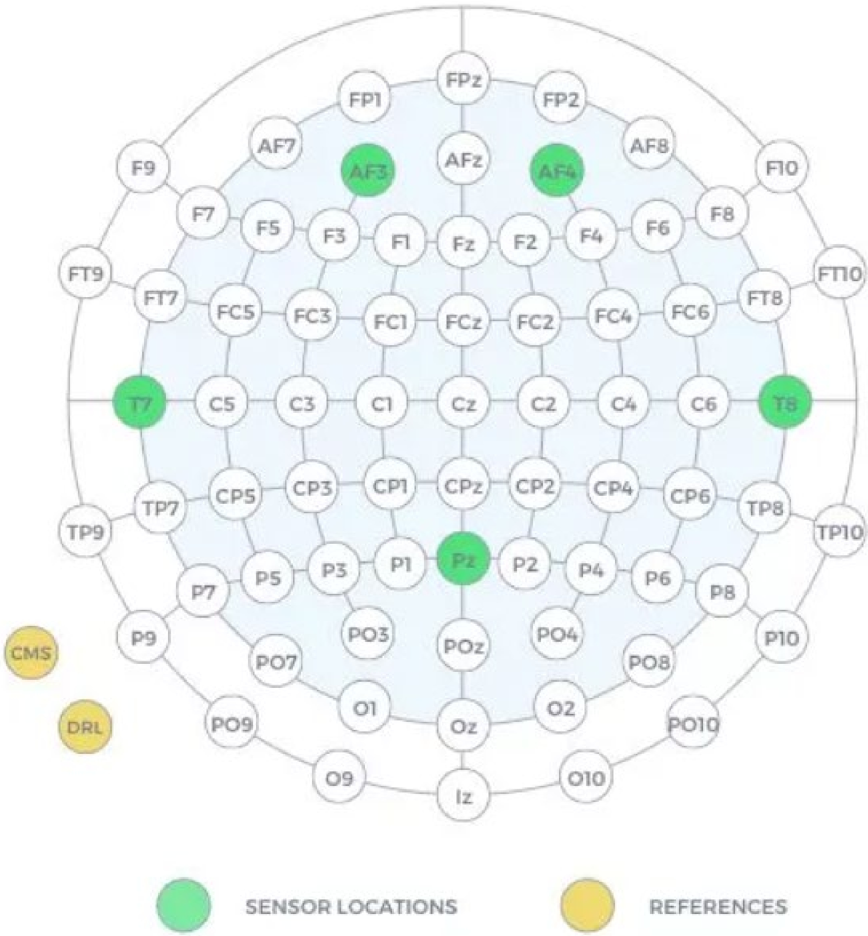

Figure 1: EEG Channels for the EMOTIV Insight 2 headset

The EEG datasets contain the following raw data:

- Timestamp
- EEG signal, measured in microvoltage for the five channels (AF3, AF4, T7, T8 and Pz)
- Contact quality indicators (this assesses how well the headset fits the participant in real-time)

Subsequently, the dataset also contains real-time processing of the EEG data. This processing is not available for each time increment but is granular enough to enable the necessary analysis. These variables are as follows:

- EEG quality indicator (a machine learning algorithm classifying the data quality, based on signal quality from the five channels and contact quality).
- Frequency bands for each channel (Theta, Alpha, Beta low, Beta high and Gamma)

- Performance metrics (Excitement, Engagement, Focus, Interest, Relaxation and Stress)
- Head movements of the participants (e.g., eye blinking, head turning)

Performance metrics are derived from the frequency bands, which in turn are derived from the electric signals gathered by the EEG headsets. The classification of the frequency bandpowers aims to determine which wavelengths, associated with certain types of brain activity, contribute towards the overall electric signal and are as follows:.

- Theta waves are associated with relaxed, meditative and creative states.
- Alpha waves are associated with a relaxed and alert mode of the brain.
- Beta waves are associated with active task-oriented, busy or anxious thinking and active concentration.
- Gamma waves are associated with fast coupled processing in the brain and occur when different populations of neurons network together to carry out demanding cognitive or motor functions.

This classification is subsequently used to derive the Performance Metrics, which will be the main focus of analysis. The Performance Metrics are thus derived from the bandpowers. The Performance Metrics can be described as follows:

- **Stress** is a measure of comfort with the current challenge. High stress can result from an inability to complete a difficult task, feeling overwhelmed and fearing negative consequences for failing to satisfy the task requirements. Generally a low to moderate level of stress can improve productivity, whereas a higher level tends to be destructive and can have long term consequences for health and wellbeing.
- **Engagement** is experienced as alertness and the conscious direction of attention towards task-relevant stimuli. It measures the level of immersion in the moment and is a mixture of attention and concentration and contrasts with boredom. Engagement is characterized by increased physiological arousal and beta waves along with attenuated alpha waves. The greater the attention, focus, and workload, the greater the output score reported by the detection.
- **Interest** is the degree of attraction or aversion to the current stimuli, environment or activity and is commonly referred to as Valence. Low interest scores indicate a strong aversion to the task, high interest indicates a strong affinity with the task while mid-range scores indicate you neither like nor dislike the activity.
- **Excitement** is an awareness or feeling of physiological arousal with a positive value. It is characterized by activation in the sympathetic nervous system which results in a range of physiological responses including pupil dilation, eye widening, sweat gland stimulation, heart rate and muscle tension increases, blood diversion, and digestive inhibition. In general, the greater the increase in physiological arousal the greater the output score for the detection. The Excitement detection is tuned to provide output scores that reflect short-term changes in excitement over time periods as short as several seconds.
- **Focus** is a measure of fixed attention to one specific task. Focus measures the depth of attention as well as the frequency that attention switches between tasks. A high level of task switching is an indication of poor focus and distraction.
- **Relaxation** is a measure of an ability to switch off and recover from intense concentration. Trained meditators can score extremely high relaxation scores.

These metrics are scaled from 0%-100%, with 100% representing a high score for the Performance Metric, and 0% a low score for the Performance Metric.

Video footage inside vehicle

The video footage was captured through a quick release dashcam camera placed in the top corner of the shuttle to provide a view of the participants and was used to monitor real-time movements of participants. The video footage includes timestamps, which enables a real-time link with EEG datasets and was collected to identify events that may impact on the emotive state of participants. The video data does not include audio recordings.

Video footage of the vehicle trajectory

The video footage was captured through a quick release dashcam camera placed on the front windows of the shuttle and pod to provide a view of the road ahead. This was used to monitor real-time traffic situations, road characteristics (e.g., driving on A road versus local access road), as well as the real-time vehicle kinematics of the shuttle /pod (e.g., braking, accelerating, turning). The footage includes timestamps which enables a real-time link with EEG datasets and vehicle kinematics (turning, accelerating, speed, road characteristics such as junction, roundabout, main-road, high-street, dual carriageway) and was collected to identify events that may impact on the emotive state of participants. The video data does not include audio recordings

Vehicle departure and arrival timestamps

This dataset contains recordings of the departure and arrival time of each shuttle/pod journey as well as the unique ID of participants that were on the shuttle/pod. This was used to identify when participants were on the shuttle/pod. For the pod, the timestamps for start and end of walk are also recorded.

Self-reported emotional state

The pre-and post-trial surveys collected data on participant's emotional state via a set of emotion statements which can be used to validate and contextualise the EEG Performance Metrics. These statements were carefully selected to ensure that positive, negative and more neutral emotions were presented to participants. The statements included:

- I feel sad
- I feel scared
- I feel happy
- I feel alert
- I feel active
- I feel irritated
- I feel confident
- I am worried about what people think of me
- I feel in control of things
- I feel motivated

- I feel safe
- I feel bored
- I feel content
- I feel annoyed
- I feel pleased
- I feel melancholic
- I feel amused
- I feel surprised

These statements were presented on a five-point Likert scale, ranging from Strongly disagree to Strongly agree. The outcomes of the pre- and post-trial surveys were compared with the baseline EEG and EEG readings during the shuttle ride.

Socio-demographics and attitudinal data

Socio-demographic and attitudinal data was also collected to contextualise the EEG data.

Data cleaning

After data collection data was combined to provide a comprehensive dataset, following which careful steps were taken to assess the quality of the data. These are outlined in the next section.

Data quality assessment

After data was collected, the first indicator to be assessed was the contact quality indicator. This indicator measures for each of the EEG channels how well the sensor was attached to the scalp. It can be seen in Figure 2 that the contact quality is consistently high across all the data readings for the participants.

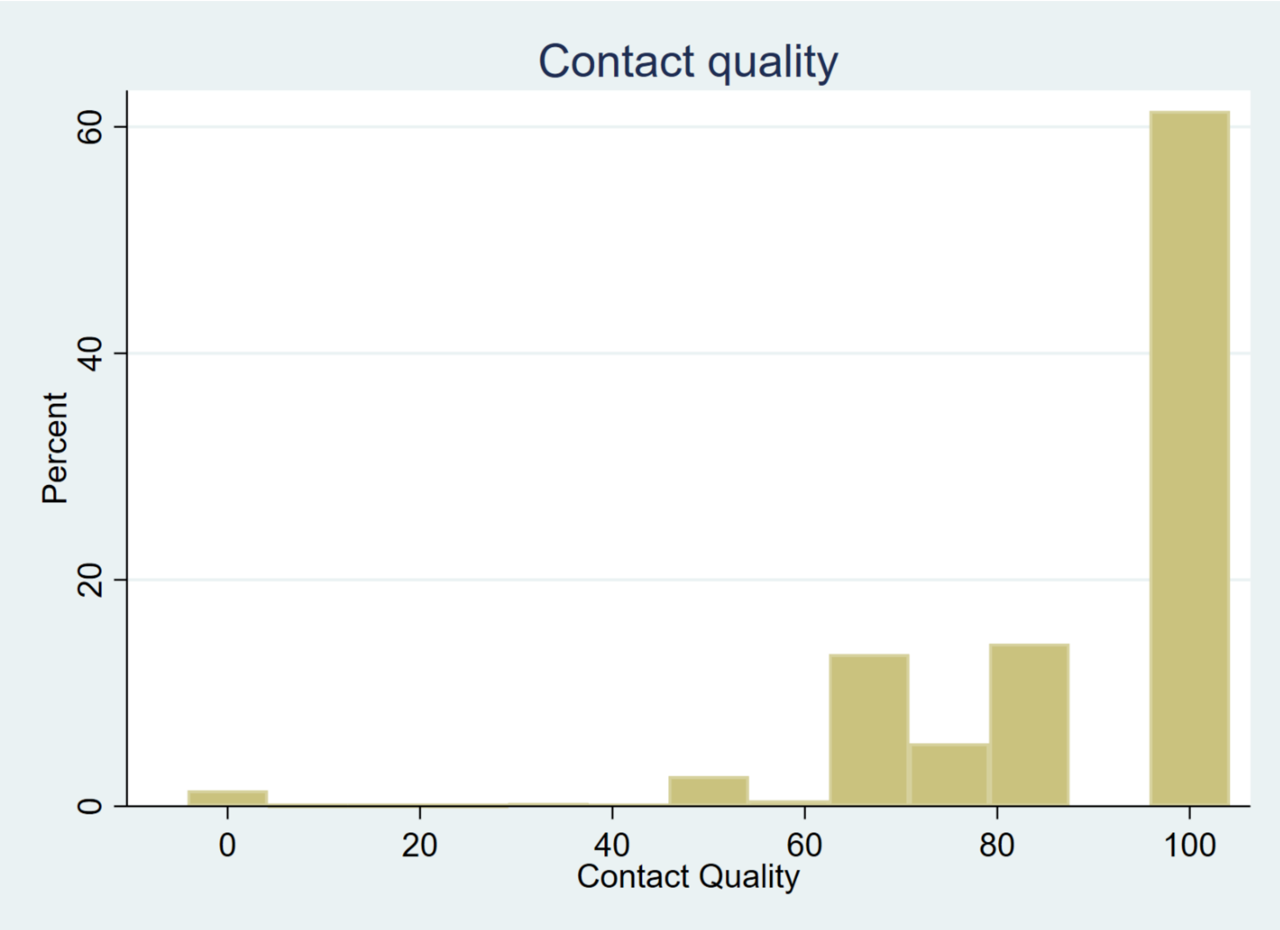

Figure 2. Contact quality across the EEG datasets.

The second step was to assess the level of noise/artifacts in the EEG data. Generally, there are two types of EEG artifacts, external or environmental and physiological. The external sources can include electric power lines, lighting, and a large variety of electronic equipment (e.g, mobile phone usage). Physiological noises relate to body activities, such as body movements with the main ones being eye movements, electrocardiographic movements (heart), respiration and scalp recorded muscle activity. Given that this study took place in an uncontrolled setting, there was the potential for high levels of background noise that could interfer with the data and therefore data quality significantly varied across participants.

To assess EEG quality, EMOTIV has developed a machine learning algorithm. This algorithm makes use of the information from the raw EEG data, the five EEG channels and the bandpowers derived for each frequency bandwidth (Alpha, Beta, Gamma Theta). Figure 3 displays raw EEG readings for a participant from one of the five EEG channels (AF3) and the derived bandpowers for each frequency bandwidth. It also demonstrates a dataset where there is significant noise and therefore where the inferences are unreliable. For instance, the large fluctuations in the electric signal before time increment 38600 and between time increments 3900-39200 suggest that the inferences are unreliable for these time increments.

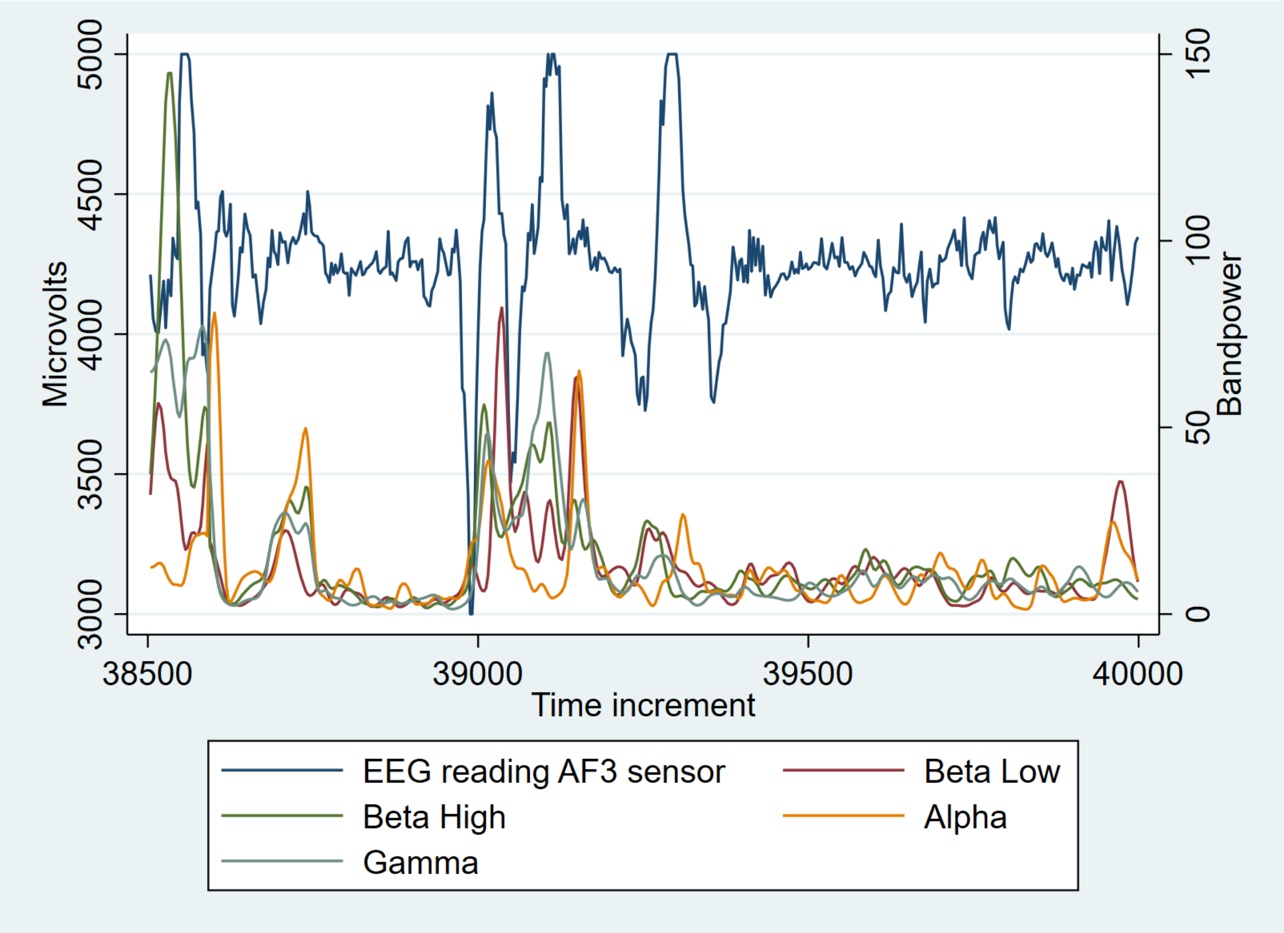

Figure 3: EEG reading and resulting bandpowers

It can be seen in Figure 4 that the EEG Quality indicator indeed classifies these time increments as having very poor EEG quality. Given that the EEG quality indicator adequately captures the signal quality, it was decided that this indicator could be used as a reliable indicator of overall data quality.

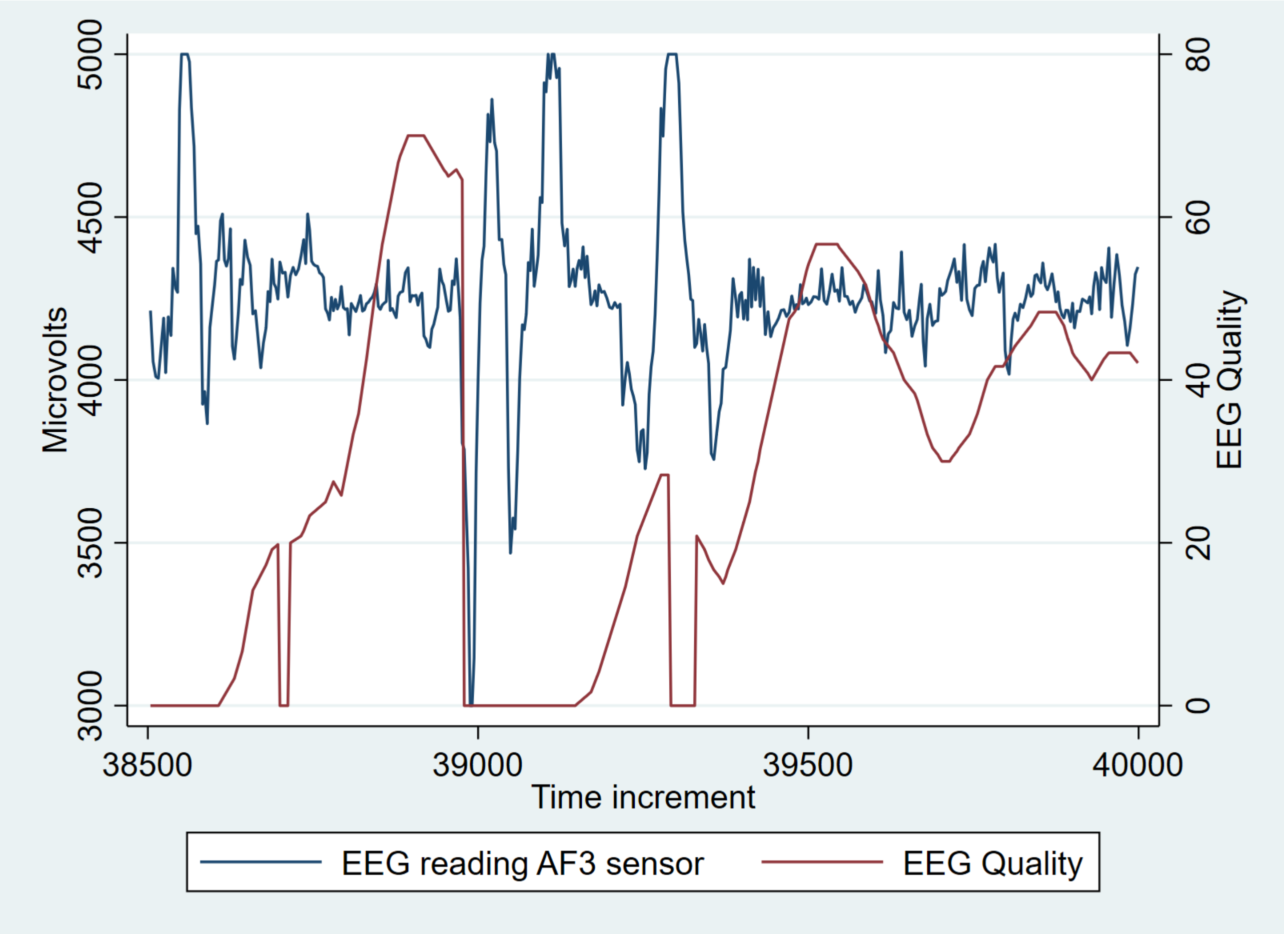

Figure 4: EEG reading and EEQ quality

Data cleaning considerations/steps

During the controlled setting of the recording, the quality of the EEG baseline readings was satisfactory, with average EEG quality of 44% across the samples. This is displayed in Figure 5.

The EEG data collected during the uncontrolled settings (pod ride, walk around the pods and shuttle ride) have much lower quality, particularly the pod walk, with average EEG quality readings of 18%. Figure 6 and Figure 7 show the EEG quality distributions for the pod and shuttle rides respectively, which shows that there was more noise in the shuttle data compared to the pod. This could be because of the size of the vehicle and the higher number of passengers compared to the pod meaning participants could hold more conversations and had more space to move around, all of which could distort the data. Overall, pod rides had an average EEG quality of 33%, whilst the shuttle rides had an average EEG quality of 24%. Finally, there is a significant difference in EEG quality between males and females, whereby males had an average EEG quality of 31% compared to 22% for females. This was likely due to the higher potential of distortions due to sensors being caught in between hairs.

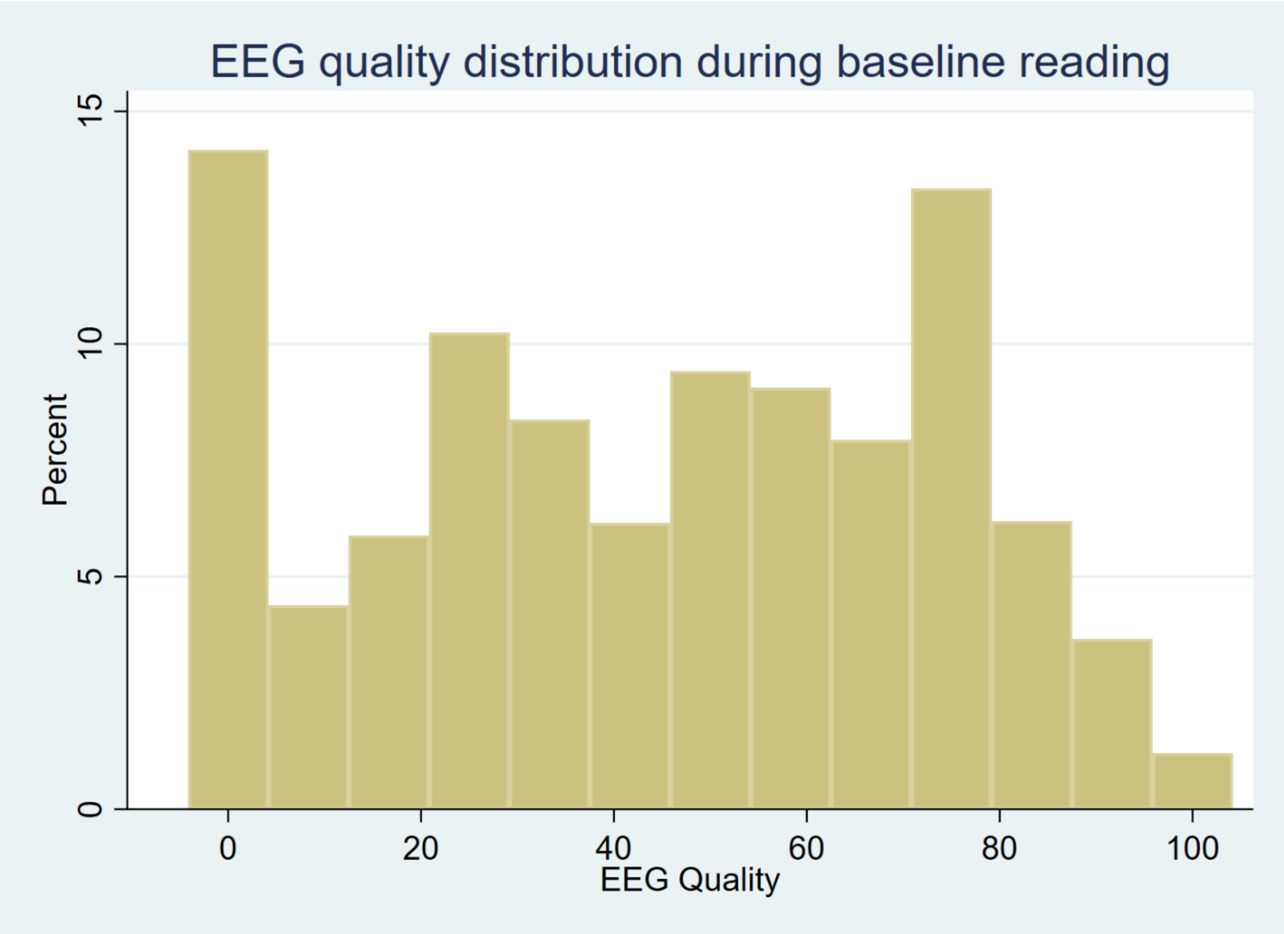

Figure 5. EEG quality during baseline reading

In order to assess whether noisy data needed to be discarded careful data inspection took place, whereby the impact of different levels of EEG quality was assessed. Finally, it was decided to cut-off any observations whereby the EEG quality indicator had a value below 20%. Across the samples, this resulted in a loss of roughly 60% of the datapoints.

Whilst this is a significant loss of data, this is not unexpected given the uncontrolled setting in which this study took place. In addition, despite this loss of data the overall sampling frequency ensured there was still sufficient coverage to enable robust analysis.

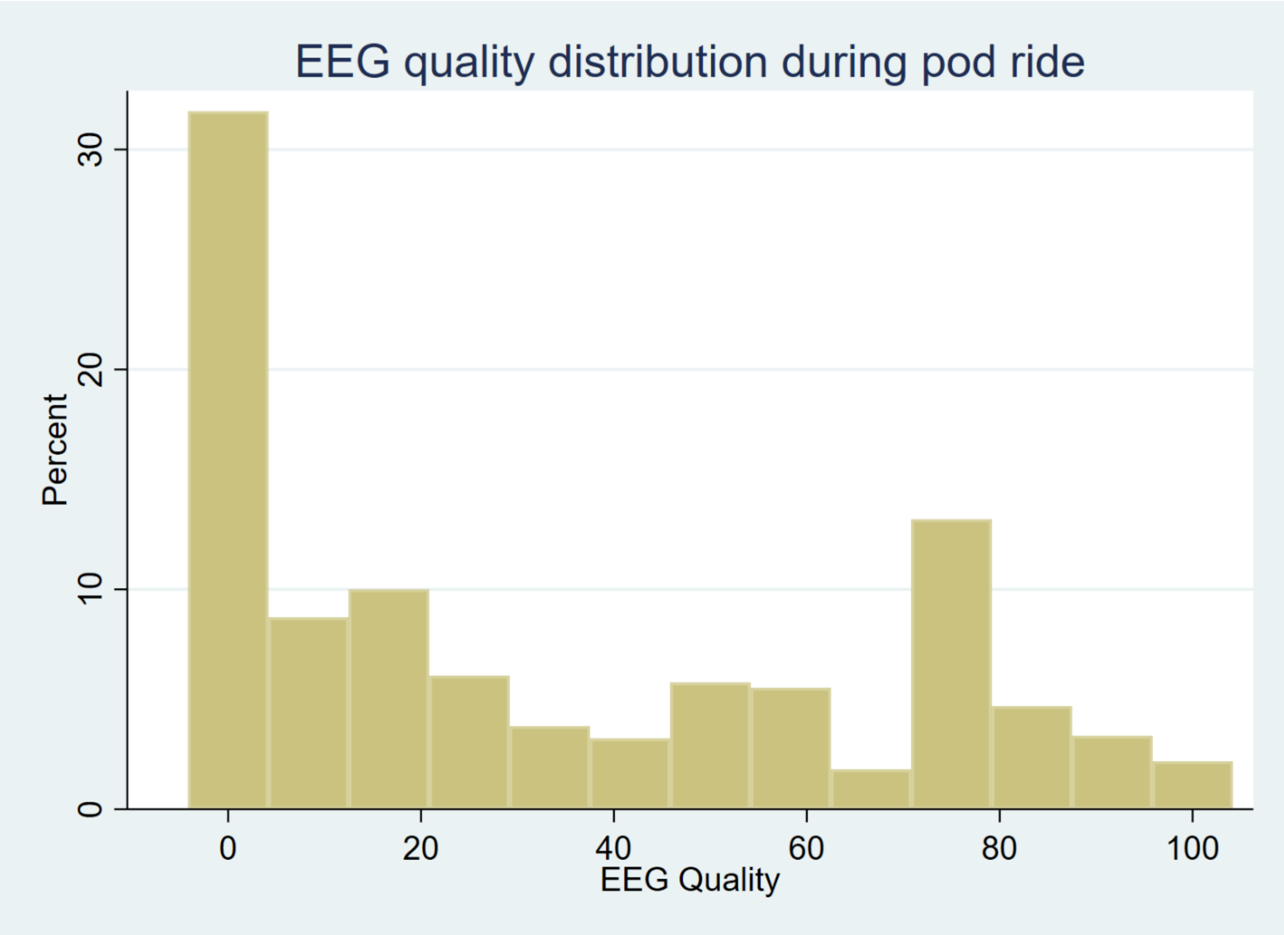

Figure 6. EEG quality during pod ride

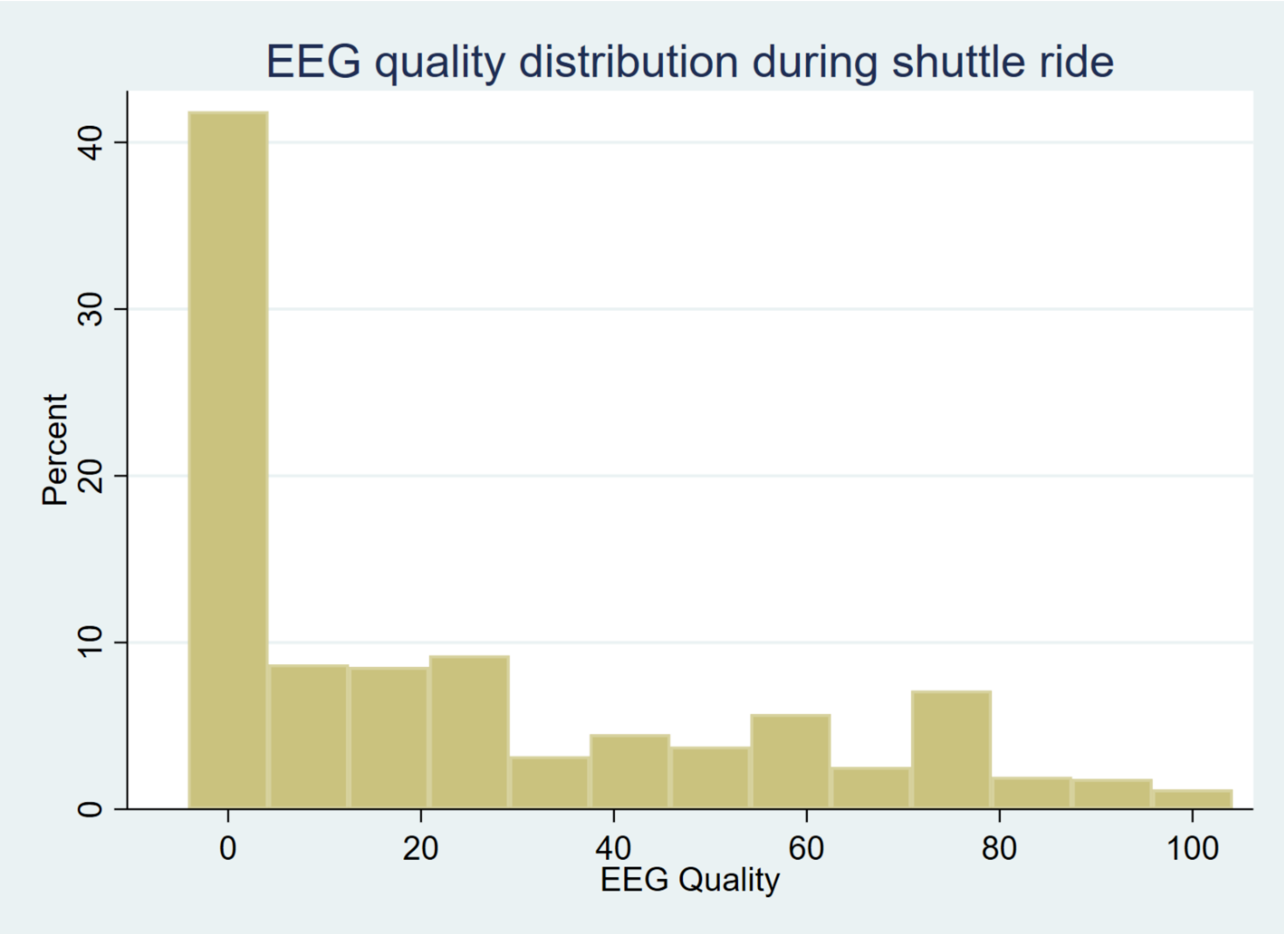

Figure 7. EEG quality during shuttle ride

4. Analysis results

This section describes the results obtained from the EEG data collection. The methods are described, followed by the results. These are split out for the shuttle, the pod and finally some comparisons are made between the two vehicles.

Methods

For the analysis, box plots were generated for the Performance Metrics under different event scenarios. These provide a robust non-parametrical graphical representation of the variation in the Performance Metrics through their quartiles. The spacing in each subsection of the box indicates the degree of dispersion and skewness of the data. The box is drawn from the first quartile (Q1, at the 25th percentile) to the third quartile (Q3, at the 75th percentile) and covers the Interquartile Range (IQR). The middle point represents the median (Q2, the 50th percentile). Finally, whiskers are presented, whereby the boundary of the whisker is based on the 1.5 IQR value. This means that from the upper value Q3, as well as the lower value Q1, a distance of 1.5 times the IQR is measured out and the whisker is drawn to the largest observed datapoint that falls in this distance. The box plots can be easily compared with each other and provide a quick overview of the differences in the Performance Metrics between events during the ride. Furthermore, two statistical tests were performed, Kolmogorov-Smirnov to test whether the distribution of the non-event differs from the event that was studied (see Figure 8 for an example visualisation), and pairwise t-tests to determine whether there are any differences in the means of the Performance Metrics between the baseline EEG readings and shuttle EEG readings across participants. For the pairwise t-tests, rather than the more conventional 5% confidence interval, a 10% confidence interval is used throughout the report. This is used because of the low sample size, particularly when analysing differences within sub-groups (e.g., gender, socio-economic status).

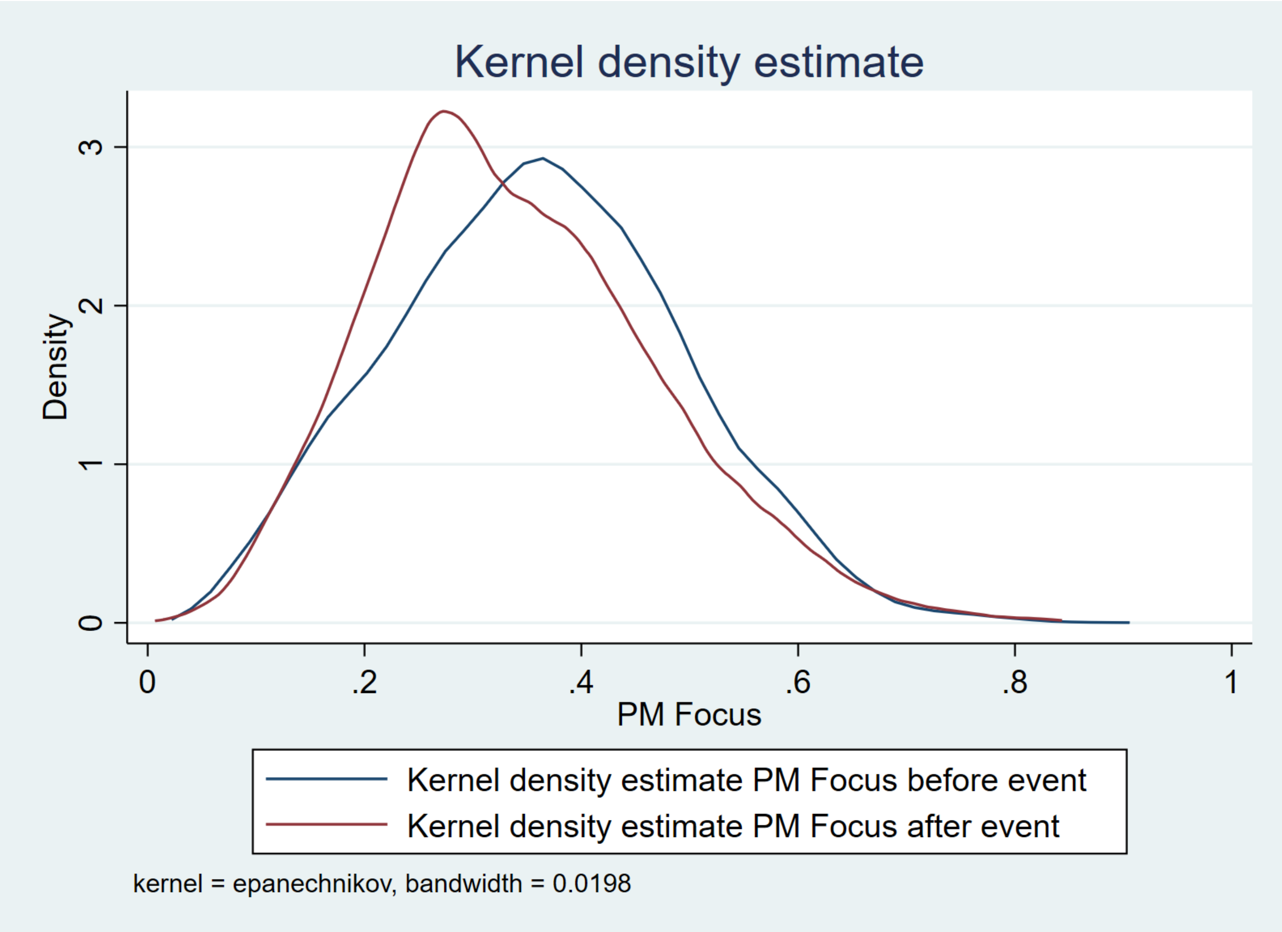

Figure 8. Example comparison between distributions

Analysis Results: Shuttle

This section discusses the findings from the shuttle ride analysis including: results and general findings, differences across groups, observed changes in emotional states during the ride, and the impact of vehicle kinematics on emotional states. The shuttle rides themselves took place across all three locations, and lasted on average 10 minutes in the town, 12 minutes in the city and 10 minutes in the rural location. Recordings were taken from 38 participants, 15 in the town (from across five shuttle runs), 25 in the rural location (from across 10 shuttle runs) and 23 in the city (from across six shuttle runs).

Shuttle-bus rides: General findings

This section discusses the general findings on the Performance Metrics during the shuttle rides. First, average findings on the baseline EEG readings are presented and contrasted with the findings for the EEG readings during the shuttle ride in Figure 9. This was subsequently split out according to several socio-demographics factors including:

- Gender (Figure 10 and Figure 11), split out according to male (n=28) and female (n=33)
- Social grade (Figure 12 and Figure 13), split out according to social grades A and B (n=13) and C1, C2, D and E (n=48).

- Age (Figure 14, Figure 15 and Figure 16), split out according to participants aged under 31 years(n=14), aged 31-55 years (n=28) and older than 56 (n=18),
- Across locations (Figure 17, Figure 18 and Figure 19), split out between city (n=23), rural (n=25) and town locations (n=15).

Regarding the average Performance Metrics for the baseline EEG readings versus the shuttle-bus ride in Figure 9, the following conclusions can be drawn:

- The box plots show that for the baseline EEG readings, Engagement, Interest and Focus have the highest median scores. For the shuttle ride EEG readings, Engagement, Interest and Excitement have the highest median scores. This suggests that participants are alert, with a degree of being immersed in the moment and have a degree of affinity with the task.There is a significant increase in levels of Excitement between the baseline measures and during the shuttle ride. The change for other Performance Metrics is less pronounced.
- Stress levels are generally low during the shuttle ride, suggesting that the experience did not cause adverse emotions.
- The box plots suggest that there are large dispersions around the median for Engagement and particularly for Excitement during the shuttle ride. This implies that there is heterogeneity between participants in their emotional response with some experiencing much higher levels of Excitement than others (these differences will be explored later in this section).
- Based on the box plots, for Focus, Stress, Interest and Relaxation the dispersion around the median is small, suggesting limited differences between the participants. This goes for the baseline EEG readings as well as for the EEG shuttle readings.
- The pairwise t-test shows that there is a statistically significant difference in the average emotional state for Excitement (30% for baseline versus 43% for the shuttle), Focus (30% versus 35%), Engagement (45% versus 52%) supporting the shifts observed in the box plots.
- However, there are no statistically significant differences for the Performance Metrics Interest, Stress and Relaxation between the baseline and shuttle rides.
- Finally, the Kolmogorov-Smirnov test suggests that the distributions for all Performance Metrics are significantly different between baseline and shuttle EEG measurements. This suggests that there are some differences in how the emotional state is distributed amongst participants between the baseline readings and the shuttle ride, even if differences in means are not statistically significant.

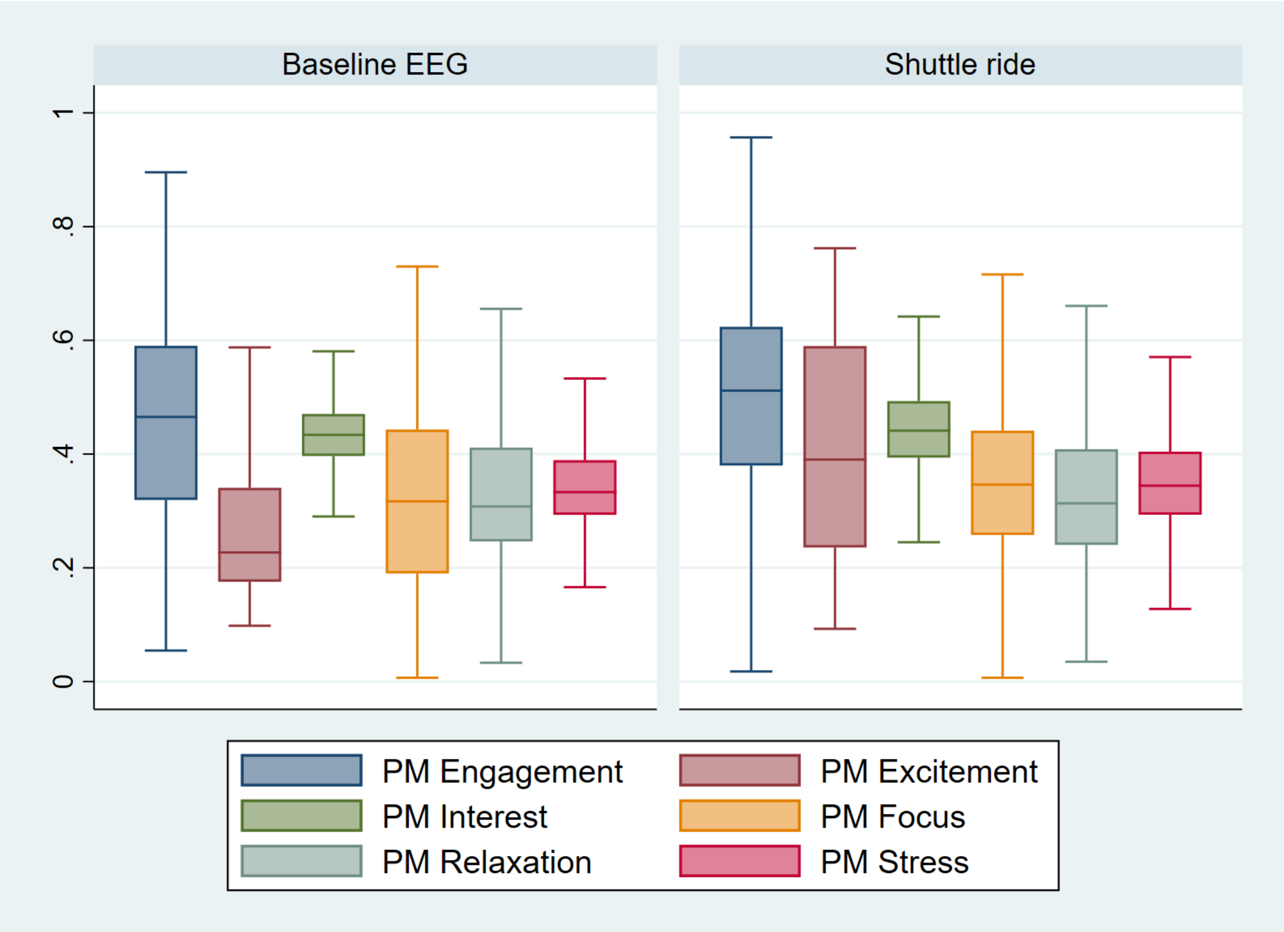

Figure 9. Baseline EEG reading versus shuttle ride.

Regarding gender differences in the Performance Metrics for the baseline EEG readings versus the shuttle ride in Figure 10 and Figure 11, the following conclusions can be drawn:

- For both males and females, there is a signifcant dispersion for most Performance Metrics, suggesting a degree of heterogeneity between participants. This applies to both the baseline EEG readings as well as for the EEG shuttle readings.
- For Focus and Stress, the dispersion is more limited, suggesting a limited degree of heterogeneity. This applies to the baseline EEG readings as well as for the EEG shuttle readings.
- For both males and females, the Kolmogorov-Smirnov test suggests that for all the Performance Metrics, the distributions are significantly different.
- For males, based on the pairwise t-test it can be concluded that the average emotional state during the shuttle ride is different for Excitement (32% for baseline versus 44.5% for the shuttle), Focus (29% versus 35.5%) and Engagement (44% versus 52%)
- For females, based on the pairwise t-test, it can be concluded that the average emotional state during the shuttle ride is different for Excitement (29% for baseline versus 42% for the shuttle), Focus (31% versus 35.7%)and Engagement (47% versus 53%)
- However, for both males and females, there are no statistically significant differences for the Performance Metrics Interest, Stress and Relaxation between the baseline and shuttle rides.

- For males, average Excitement levels are higher compared to Females.

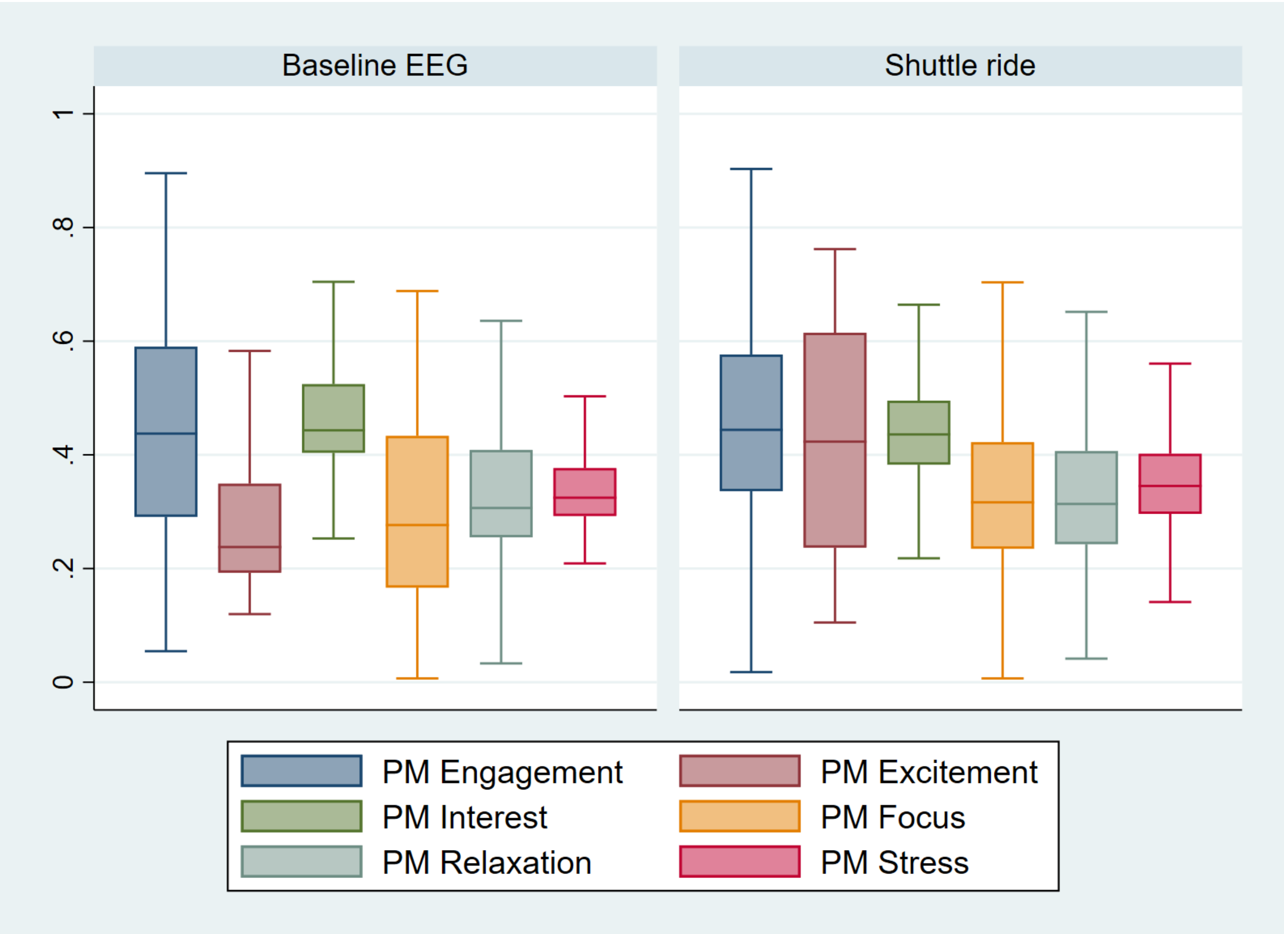

Figure 10. Baseline EEG reading versus shuttle ride for males

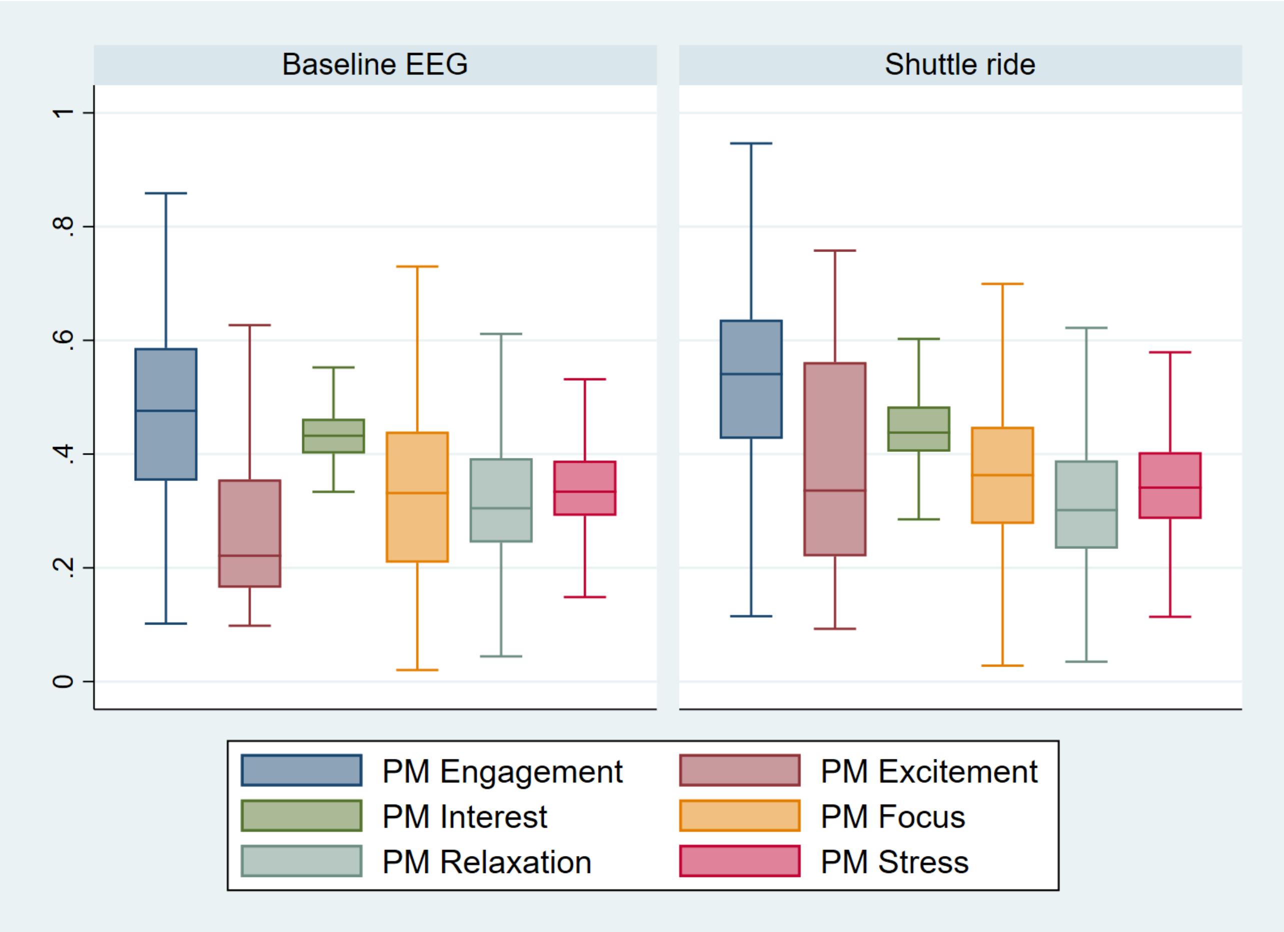

Figure 11. Baseline EEG reading versus shuttle ride for females

Regarding differences based on social grades (A and B versus C1, C2, D and E) on the average Performance Metrics for the baseline EEG readings compared the shuttle ride in Figure 12 and Figure 13, the following conclusions can be drawn:

- For both social grade categories, there is a signifcant dispersion for most Performance Metrics, suggesting a degree of heterogeneity between participants. This applies to both the baseline EEG readings andthe EEG shuttle readings.
- For both social grade categories, the Kolmogorov-Smirnov test suggests that for all the Performance Metrics, the distributions are significantly different.
- The pairwise t-test suggests that the means for Engagement, Excitement and Focus are statistically significantly different between baseline EEG and shuttle ride EEG.
- For participants with social grade C1, C2, D or E, Engagement levels are slightly higher on average.
- For both social grades, Excitement is significantly higher during the shuttle ride compared to the baseline
- For participants with social grade A or B, Excitement is lower compared to participants with social grade C1, C2, D or E (40% versus 43.7%).

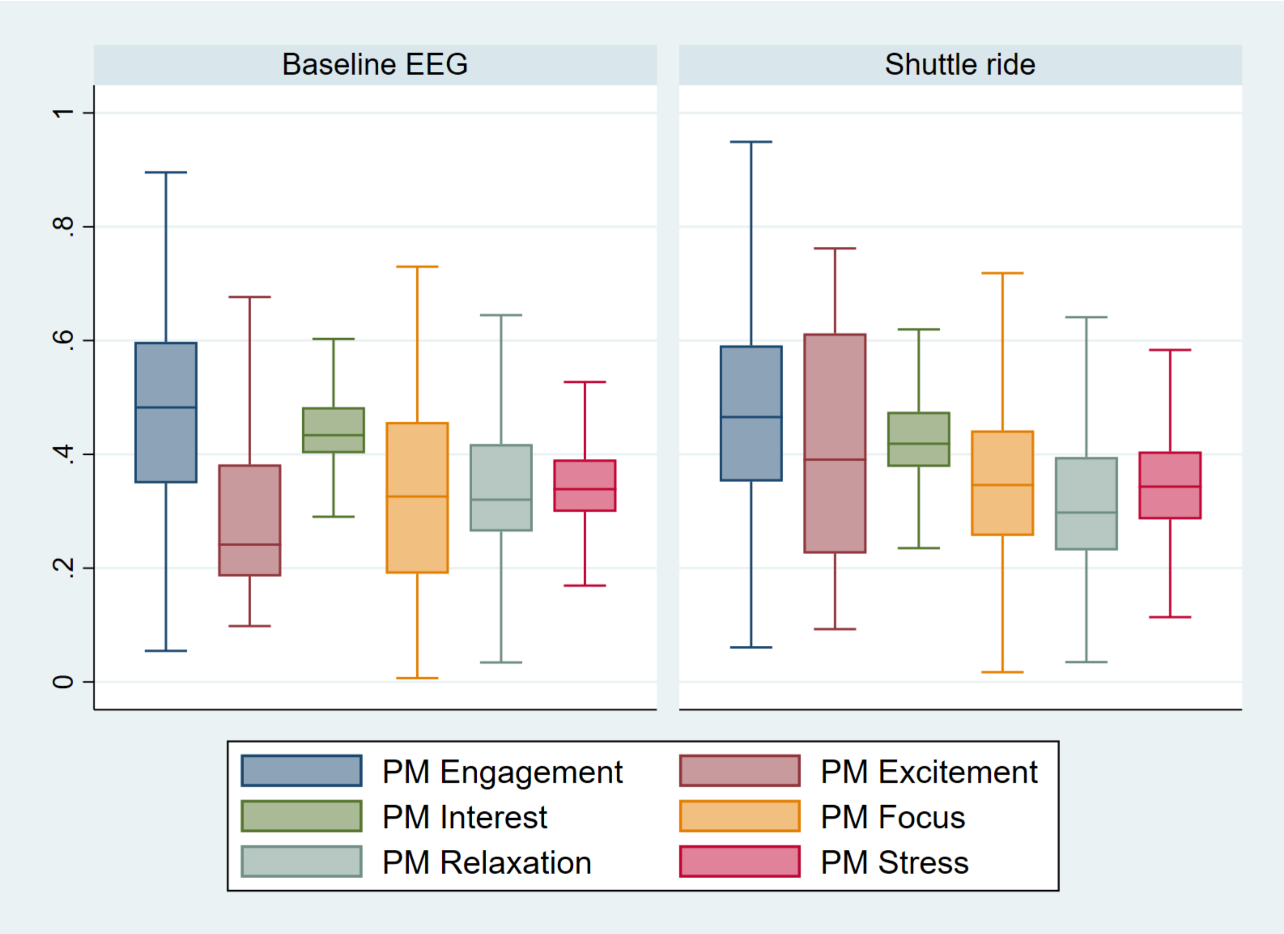

Figure 12. Baseline EEG versus shuttle ride for social grade C1, C2, D and E.

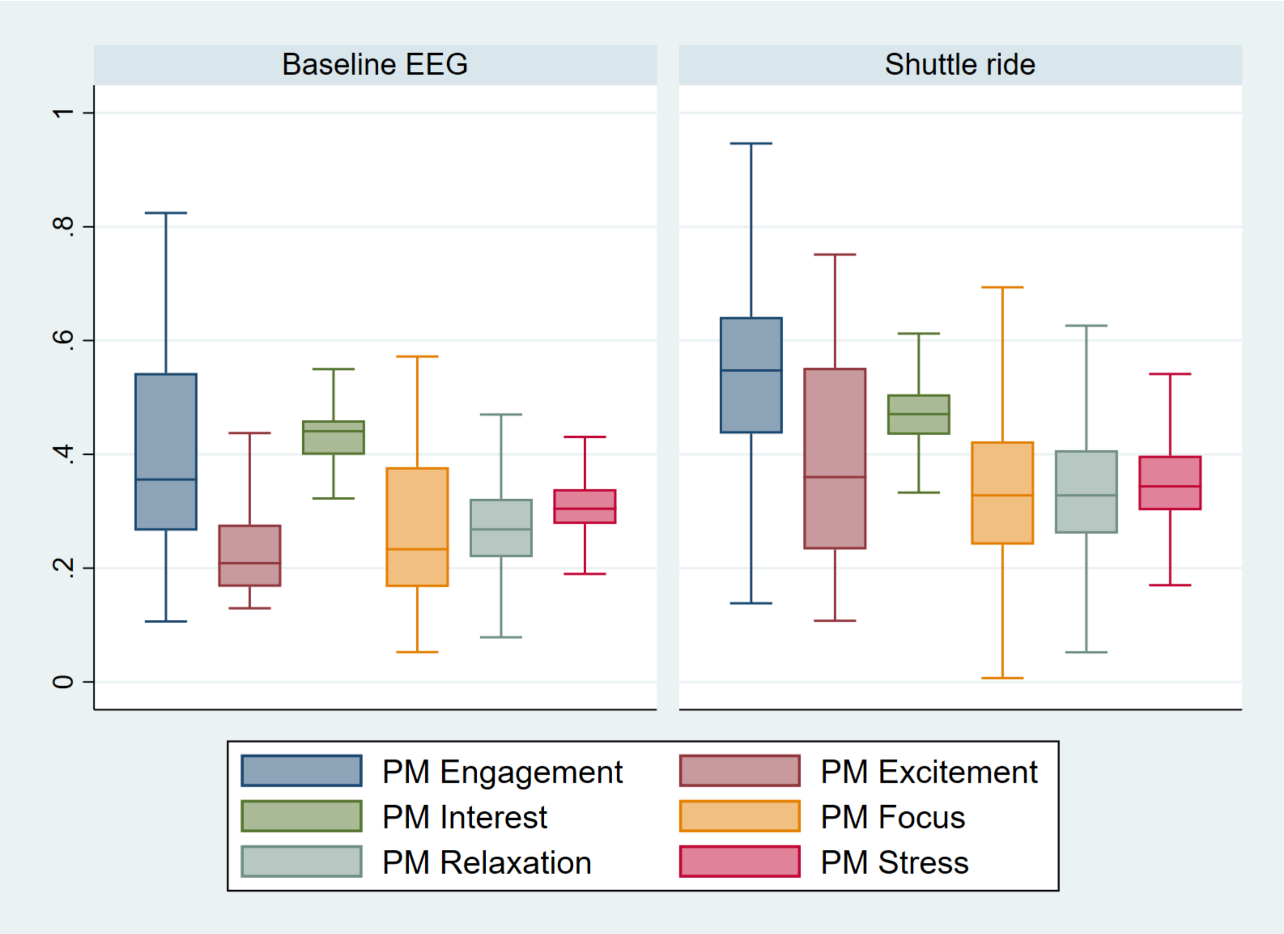

Figure 13. Baseline EEG versus shuttle ride for social grades A and B

Regarding age based differences in the Performance Metrics for the baseline EEG readings compared to the shuttle ride in Figure 14, Figure 15 and, the following conclusions can be drawn:

- For all age categories, there is a signifcant dispersion for most Performance Metrics, suggesting a degree of heterogeneity between participants. This goes for the baseline EEG readings as well as for the EEG shuttle readings.
- For Focus and Stress, the dispersion is more limited, suggesting a limited degree of heterogeneity. This applies to both the baseline EEG readings and the EEG shuttle readings.
- For all age categories, the Kolmogorov-Smirnov test suggests that the distributions are significantly different for all the Performance Metrics.
- The pairwise t-test suggests that only Excitement is significantly different for participants aged under 31 between baseline EEG and shuttle EEG (29% versus 43%).
- For participants aged between 31 and 55, Excitement (29% versus 44%), Focus (28% versus 36%), and Engagement (46% versus 53.4%) are significantly higher.
- For participants aged 56 and over, Excitement (34% versus 41%), Engagement (42% versus 54%), Interest (43% versus 49.6%) and Focus (28% versus 35%) are significantly higher during the shuttle ride.

- For the participants aged 56 and over, there is a lower increase in Excitement compared to the other age categories. Participants aged between 31 and 55 have the highest values for Excitement.
- Engagement significantly increases between baseline EEG and shuttle ride for participants aged 56 and over.
- Findings for Focus show that for participants aged under 31 there are no significant differences in Focus levels between the baseline and shuttle ride (roughly 35% for both baseline EEG and shuttle ride). There is however a significant increase in focus observed for the two older age groups. This suggests that older participants may have a slightly lower degree of comfort during the journey or are more focused on the journey itself.

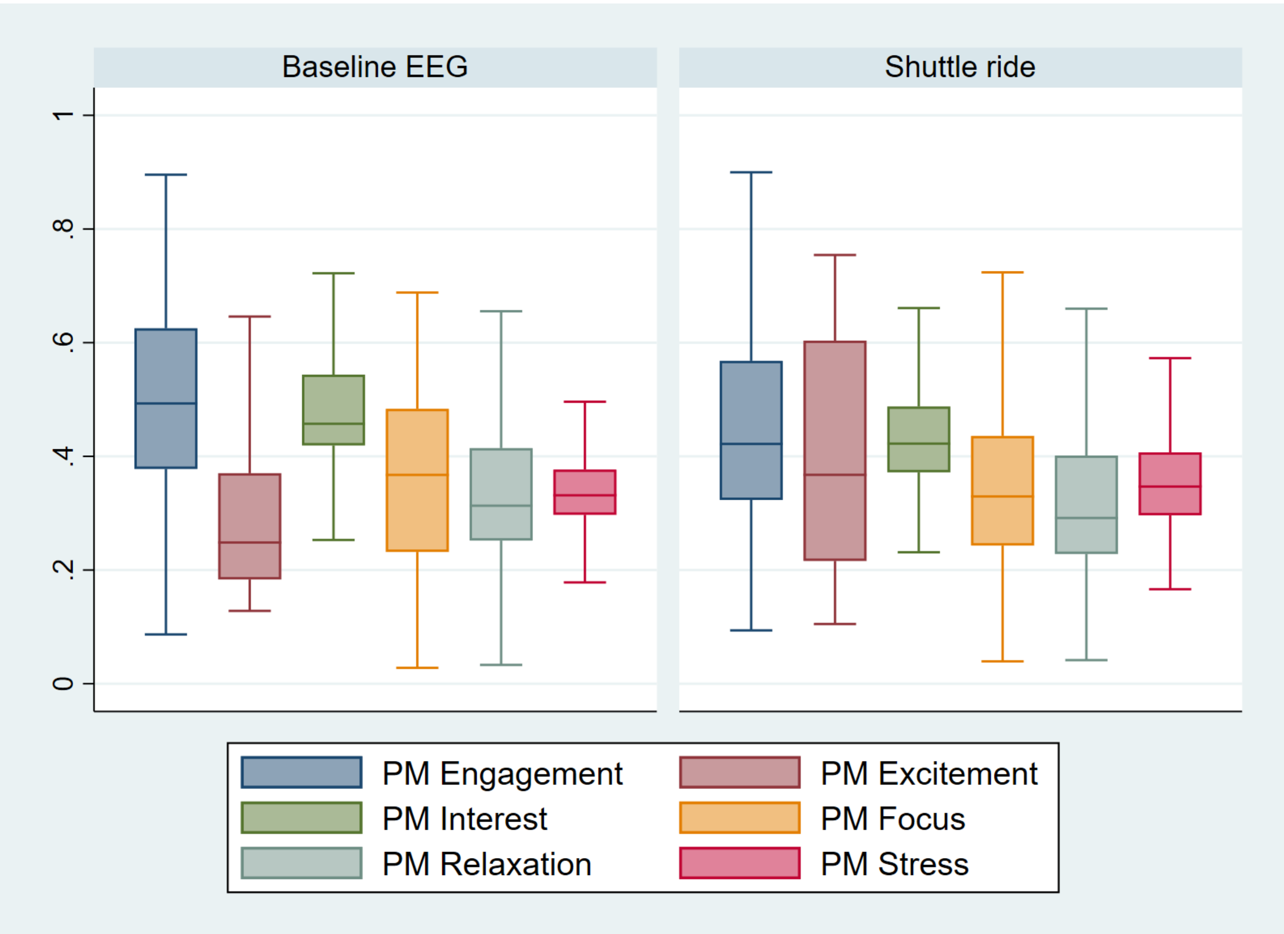

Figure 14. Baseline EEG readings versus shuttle ride for participants aged under 31 years

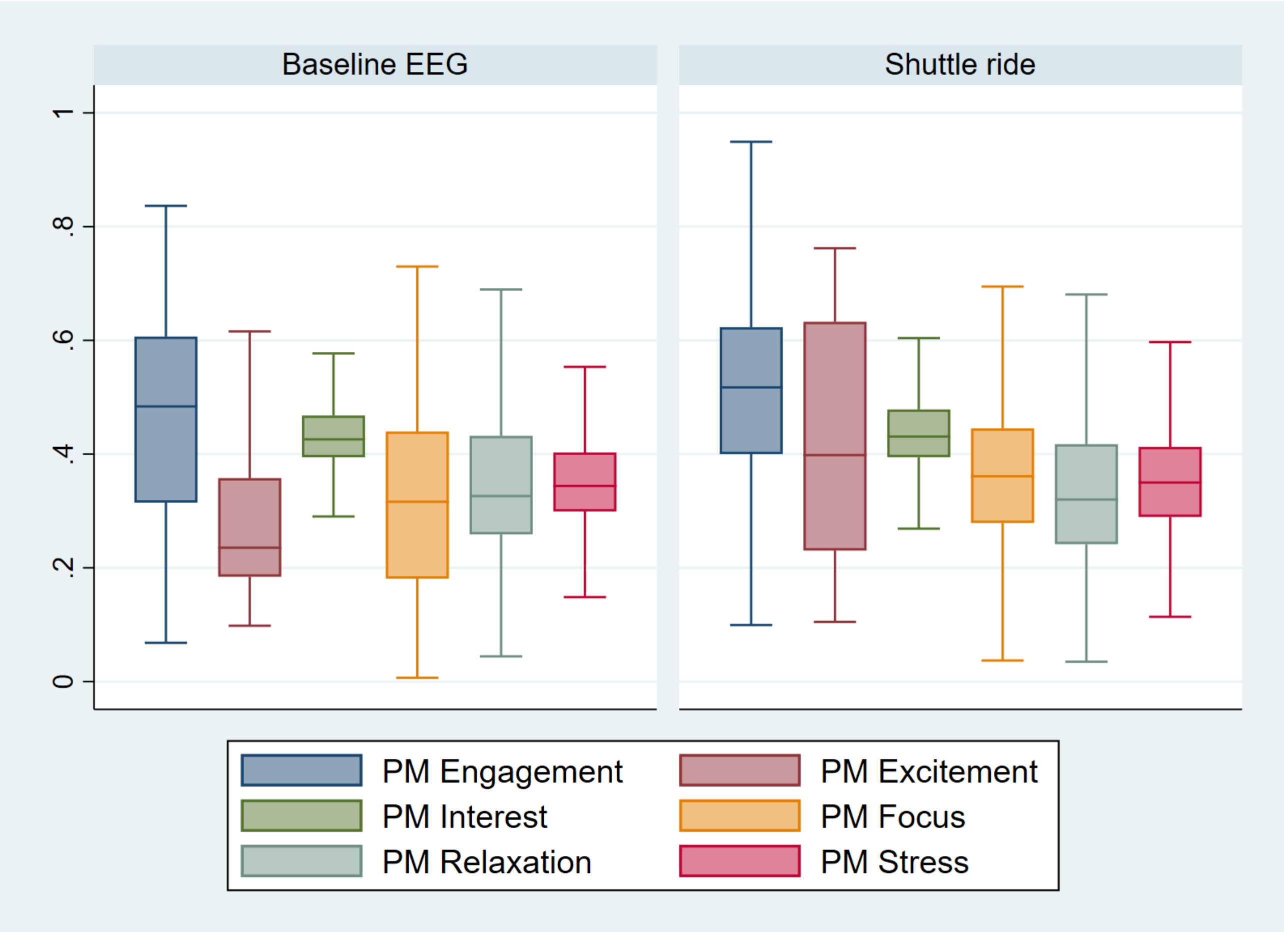

Figure 15. Baseline EEG readings versus shuttle ride for participants aged between 31 and 55

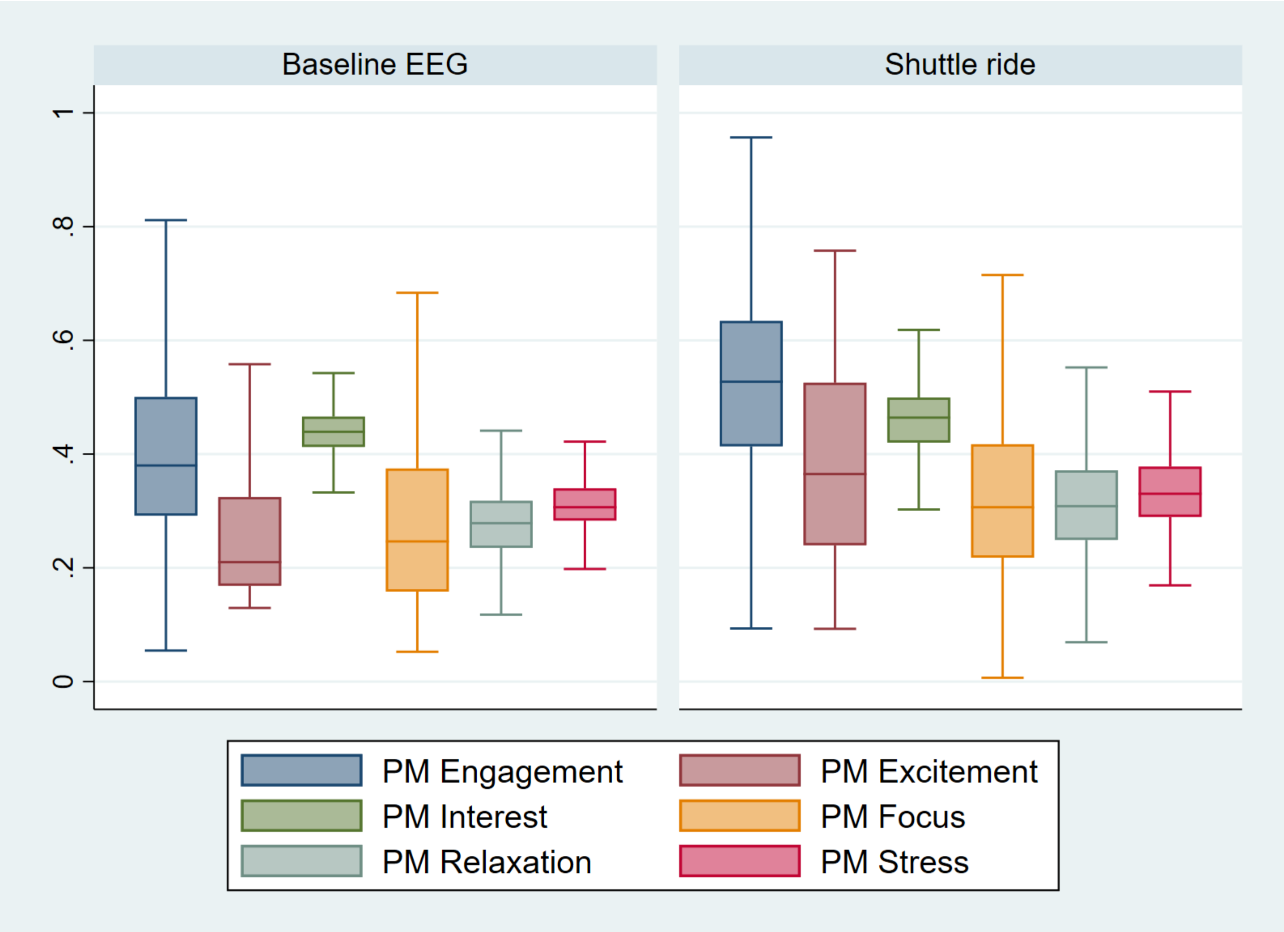

Figure 16. Baseline EEG readings versus shuttle for participants aged 56 years and over

Regarding location based differences in the Performance Metrics for the baseline EEG readings compared to the shuttle ride in Figure 17, Figure 18 and Figure 19, the following conclusions can be drawn:

- For all locations, there is a signifcant dispersion for most Performance Metrics, suggesting a degree of heterogeneity between participants. This goes for the baseline EEG readings as well as for the EEG shuttle readings.
- For Focus and Stress, the dispersion is more limited, suggesting a limited degree of heterogeneity. This goes for the baseline EEG readings as well as for the EEG shuttle readings.
- For all locations, the Kolmogorov-Smirnov test suggests that the distributions are statistically significantly different for all the Performance Metrics.
- The pairwise t-test suggests that for the city Excitement (29% versus 44%) and Engagement (45.5% versus 53%) were significantly higher during the shuttle ride
- For the town, Excitement is also significantly higher (29% versus 47%) but so is whilst Stress (34% versus 37%). Both effects could be explained by the more complex trial route that was followed in the town.
- For the rural location, Engagement (45% versus 53%), Focus (29% versus 36%) and Excitement (31.5% versus 38.2%) were significantly different.
- Whilst Excitement was higher than the baseline for all locations the largest observed increase was for the town.

The most notable difference is that participants in the town have higher levels of Excitement during the shuttle ride compared to the rural location and the city, with the city having the lowest levels of Excitement overall. This could be due to differences in the vehicle trajectory. In the city, the vehicle navigated on a dual carriageway for most of the ride, with a turn around point within a car park. In the town, the vehicle navigated through sometimes narrow streets, and a high street with higher levels of mixed traffic (e.g. pedestrians) and traffic movements around the vehicle. It could be that the shuttle ride in the town was more unpredictable, raising the levels of Excitement during the journey. This could also be due to some of the variation across socio-deomgraphics and broader attitudes towards technology (see The Great Self-Driving Exploration: A citizen view of self-driving technology in future transport systems for further detail).

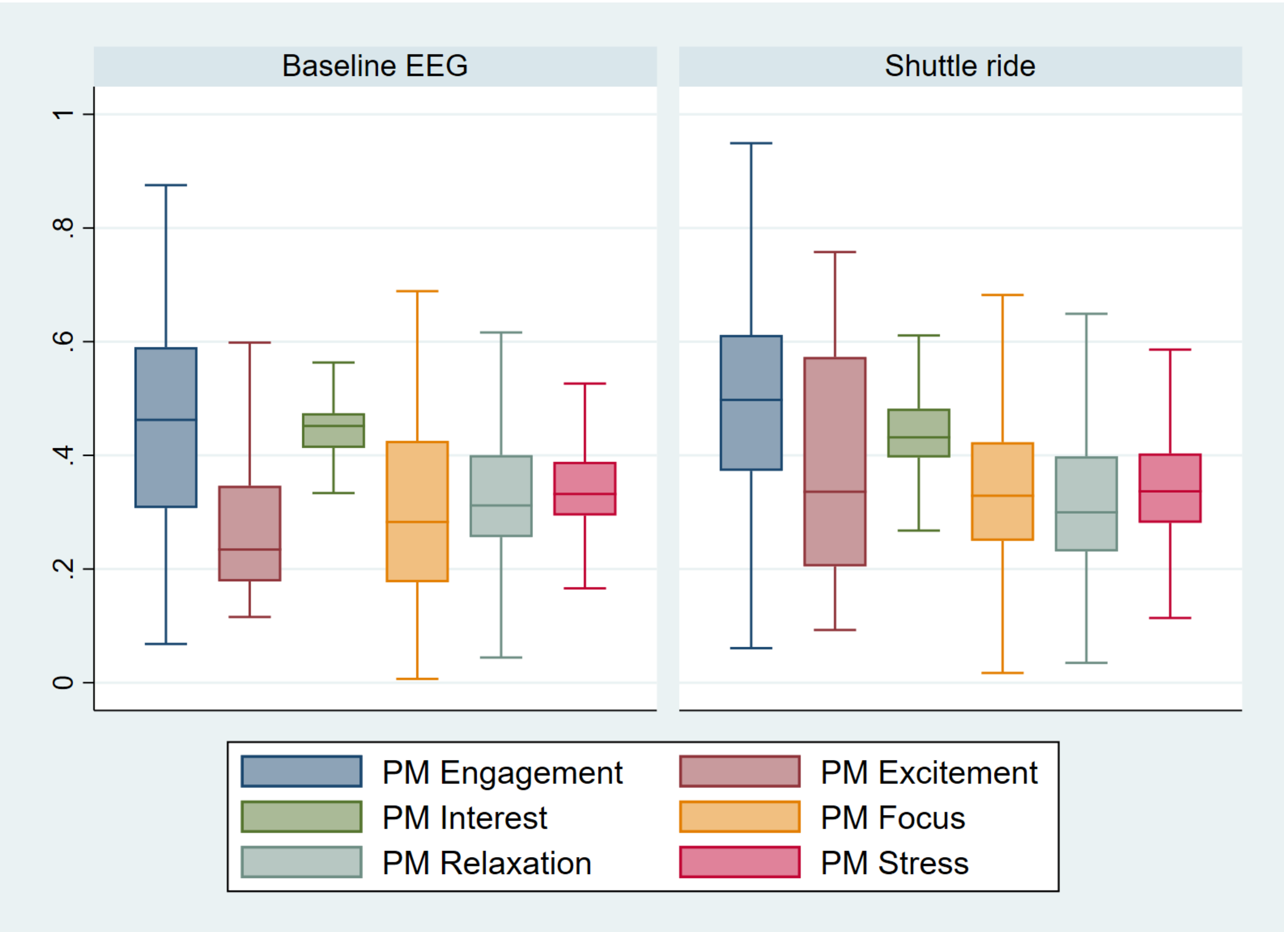

Figure 17. Baseline EEG versus shuttle ride for the city

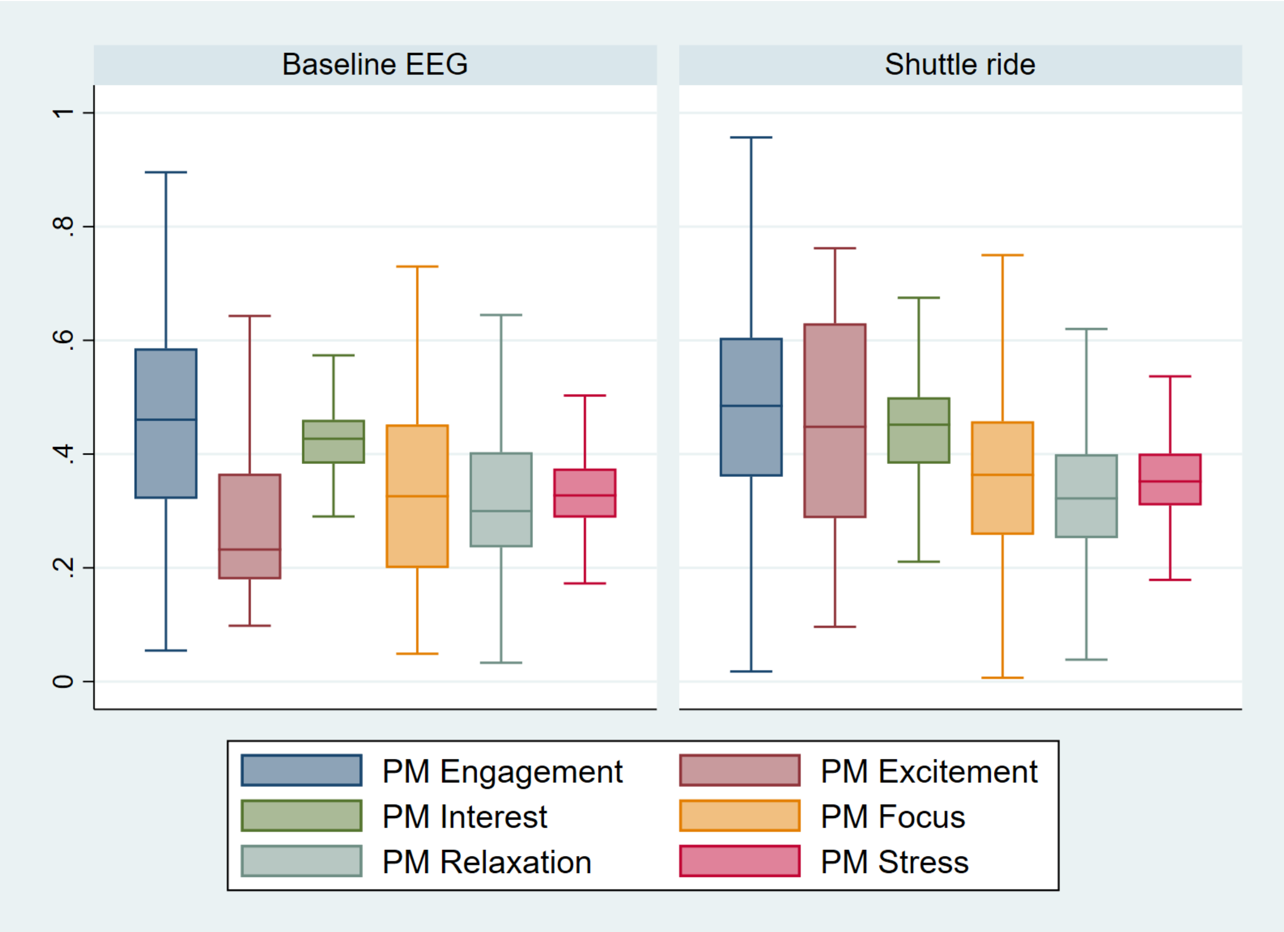

Figure 18. Baseline EEG versus shuttle ride for the town

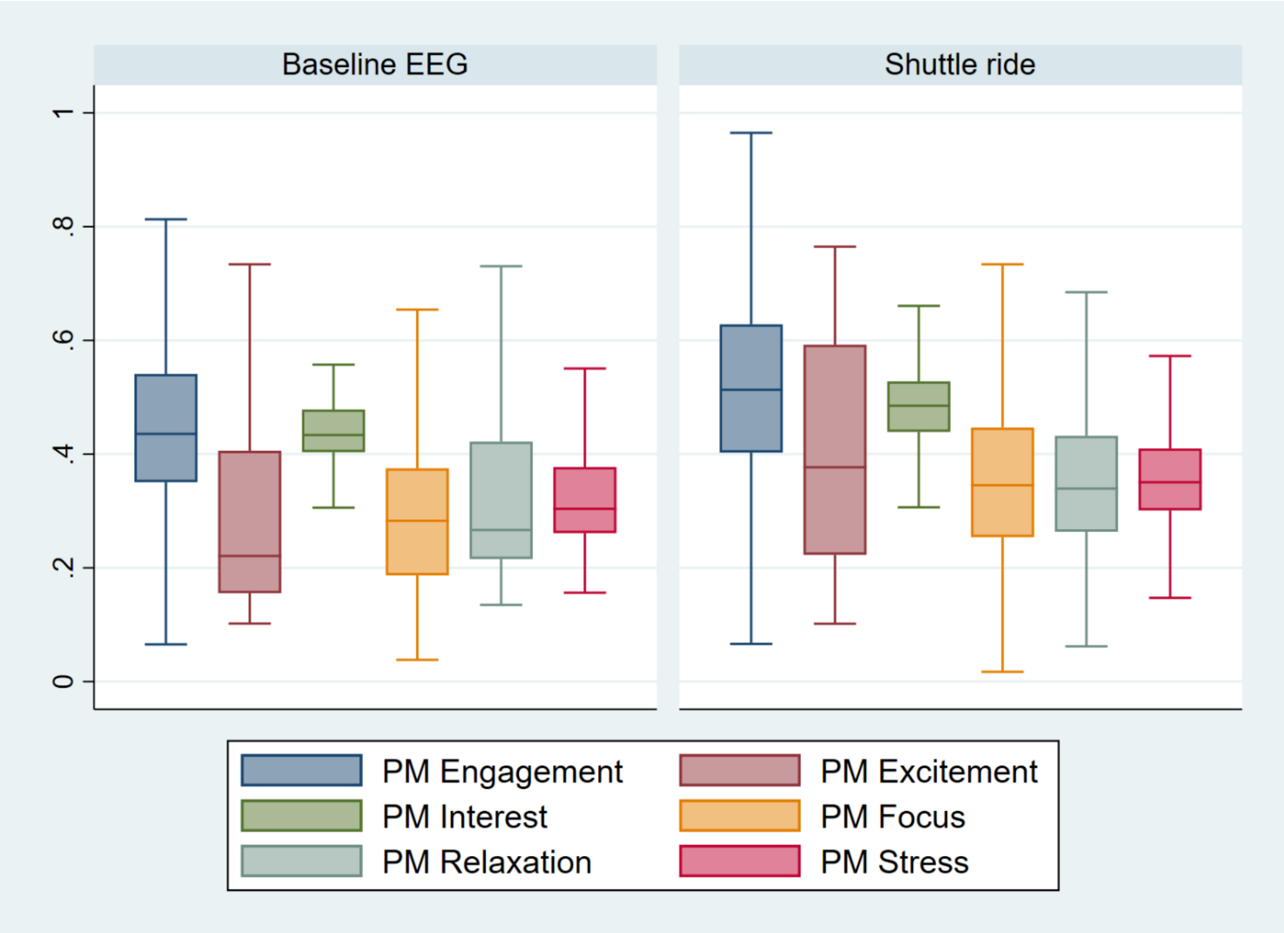

Figure 19: Baseline EEG versus shuttle ride for the rural location

Changes in emotions during the shuttle ride

This section discusses the findings on changes in emotional states throughout the shuttle ride, based on the Performance Metrics. For this, the emotional state during the first five minutes is compared with the subsequent emotional state for the remainder of the ride. First, average findings are presented, followed by findings for socio-demographics and locations. The average findings are presented in Figure 20.

- The Kolmogorov-Smirnov test suggests that for all the Performance Metrics, the distributions are statistically significantly different between the first five minutes and latter part of the ride.
- The pairwise t-test suggests that the means for the Performance Metrics Excitement (44.3% vs 42.2%) and Focus (37.5% vs 34.5%) are statistically significantly different between the first five minutes and latter part of the ride.
- This suggests that Excitement levels wane off during the ride, perhaps as a result of increased familiarity as the journey progresses. The same goes for Focus, whereby it seems participants are less focused on specific tasks perhaps reflecting an increasing level of trust in the vehicle during the ride. Although it is important to note that the Focus levels were low from the start of the journey.
- Stress levels are slightly higher during the first five minutes of the ride (36.4% versus 35.6%).These findings suggest that there they may be a reduction in stress throughout the journey for some participants. Again it is important to note that the Stress levels are low from the start of the journey.

- However, when taken together the change in Stress, Excitement and Focus suggests that participants emotional responses subside and they become more comfortable as the novelty of the experience reduces. It could be that initial apprehension of operating in that environment reduced once participants saw that the vehicle could operate and interact safely with other road users which would be in line with self-reported findings (see The Great Self-Driving Exploration A citizen view of self-driving technology in future transport systems for further details).
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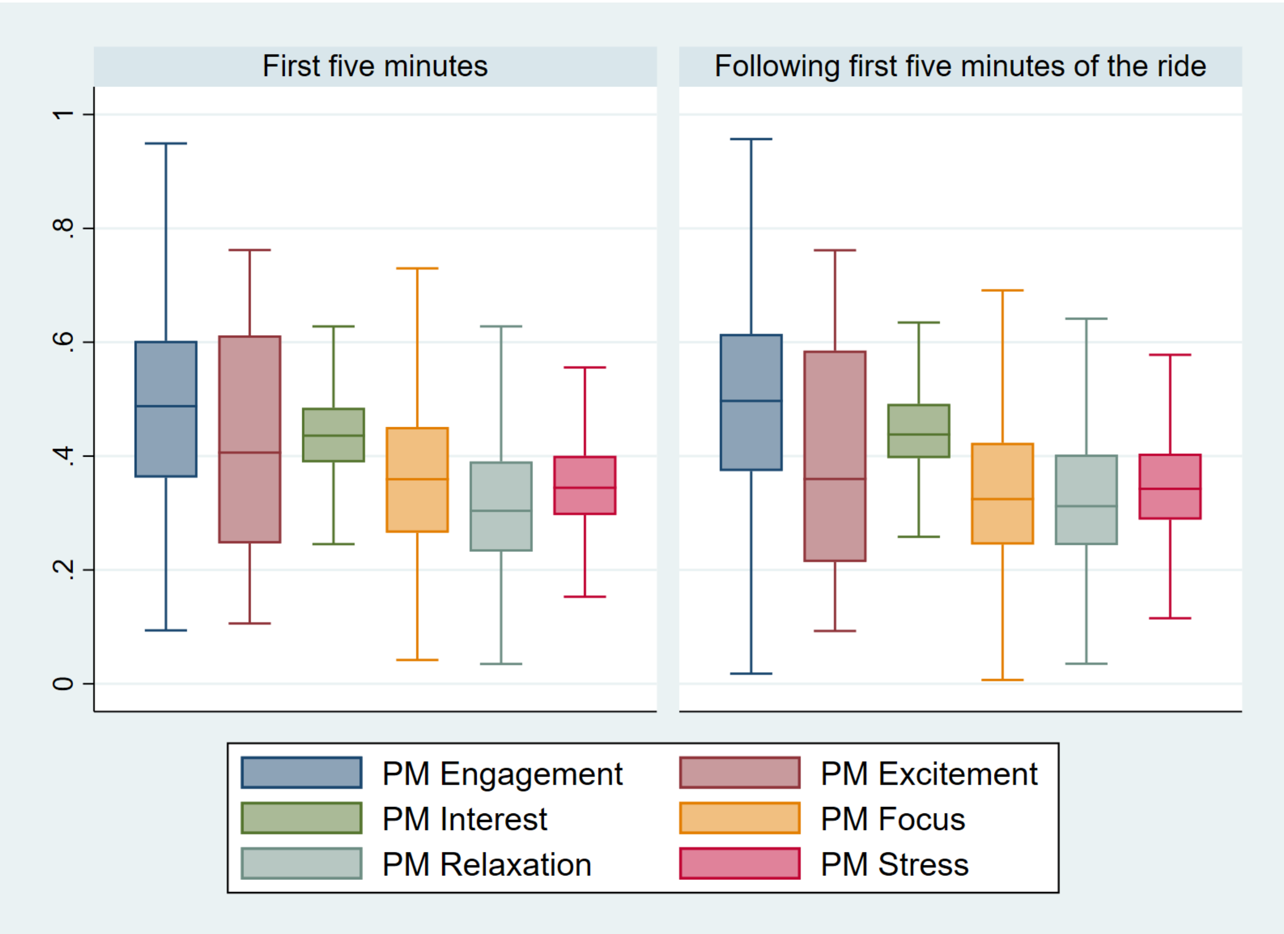

Figure 20. EEG readings during first five minutes on shuttle ride versus the following minutes on the shuttle ride

Regarding gender based differences in the Performance Metrics for the first five minutes on the shuttle ride compared to the remainder of the ride in Figure 21 and Figure 22 the following conclusions can be drawn:

- The Kolmogorov-Smirnov test suggests that for all the Performance Metrics, the distributions for the Performance Metrics are significantly different between the first five minutes and latter part of the ride. This applies to both males and females.
- The pairwise t-test suggests that for males, there are statistically significant differences in the means for Excitement (45.4% versus 41%) and Engagement (48.5% versus 50.3%), whilst for females, only Focus (38.5% versus 33.8%) is significantly different.
- For females, there are also notable reductions in Engament and Stress but these are not statistically significant.

- For males,they seem to experience more subdued emotional reactions (Excitement) as the ride progresses, whilst this is not the case for females. The drop in Excitement on average, is thus a male specific phenomenon. Males also become more immersed in the moment as the ride progresses.
- For females, the level of attention towards one task (Focus) drops, whilst this is not the case for males. This is thus a female specific phenomenon. The findings suggest that they are less focused on the specific task and show lower levels of stress. When taken together this might suggest that trialling self-driving vehicles helps women feel more comfortable with the technology, as seen in the self-reported findings (see The Great Self-Driving Exploration A citizen view of self-driving technology in future transport systems for furter detail).
- As for the main findings, Engagement and Excitement levels are associated with a high degree of heterogeneity across participants.

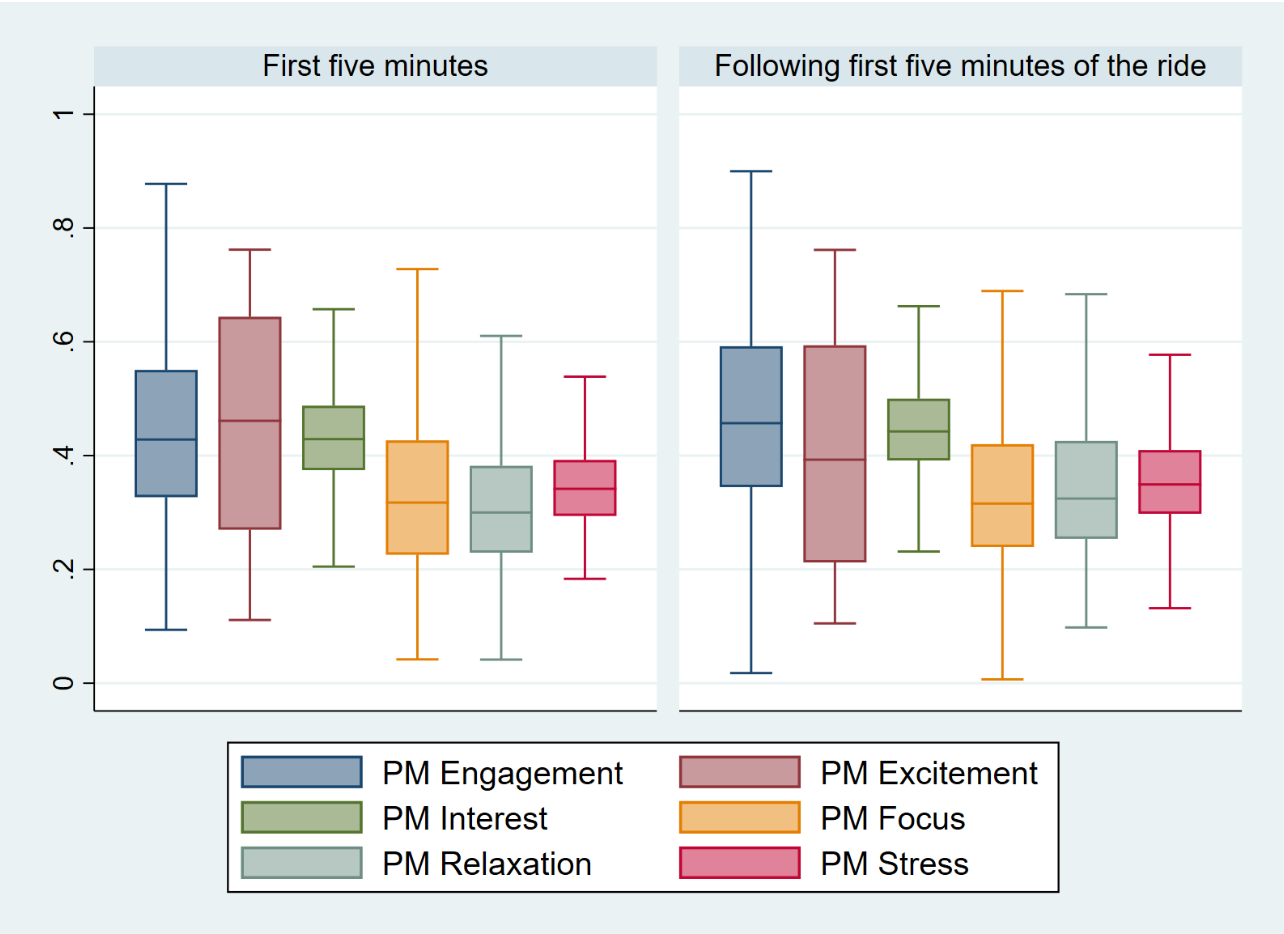

Figure 21. EEG readings during first five minutes on shuttle ride versus the following minutes on the shuttle ride for males

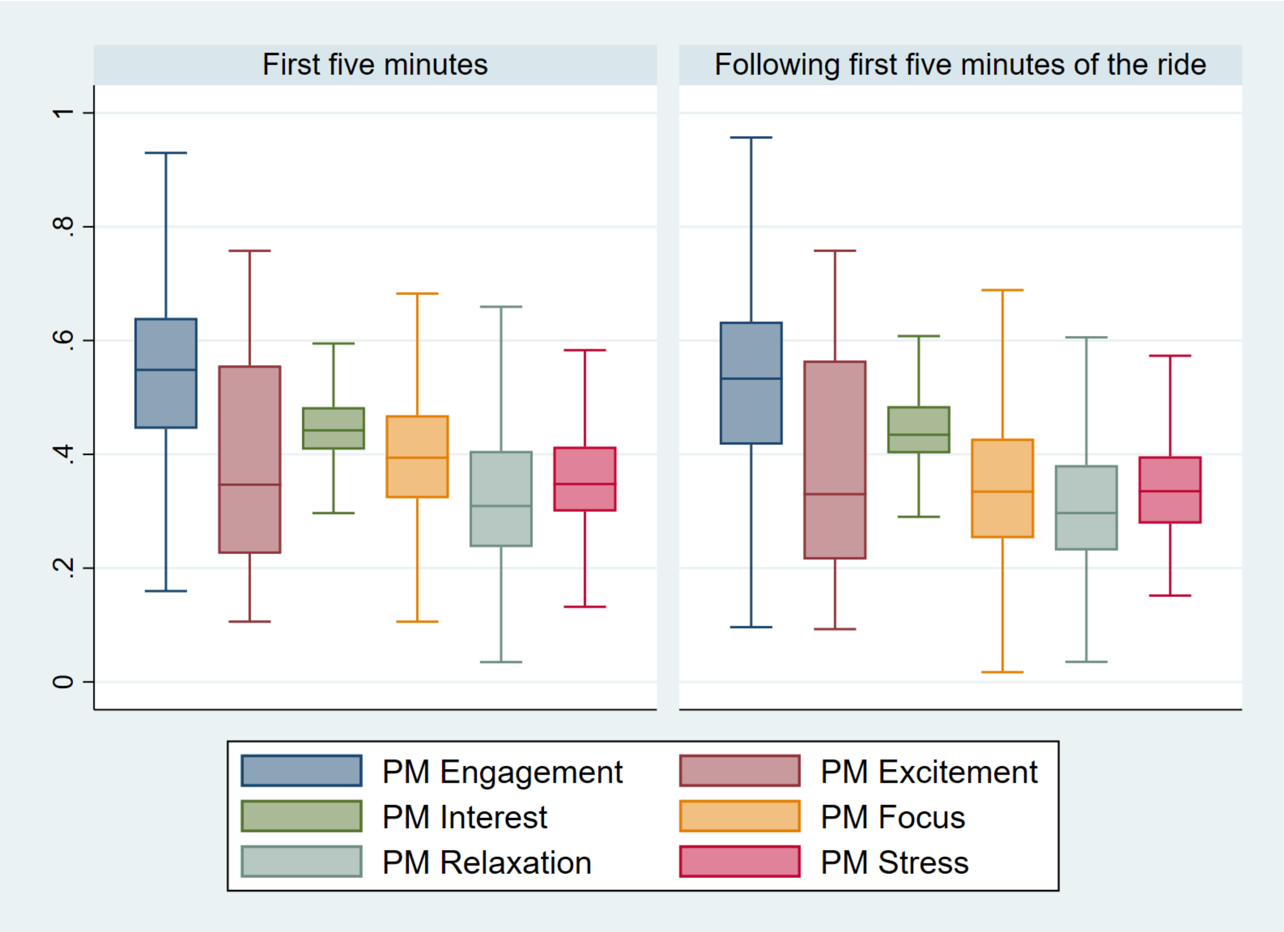

Figure 22. EEG readings during first five minutes on shuttle ride versus the following minutes on the shuttle ride for females

Regarding age based differences in the Performance for the first five minutes on the shuttle ride compared to the remainder of the ride in Figure 23, Figure 24 and Figure 25, the following conclusions can be drawn:

- Given the smaller number of participants in each age group it is important to note that it is more difficult to obtain statistically significant results.
- The Kolmogorov-Smirnov test suggests that for all the Performance Metrics, the distributions are significantly different between the first five minutes and latter part of the ride. This goes for all age groups.
- The pairwise t-test suggests that there is a statistically significant reduction in levels of Excitment for those aged over 56 after the first five minutes (43.3% versus 37.7%). A similar pattern was observed for those aged under 31, but this was not statistically significant (45.3% versus 43.2%). No significant difference was found for those aged between 31 and 55, this is likely caused by an overrepresentation of females in this group.
- For younger participants (aged under 31), Focus (35.95 versus 33.9%) and Stress (37.4% versus 36%) subside during the ride.
- For the two other age groups levels of Focus significantly reduce during the ride (38.5% versus 35% for those aged between 31 and 55, and 36.6% versus 34.1% for those aged 56 and over). No differences were observed for Stress however.
- The patterns across the age groups are in line with the main findings, which suggests that age only has a limited impact on changes in emotional state throughout the journey. They also align with the broader findings that participants emotional

reactions become more moderate as the journey progresses and they become more familiar with the technology.

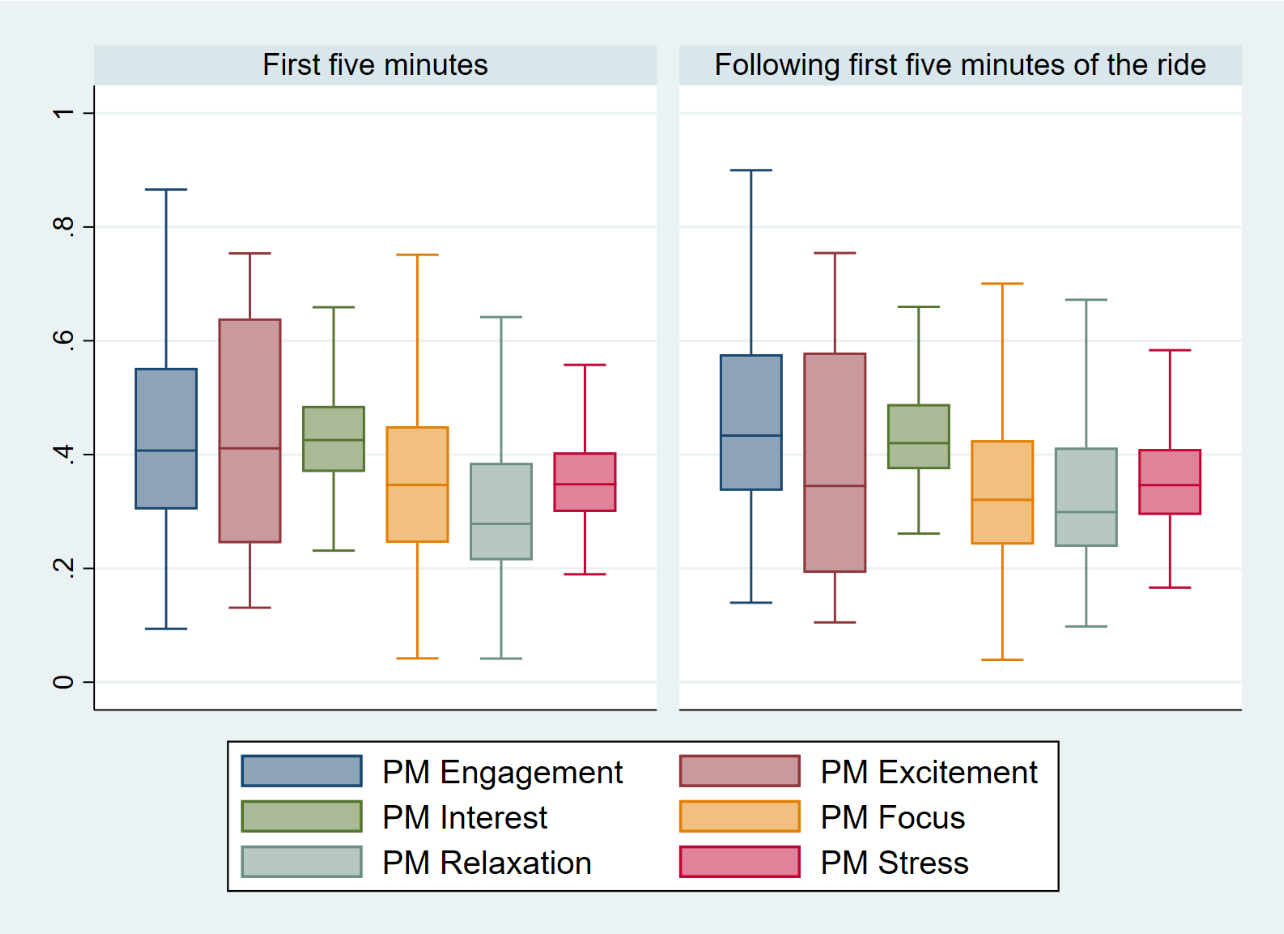

Figure 23. EEG readings during first five minutes on shuttle ride versus the following minutes on the shuttle ride for participants aged under 31 years

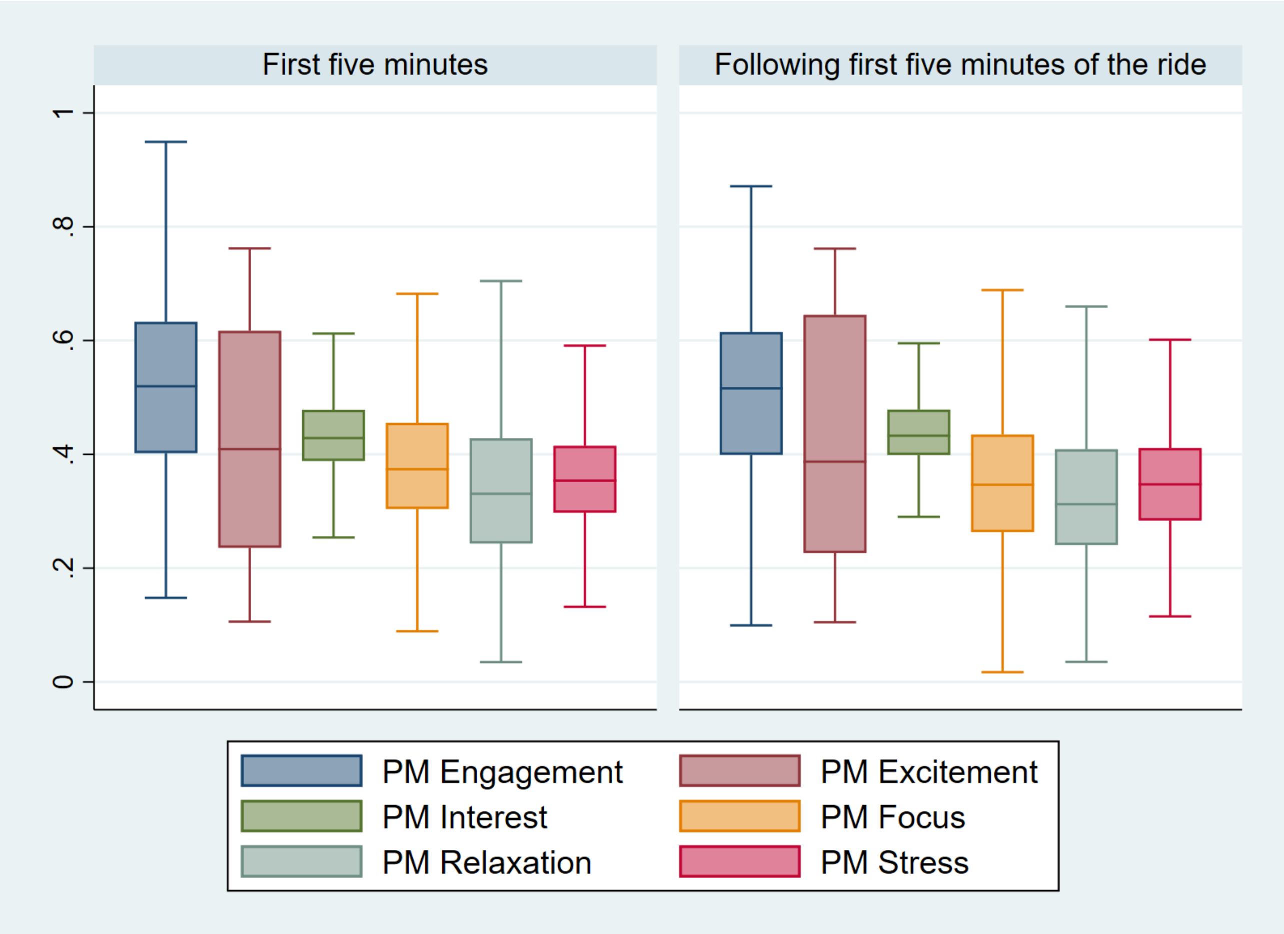

Figure 24. EEG readings during first five minutes on shuttle ride versus the following minutes on the shuttle ride for participants aged between 31 and 55

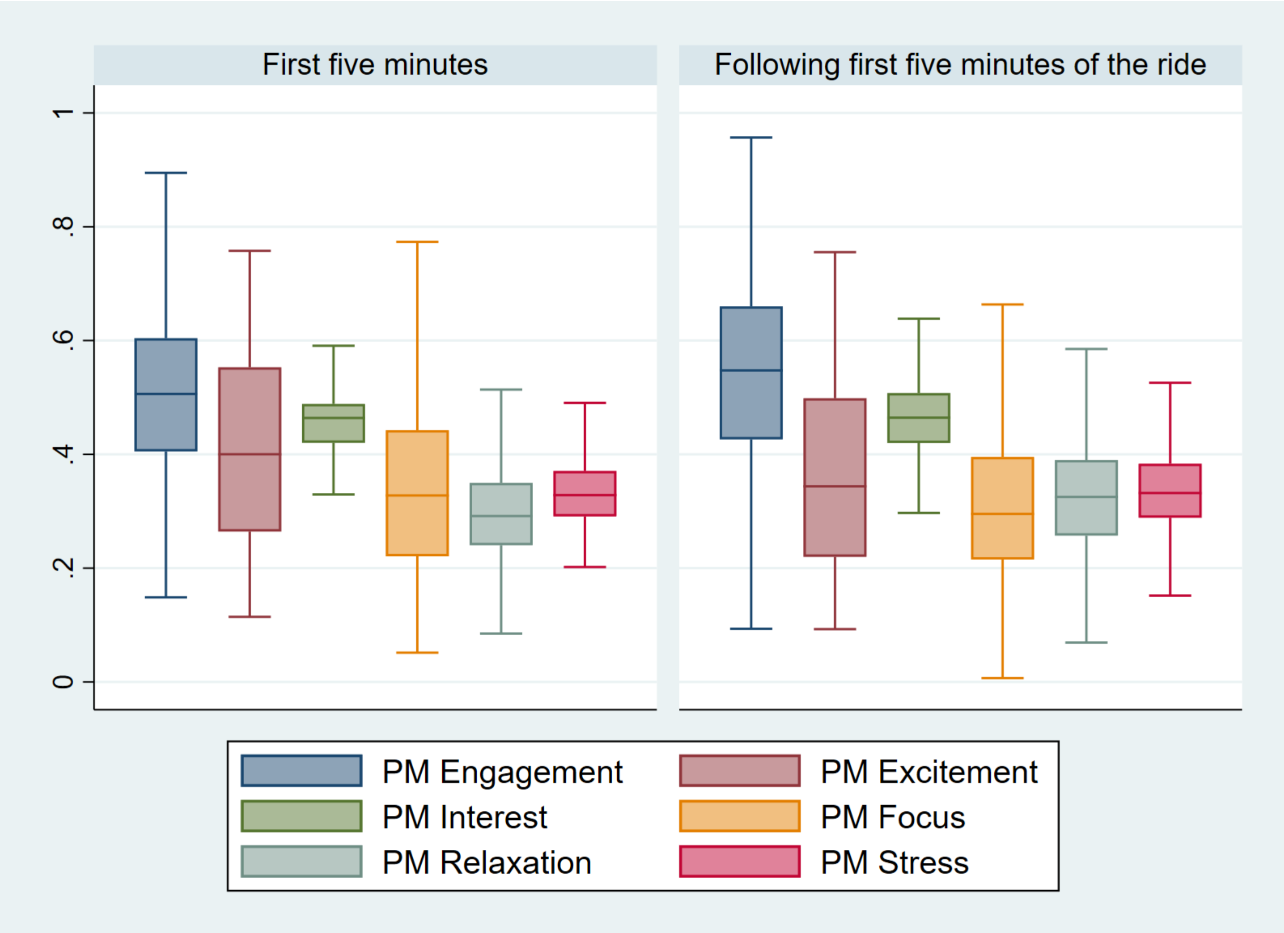

Figure 25. EEG readings during first five minutes on shuttle ride versus the following minutes on the shuttle ride for participants aged 56 years and over

Regarding differences based on social grades (A and B versus C1, C2, D and E), for the first five minutes on the shuttle ride compared to the remainder of the ride in Figure 26 and Figure 27, the following conclusions can be drawn:

- The Kolmogorov-Smirnov test suggests that for all the Performance Metrics, the distributions are significantly different between the first five minutes and latter part of the ride. This goes for all social grades.
- The pairwise t-test suggests that the means for Excitement (45.5% versus 43.2%) and Focus (37.7% versus 35%) are statistically significantly different between the first five minutes and latter part of the ride for participants in social grade C1, C2, D and E.
- For participants in social grade A and B, both Focus (36.8% versus 33.7%) and Stress (36% versus 33.4%) are significantly lower in the later part of the ride. There is no significant difference in levels of Excitement however.
- These differences are not related to any imbalance between gender suggesting that this difference is due to (higher) socio-economic status, whereby participants in higher socio-economic groups perhaps experience an increased trust in the vehicle, whilst not experiencing the subsiding of Excitement (which is generally lower compared to participants in lower socio-economic groups anyways).

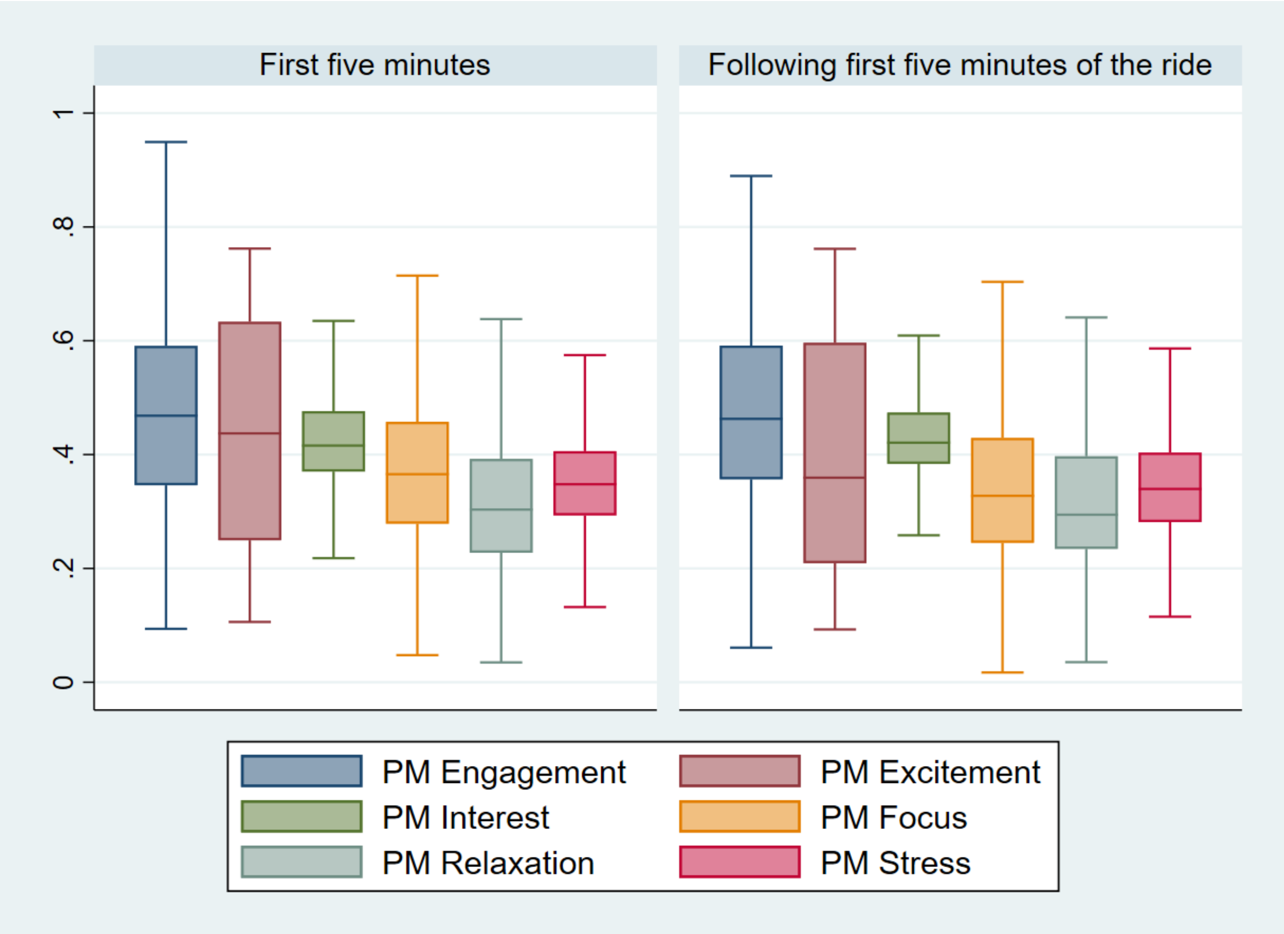

Figure 26. EEG readings during first five minutes on shuttle ride versus the following minutes on the shuttle ride for social grades C1, C2, D and E

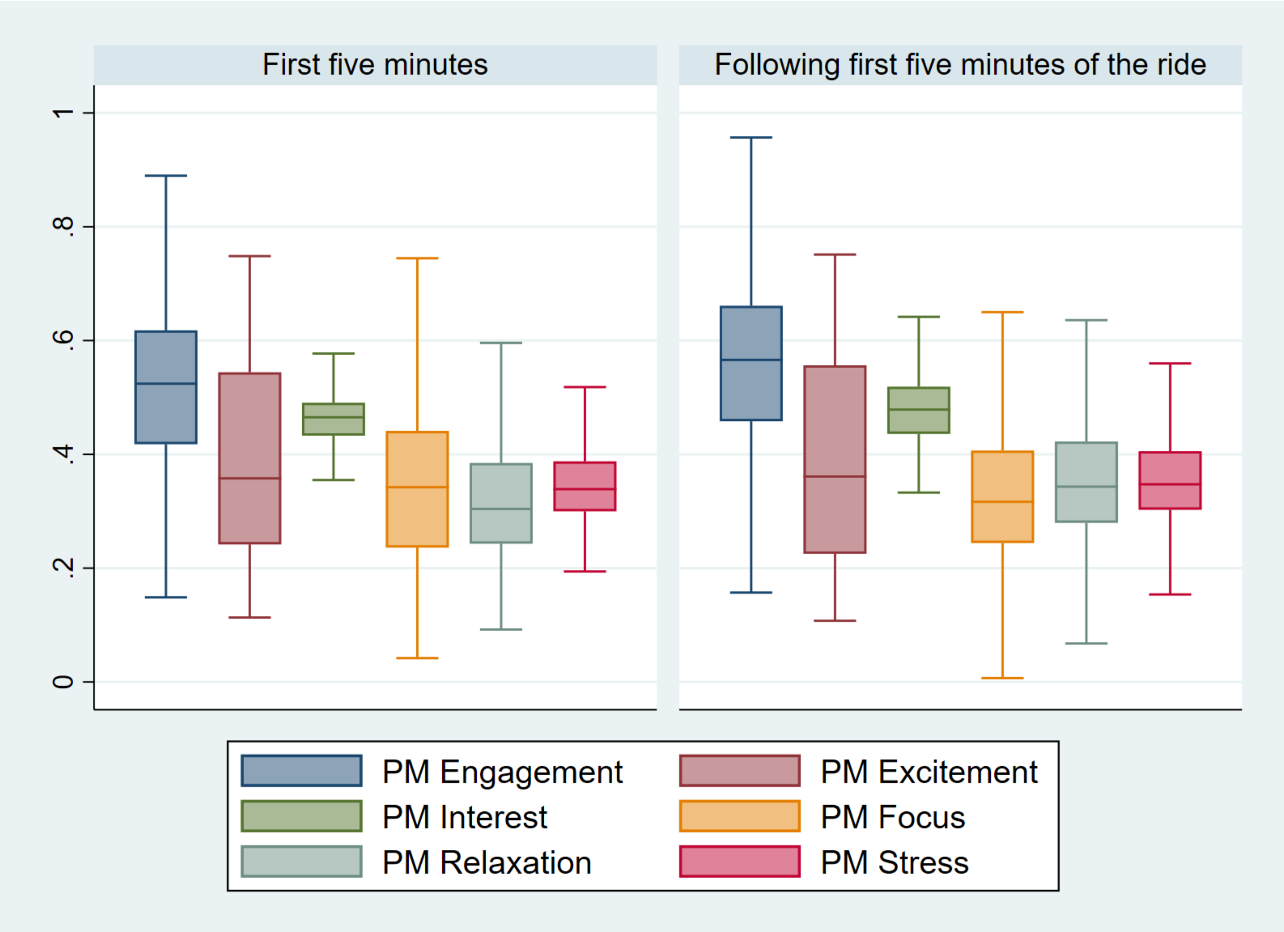

Figure 27. EEG readings during first five minutes on shuttle ride versus the following minutes on the shuttle ride for social grades A and B.

Regarding location based differences in the Performance for the first five minutes on the shuttle ride versus the remainder of the ride in Figure 28, Figure 29 and Figure 30, the following conclusions can be drawn:

- Given the smaller number of participants in each age group it is important to note that it is more difficult to obtain statistically significant results.
- The Kolmogorov-Smirnov test suggests that for all the Performance Metrics, the distributions are significantly different between the first five minutes and latter part of the ride. This goes for both locations.
- For participants in the city, there is a noticeable reduction in both Excitement (44.5% versus 42.3%) and Focus (35.4% versus 33.9%) but these differences are not significant.
- For participants in the town, there was no significant difference observed for Excitement. However, there was a significant increase in Relaxation levels (34.3% versus 37.6%), and a significant reduction in Focus levels (38.3% versus 36.3%).
- For Excitement, these observations for the town are not in line with the main findings, thus suggesting a specific pattern for this location. This could be due to the characteristics of the journey which was in a more complex environement (i.e. a busy high-street, with high levels of mixed traffic) compared to the other locations.
- For participants in the rural location, there was a significant reduction in Stress (36.6% versus 34.7%), Focus (38.7% versus 34.4%) and Excitement (42% versus 38.7%) throughout the journey. For Excitement and Focus this is in line with the main patterns, however for Stress this seems unique to the rural location. This could once

again be due to the journey characteristics and like in the town location an initial apprehension, which reduces once participants experienced the vehicle's performance or due to gender differences as there was a higher number of females participants in this location.

- It therefore appears that the location, or the specific journey characteristics, seem to impact on the emotional state of participants, particularly for Excitement, Relaxation and Stress.
- As for the main findings, these patterns are in line with the self-reported findings (see The Great Self-Driving Exploration A citizen view of self-driving technology in future transport systems for further details).

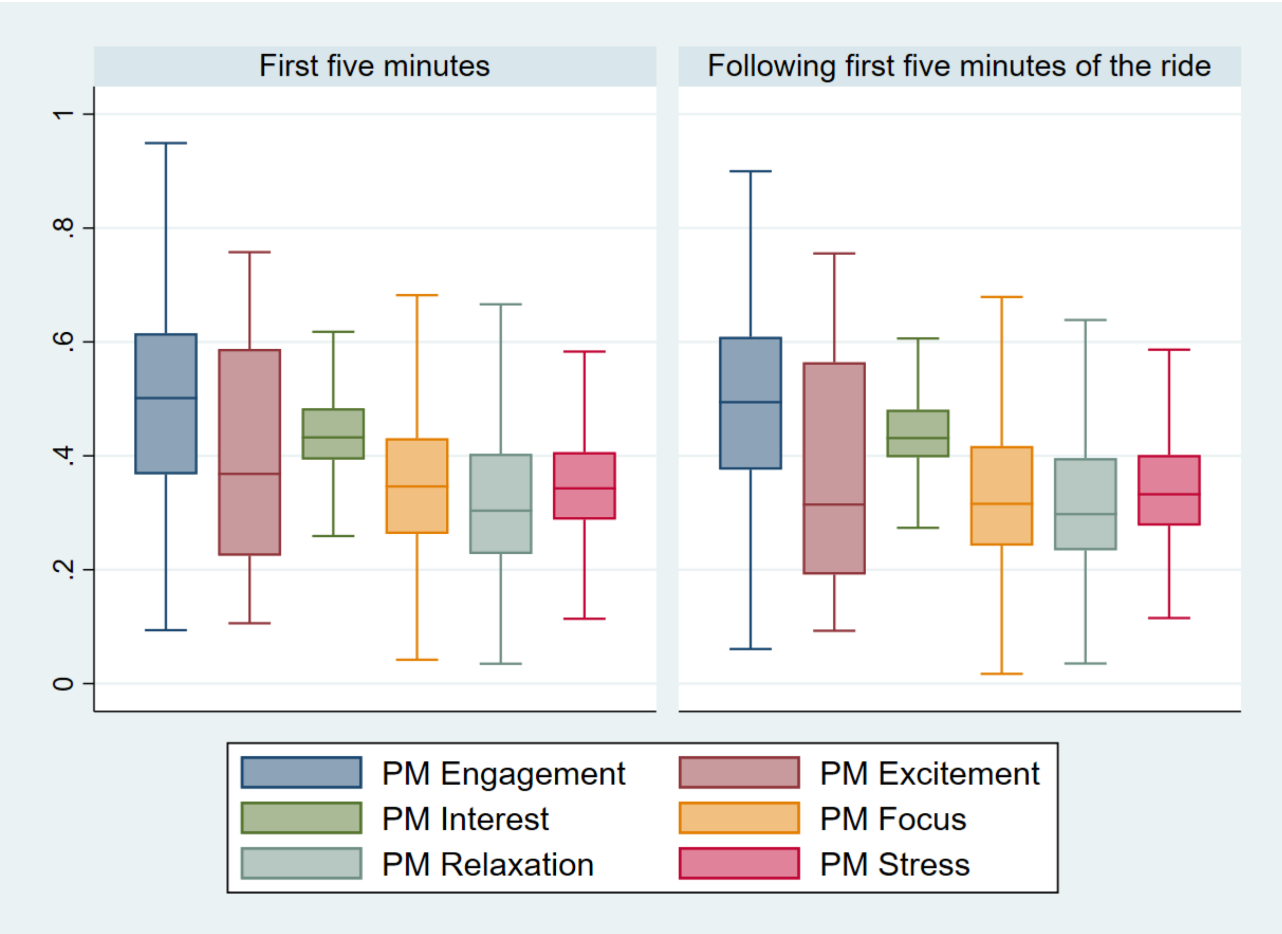

Figure 28. EEG readings during first five minutes on shuttle ride versus the following minutes on the shuttle ride for the city

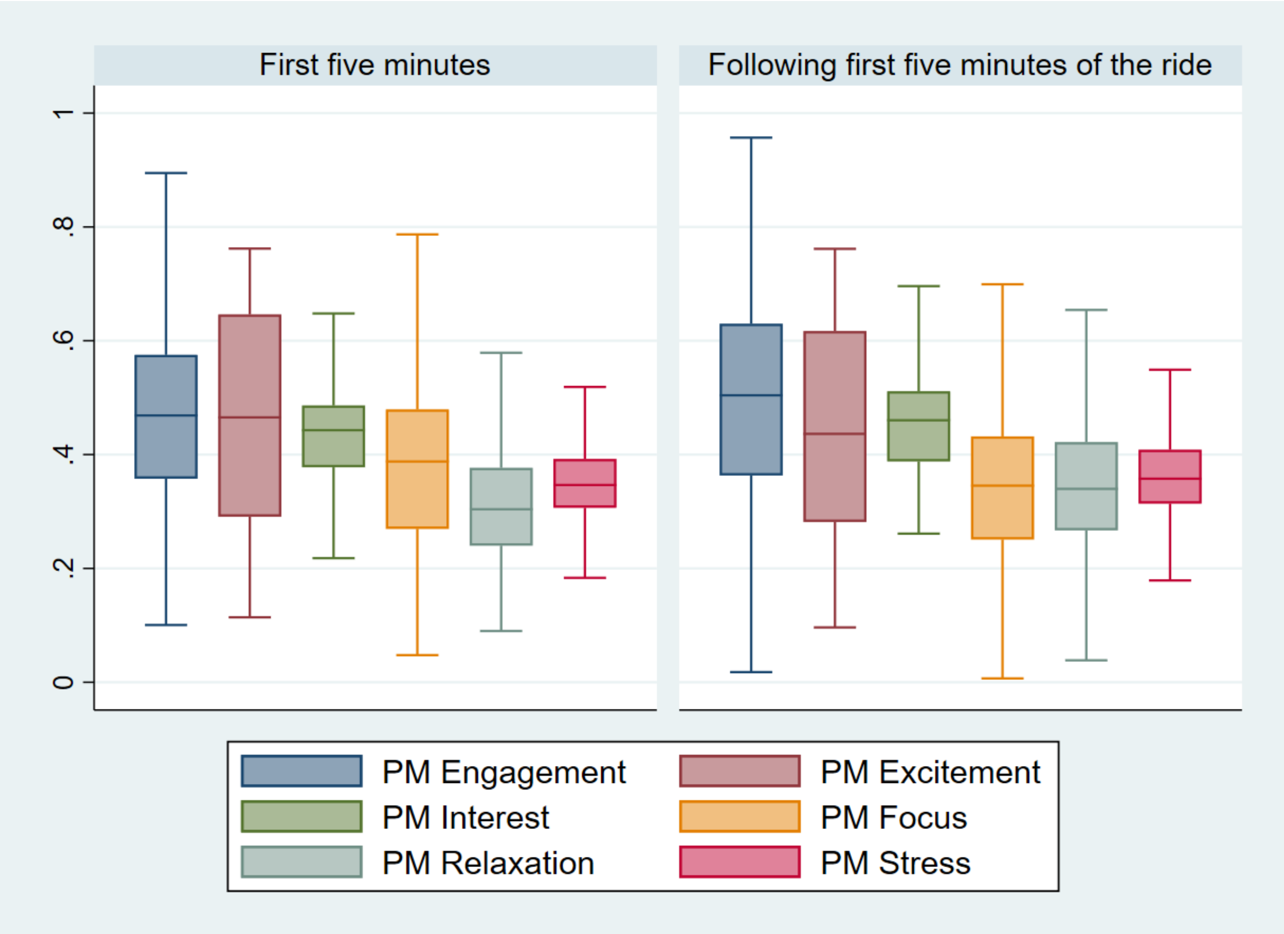

Figure 29. EEG readings during first five minutes on shuttle ride versus the following minutes on the shuttle ride for the town

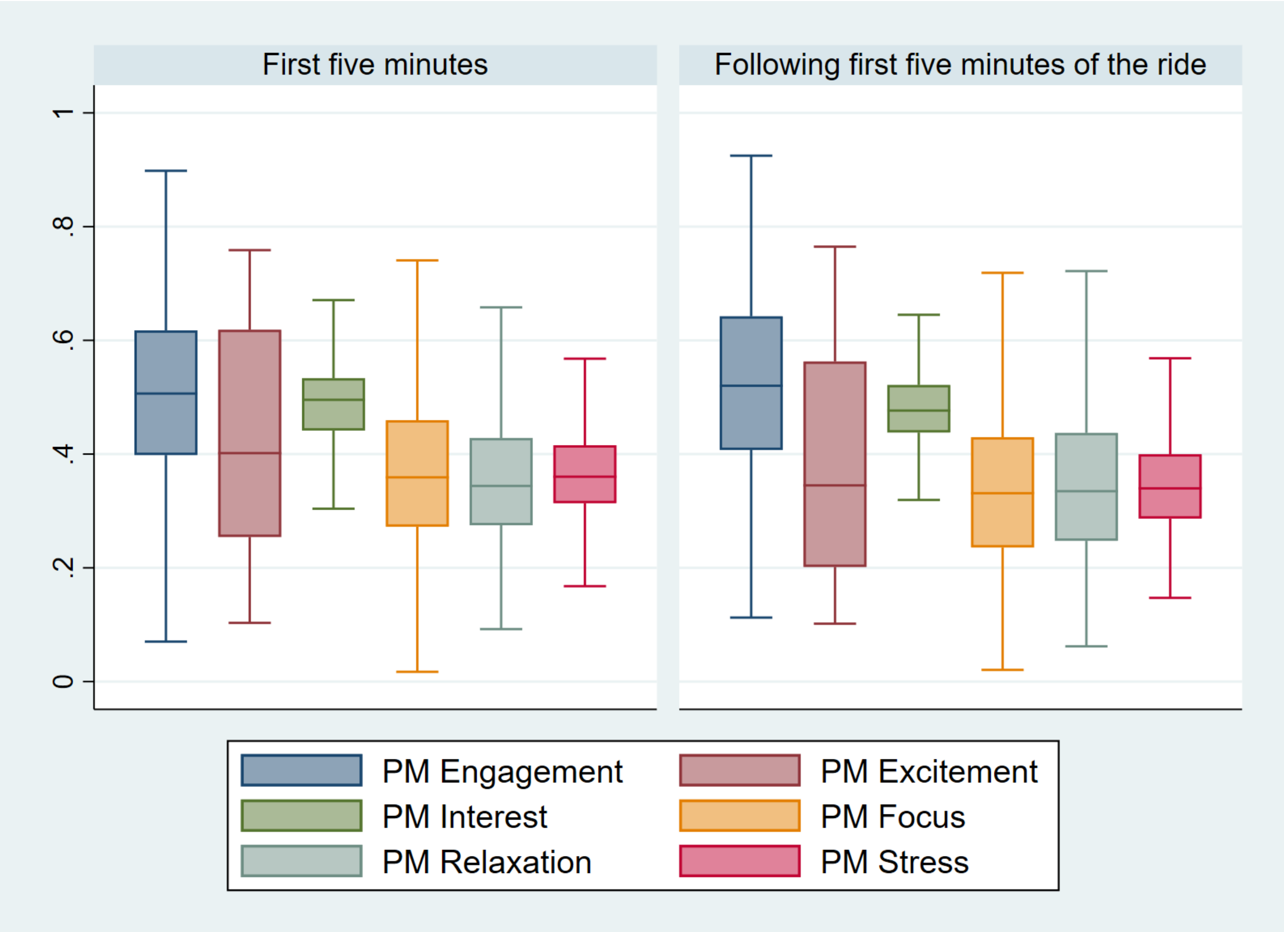

Figure 30. EEG readings during first five minutes on shuttle ride versus the following minutes on the shuttle ride for the rural location

Shuttle: Vehicle kinematics

It is hypothesised that vehicle kinematics may have an impact on the emotional state of participants. To assess this, vehicle kinematics were derived from video footage from the vehicle trajectory for shuttle rides in the city and the town. The video data was studied, and events during the ride were classified into several categories. These include vehicle movements, such as acceleration, turning, driving at speed, road characteristics and specific traffic situation that occurred during the rides. These events were time-stamped and matched with the EEG data from 37 participants in the city and the town. This allows a study into the impacts of vehicle kinematics on the emotional state of participants. For this, three vehicle events were selected, turning, acceleration and deceleration events. The effect of the vehicle being in movement compared to being stationary was also explored.

Regarding the effect of the vehicle being in a moving state versus being stationary, Figure 31 presents the Performance Metrics for both stages. The findings are as follows:

- Based on the Kolmogorov-Smirnov test, it is concluded that the distributions of the Performance Metrics are significantly different between the vehicle moving and the vehicle being stationary.
- Based on the pairwise t-tests, it is concluded that Focus levels are statistically significantly lower when the vehicle is moving (38.2% when the vehicle is stationary

versus 35.3% when the vehicle is moving). The same can be seen for 'Engagement (55% when the vehicle is stationary versus 50.9% when the vehicle is moving).

- For other Performance Metrics, no statistically significant differences are observed.
- The implication of this is that participants seem less immersed in the moment when the vehicle is moving, with a lower degree of task specific attention.This finding could be explained by the broader research insights whereby some participants reported feeling uncomfortable about not being able to see out the front of the vehicle and what the vehicle was reacting too. The absence of a front facing window impacted some participants feelings of comfort and control as they felt they wanted to see the vehicle navigating and what it was responding to for themselves. This may explain why some participants had higher levels of Engagement and Focus whilst the vehicle was stationary as they were trying to understand the reason for the vehicle stopping (See The Great Self-Driving Exploration A citizen view of self-driving technology in future transport systems for further detail).

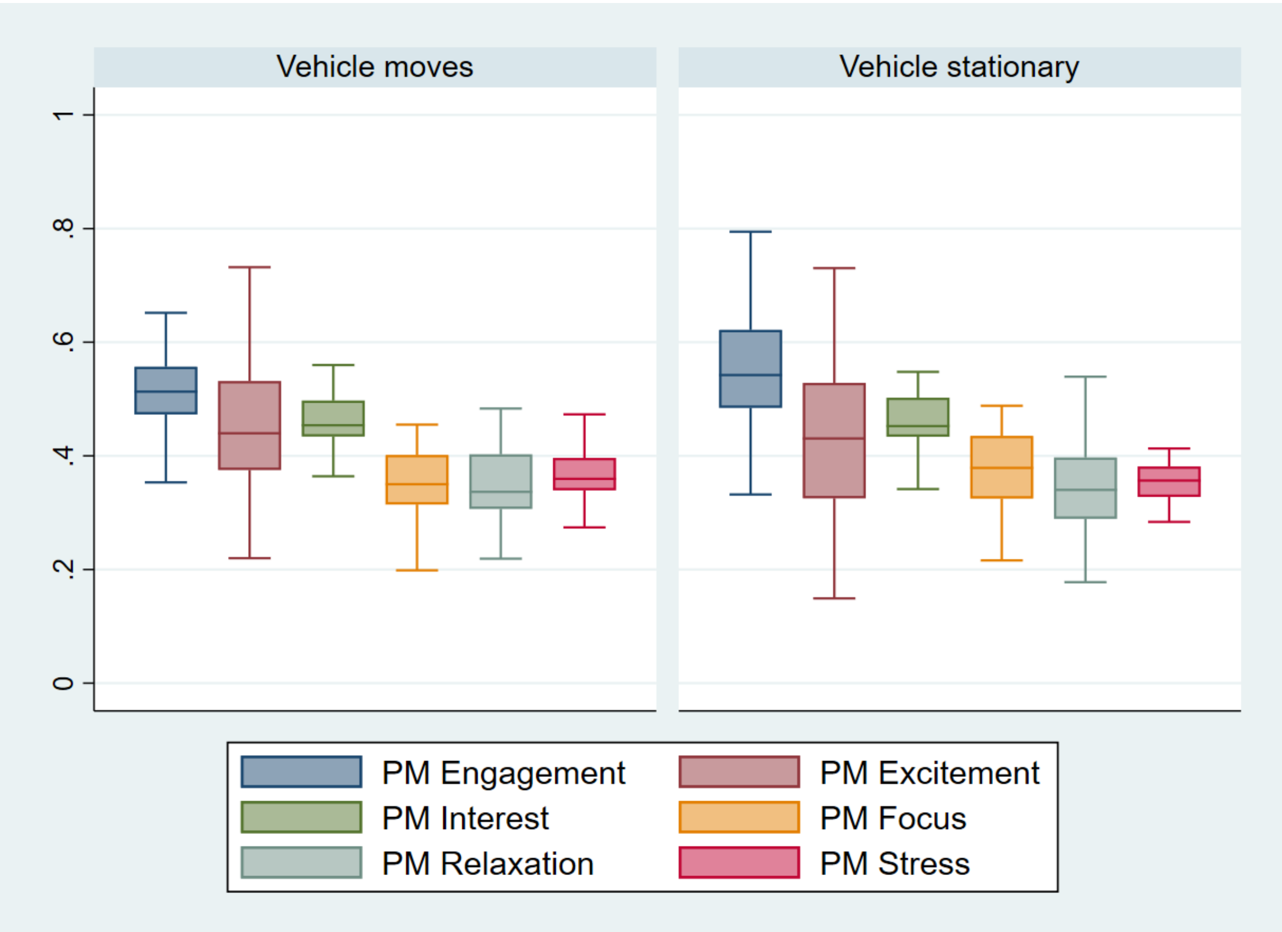

Figure 31. EEG readings during shuttle ride. Vehicle moves versus vehicle is stationary

Regarding gender based differences in the Performance Metrics when the shuttle is moving compared to when it is stationary (Figure 32 and Figure 33) the following conclusions can be drawn:

- Based on the Kolmogorov-Smirnov test, it is concluded that the distributions of the Performance Metrics are significantly different between the vehicle moving and the vehicle being in stationary state for both genders. For both males and females, the box plots for instance show a larger spread around the median for Excitement.

- Based on the pairwise t-tests, it is concluded that for both males and females, Focus and Engagement are lower whilst the vehicle is moving compared to when it is stationary.
- For other Performance Metrics, no significant differences are observed.
- However, the distribution around the median for Excitement does differ for both male and female, with shifts in the location of the median (as can be seen in the box plot in Figure 33 and 34). This implies that differences between participants arise, however on average these are not statistically significant and are unlikely to be caused by gender alone.

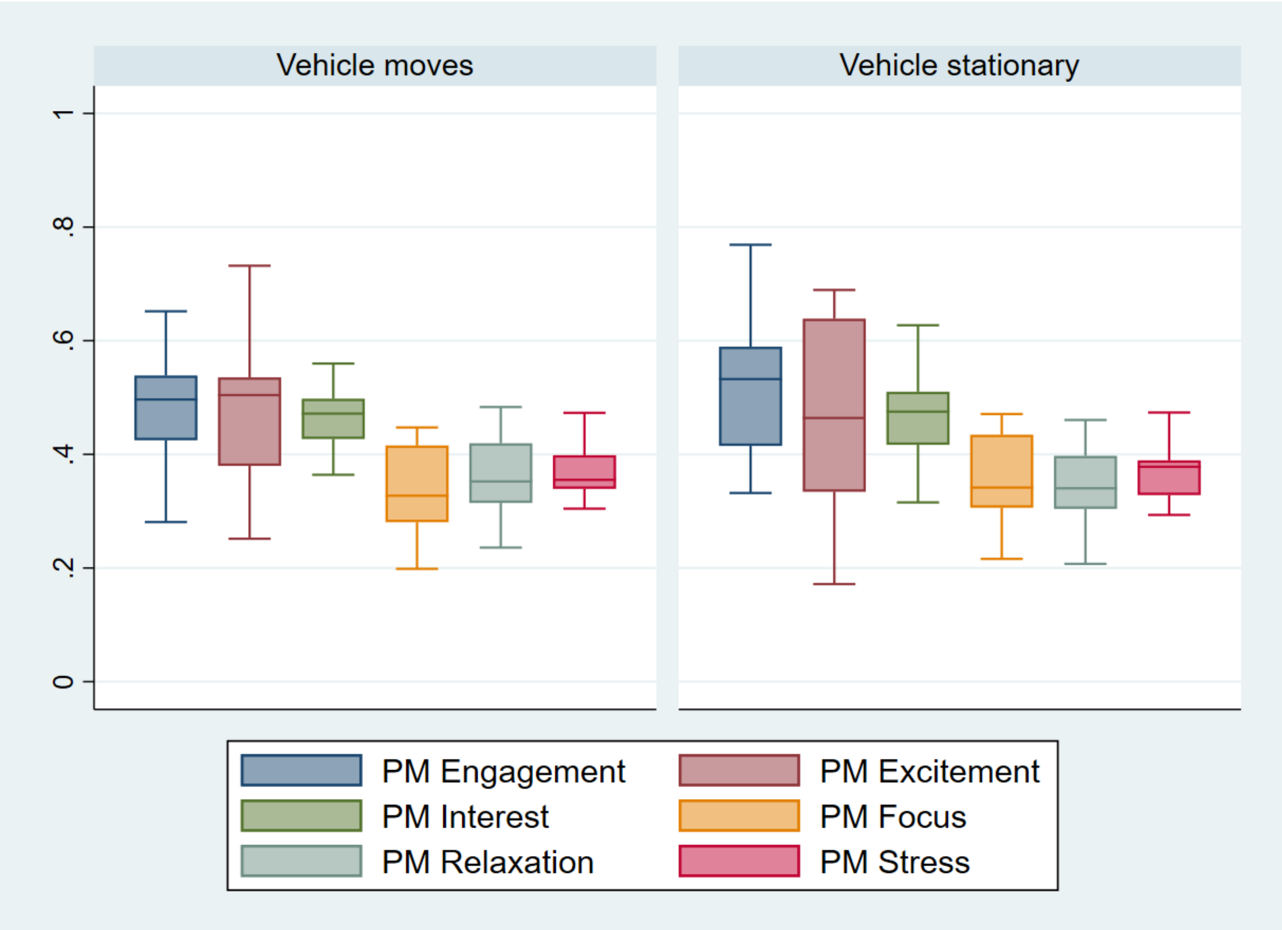

Figure 32. EEG readings during shuttle ride. Vehicle moves versus vehicle is stationary. Male

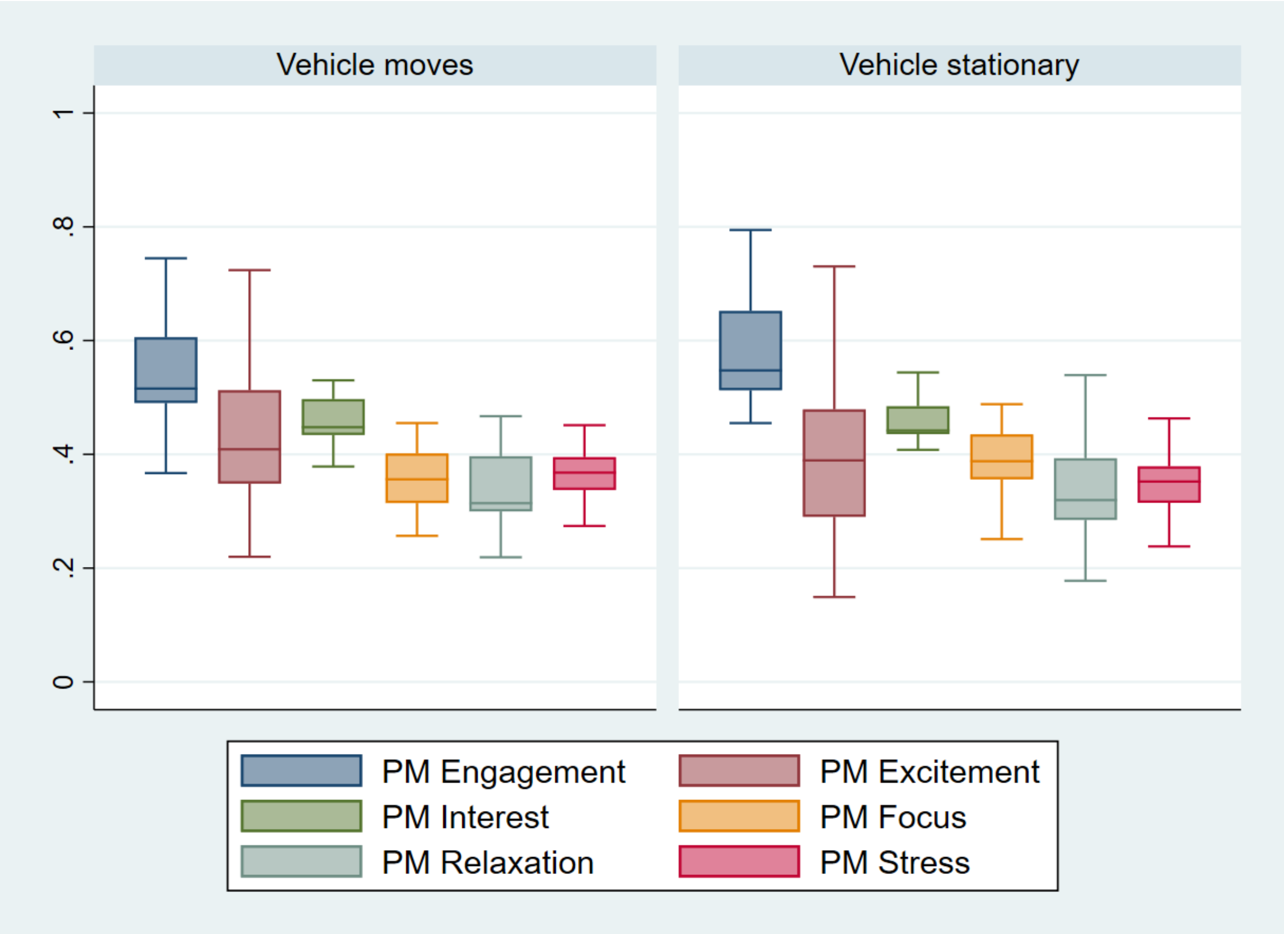

Figure 33. EEG readings during shuttle ride. Vehicle moves versus vehicle is stationary. Female

The impact of vehicle turning events was subsequently explored. Vehicle turning events were identified from the front camera. Timestamps were classed as turning events from the moment the vehicle started a turn, to the moment it was completed. On average, 12.6 turning events took place during the shuttle rides, with an average duration of 10.6 seconds, and median duration of 7 seconds. Figure 34 displays the Performance Metrics during turning events compared to no turning events and the following findings can be derived:

- Kolmorogov-Smirnov test suggest that the distribution for each Performance Metric is different between a turning and non-turning event.
- The pairwise t-tests suggests that there are no differences in the means of the Performance Metrics. A closer look at gender differences (these are not displayed in the figure) suggests however that for males, Excitement is significantly higher during the vehicle turn (49.2% versus 46.1%) and Interest is higher as well (46.7% versus 45.9%), although the latter is not statistically significant. For females, no significant differences are observed
- Generally, the findings suggest that the vehicle turning does not result in significantly different emotional states, apart for males who seem to have a more positive emotional response to the vehicle turn. The findings also suggest that this vehicle movement does not cause adverse emotions such as Stress.
- It should be noted that 'No turning events', used as baseline in the pairwise t-tests, do include events such as acceleration and deceleration. This could lead to an underestimate of the shifts in the emotional response.

Figure 34. EEG readings, Non turning versus turning events.

To further study the Performance Metrics during turning events, it was hypothesised that there could be a response at the start of any vehicle kinematic event, whilst later in the duration of this event, certain effects could subside. For this, the average value of the Performance Metrics for the first two seconds of the event were compared with the average value of the Performance Metrics for the further duration of the event. For turning events, this is displayed in Figure 35. The findings for this are as follows:

- Kolmorogov-Smirnov test suggest that the distributions for Excitement, Engagement and Focus are significantly different between the first two seconds and the latter moments during a turning events. For other Performance Metrics there is no significant difference.
- The pairwise t-tests suggests that there is only a statistically significant difference for Engagement (50.5% during the first two seconds of the vehicle turn versus 48.9% during the later stage of the vehicle turn). This suggests that participants are more immersed in the moment during the first phase of a vehicle turn
- No changes in Stress or Relaxation are found, suggesting that during the vehicle turn there are no changes in participants comfort.

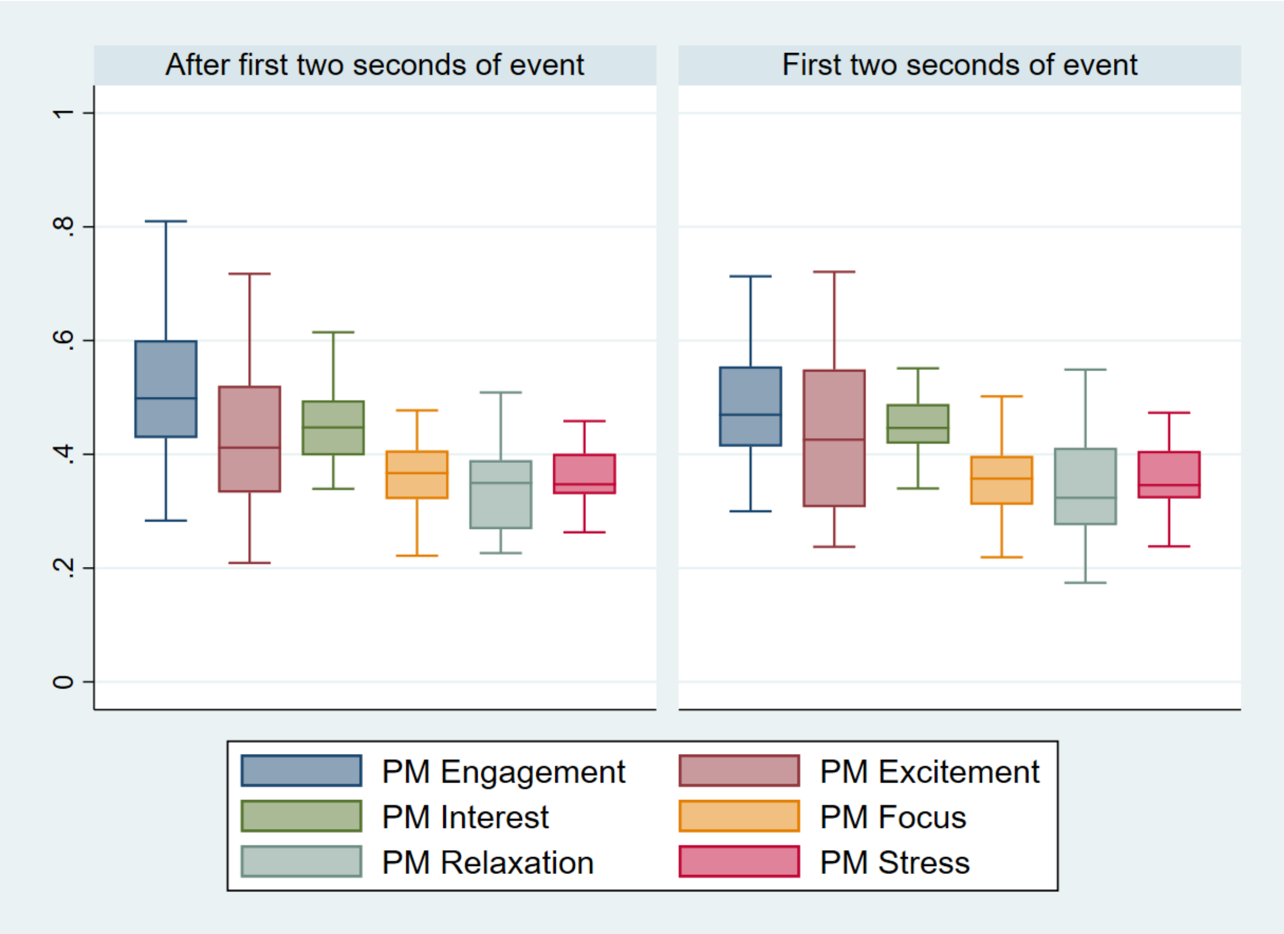

Figure 35. EEG readings during turning events. First two seconds of event versus further seconds during events.

To illustrate how these effects can be derived from the raw EEG data, figure Figure 36 and Figure 37 are plotted for a turning event encountered by two participants, whereby some of the bandpowers (Gamma and Beta High) are plotted. It is clear that there is a spike in Beta High activity during the start of a turn for both participants, as well as a spike in Gamma activity. Beta activity is associated with an active, task oriented busy thinking and active concentration, whilst Gamma waves are associated with networking effects in the brain, whereby fast processing, task switching and multitasking could take place. These effects are related to Engagement, which as seen in the pairwise t-test is indeed significantly higher during the first phase of the turn.

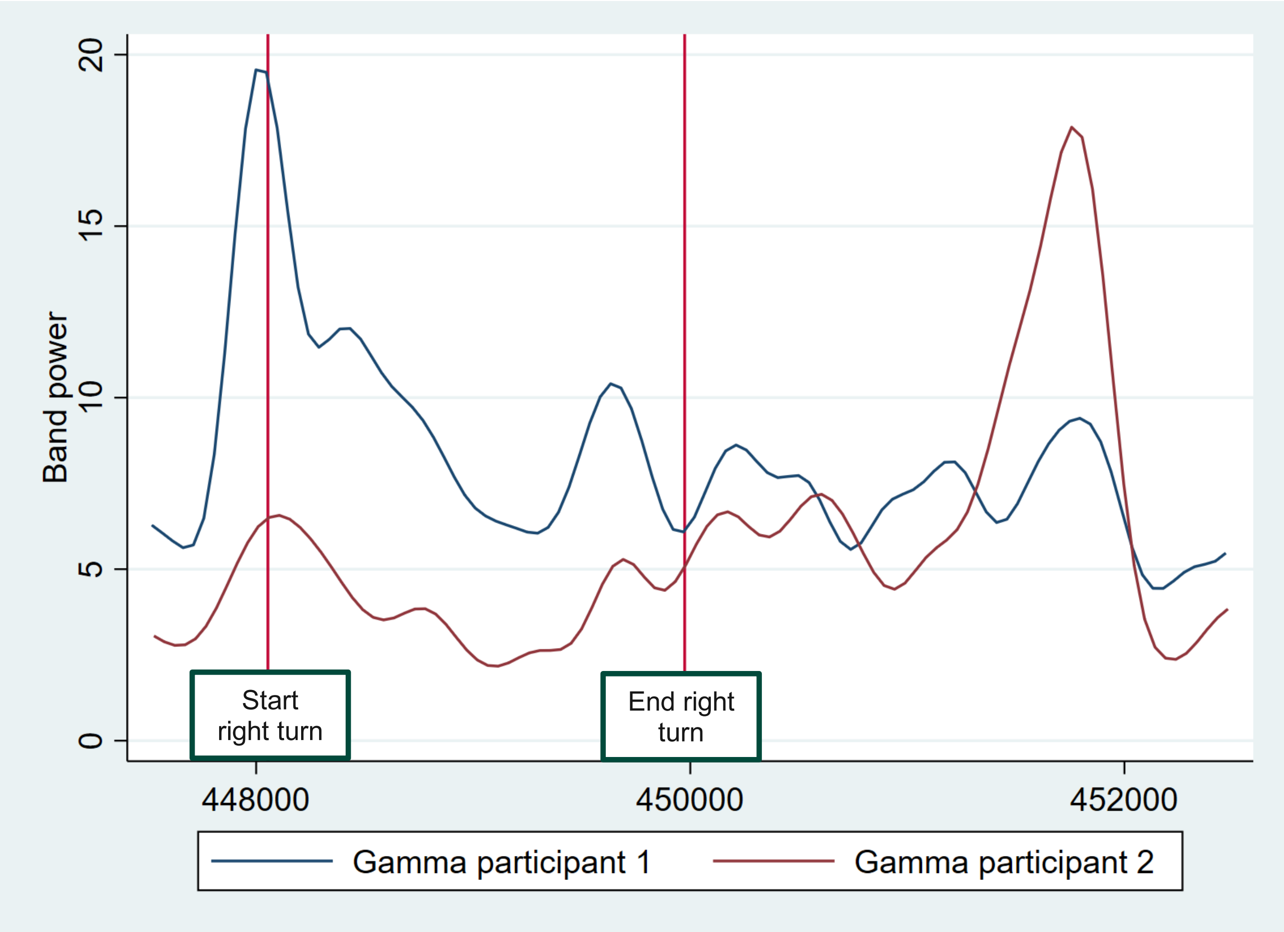

Figure 36. Gamma bandpowers during turn (please note that the turn starts at the first red line and ends at the second red line)

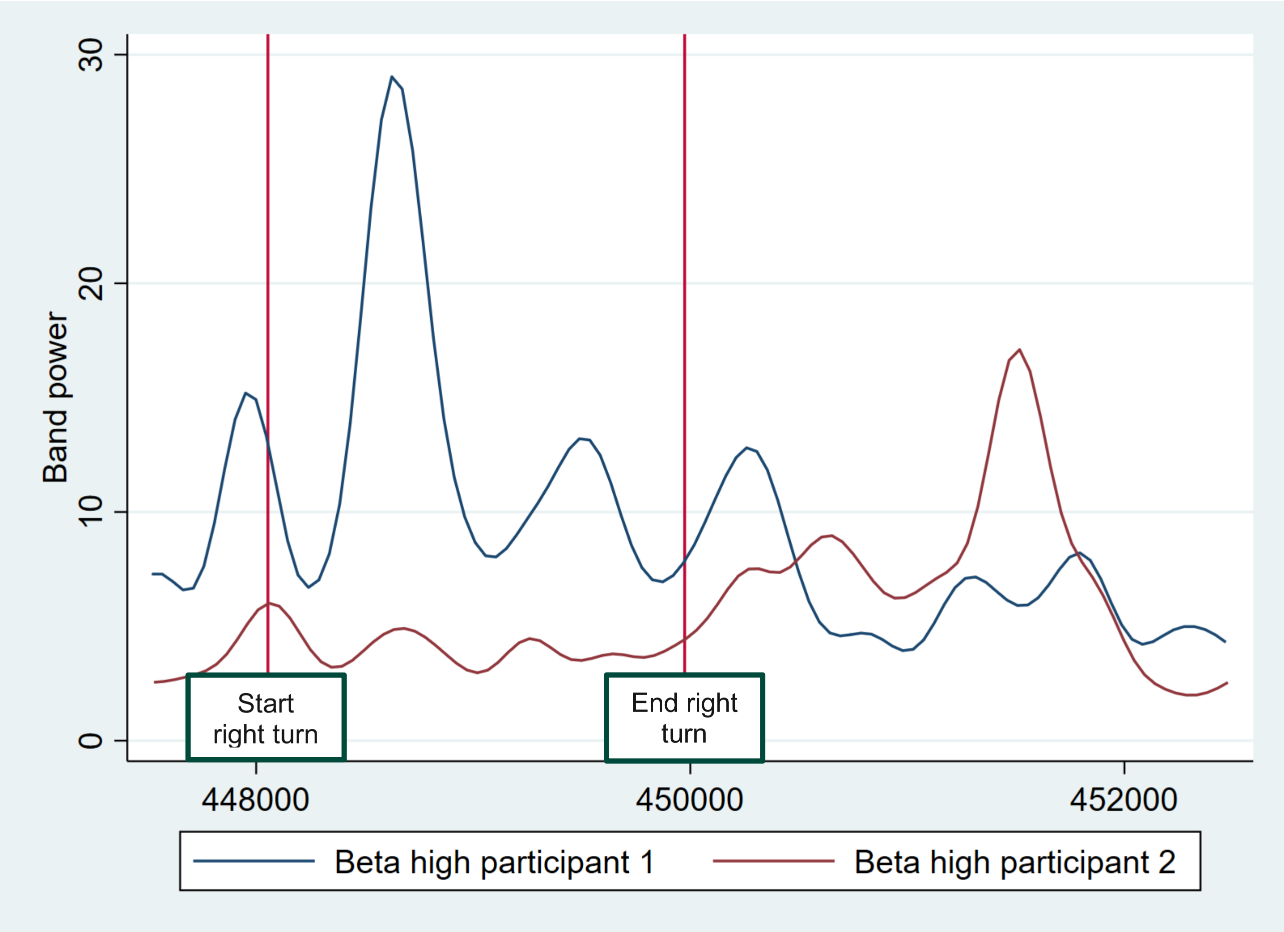

Figure 37. Beta bandpowers during turn (please note that the turn starts at the first red line and ends at the second red line)

To further assess the differences between the first two seconds of the turn and the later stage in the turn, box plots were generated to see whether there may be differences based on gender. Figure 38 and Figure 39 display the effects for males and females. The following findings can be derived:

- Kolmorogov-Smirnov test suggest that the distribution for all Performance Metrics apart from Focus are significantly different between the first two seconds and the later moments during a turning events for males.
- Pairwise t-tests suggests no significant differences in the Performance Metrics for males. For females however, Engagement is significantly lower in the later moments of a turning event (54.5% versus 52%).
- However, the median values of Excitement have shifted for both males and females, with an opposite effect. For males, the median is higher during the first two seconds of the turn (53% versus 48.7%), whilst for females, the median is much lower for the first two seconds of the turn (32% versus 36.5%). This effect could be the reason for the absence of a significant effect on Excitement for the average findings.
- For females, the spread of the distribution around the median is more confined for Relaxation and Stress during the later stage of the vehicle turn, whereby higher values for both Stress and Relaxation are experienced during the first two seconds as evidenced by the box plot. This may suggest an effect on how comfortable they feel.

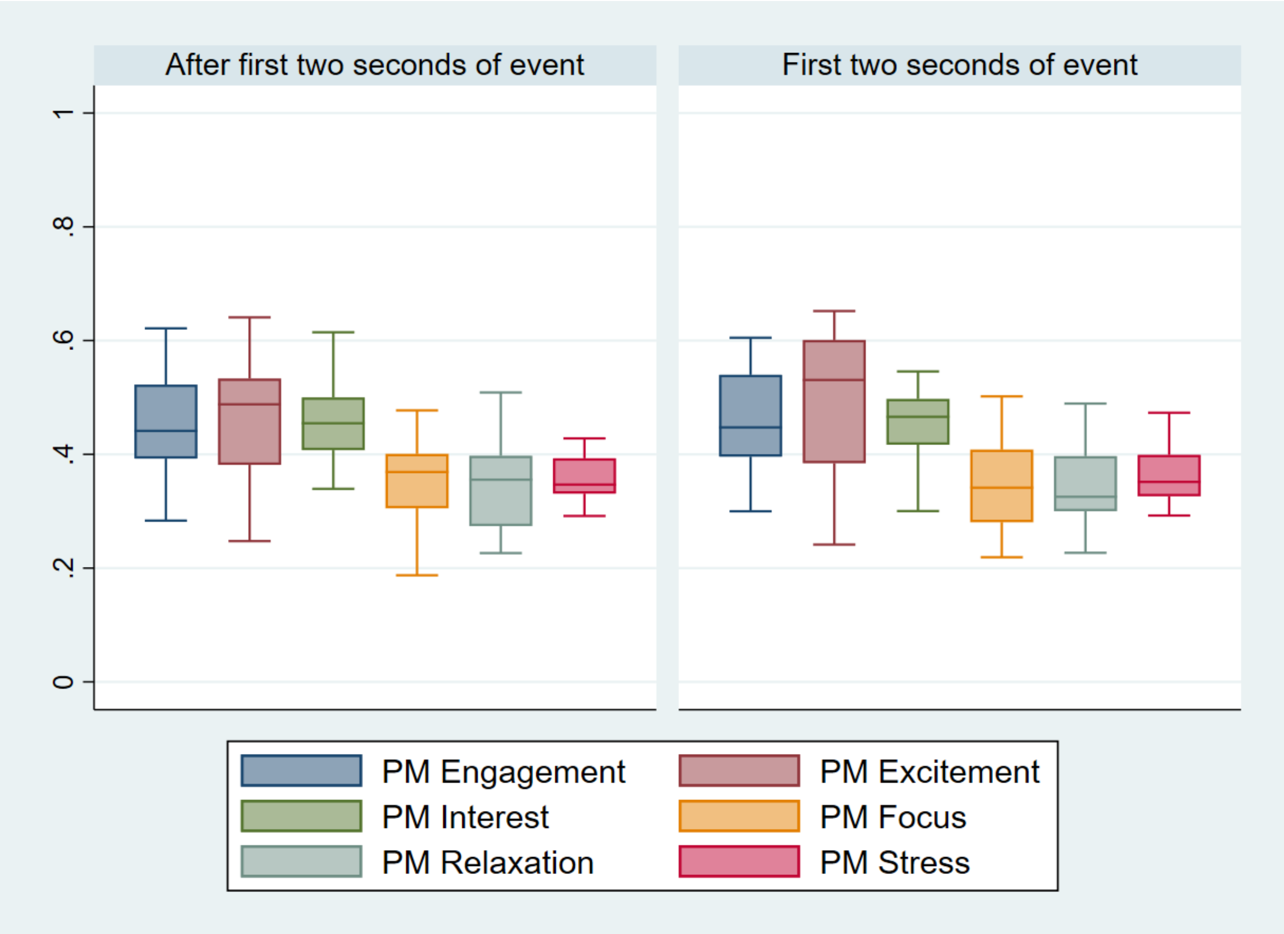

Figure 38. EEG readings during turning events. First two seconds of event versus further seconds during events for males

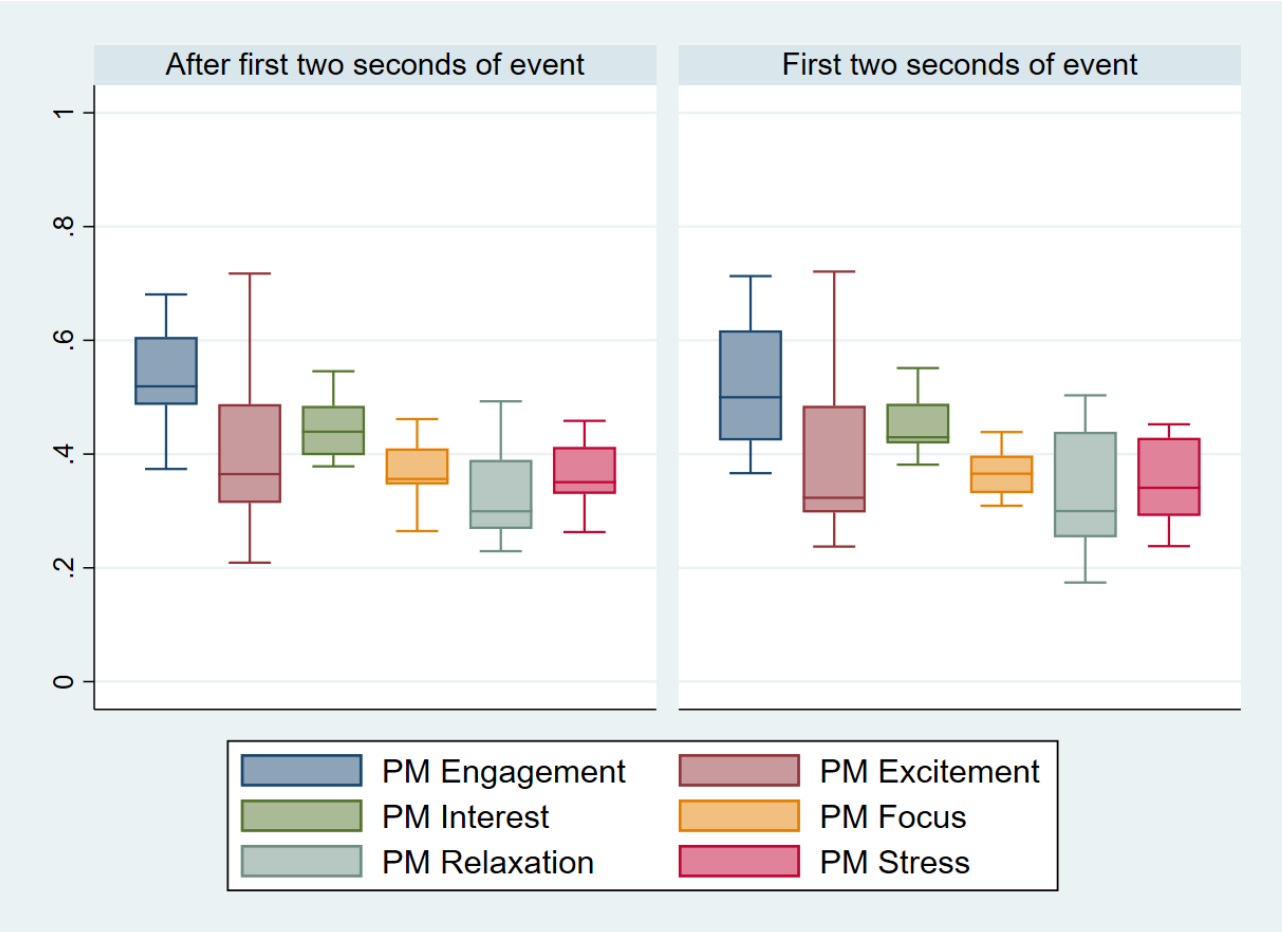

Figure 39. EEG readings during turning events. First two seconds of event versus further seconds during events for females

The impact of vehicle acceleration events was then explored. Acceleration events were identified from the front camera. Timestamps were classed as acceleration events from the moment the vehicle started accelerating, to the moment where the vehicle has a constant speed. On average, 11.2 acceleration events took place during the shuttle rides, with an average duration of 10.4 seconds, and median duration of 6 seconds. Figure 40 displays the Performance Metrics during acceleration events compared to no acceleration events. The following results are derived:

- Kolmorogov-Smirnov test suggest that the distribution for each Performance Metric is different between an acceleration and non-acceleration event apart from Relaxation.
- Pairwise t-tests suggests that there are no significant differences across any of the Performance Metrics. There were however some differences for Excitement, Focus, Engagement and Interest with each Performance Metric being higher during the acceleration event. There was also higher median values for Excitement during the acceleration event (46.7% compared to 41.2%)
- Interestingly, when looking at gender based differences (not displayed in a figure), it appears that females have statistically significant higher levels for Stress (37.4% versus 35.6%) as a result of the acceleration.
- This suggests that acceleration events impact on the emotional state of participants and seems to be associated with higher levels of Excitement. However there is underlying heterogeneity between participants based on gender.

- It should be noted that 'No acceleration events', used as baseline in the pairwise t-tests, do include events such as turning and deceleration. This could lead to an underestimate of the shifts in the emotional response.

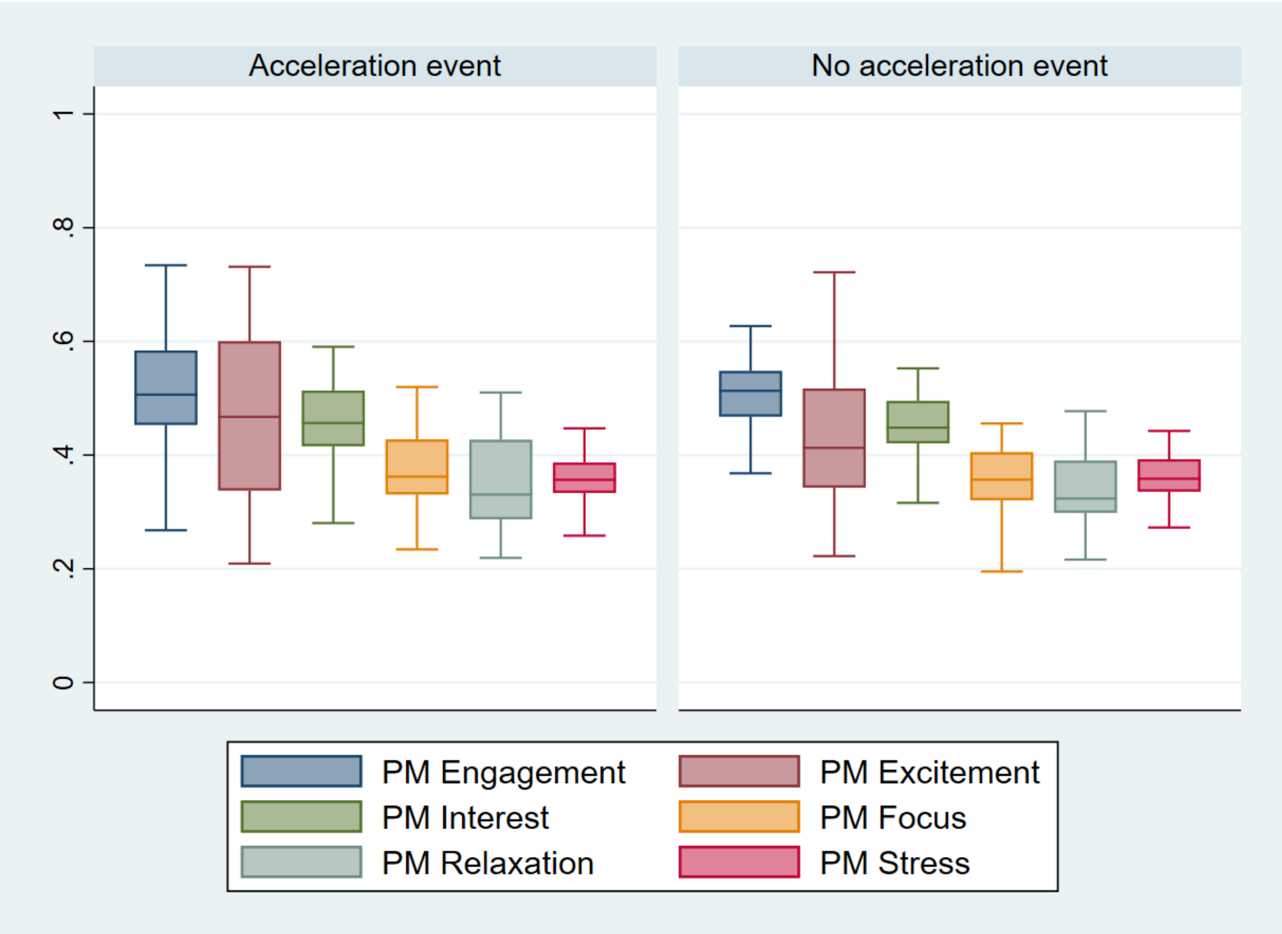

Figure 40. EEG readings, Non acceleration versus acceleration events

To further study the Performance Metrics during acceleration events, it was hypothesised that there could be a response at the start of any vehicle kinematic event, whilst later in the duration of this event, certain effects could subside. For this, the Performance Metrics for the first two seconds of the event were compared with the Performance Metrics for the further duration of the event. For acceleration events, this is displayed in Figure 41. The findings for this are as follows:

- Kolmorogov-Smirnov test suggest that the distribution for Focus and Stress is significantly different between the first two seconds and the latter moments during a turning events. For other Performance Metrics there is no significant difference.
- The pairwise t-test suggests that none of the Performance Metrics have statistically significant differences between the first two seconds and the latter stage of the acceleration event.
- The pairwise t-test suggests significant differences for Focus (37% versus 34.6%) whereby Focus drops after the first two seconds of the event.
- However, there is a large shift in the median for Excitement, whereby the median drops from 50.2% to 45.2%. This suggests underlying trends that are not picked up on by the t-test.

- The effect of 'Excitement could suggest that the start of an acceleration event is associated with higher levels of Excitement with this effect subsiding as the vehicles speed stabilises. Regarding Focus the findings suggest that participants may feel more comfortable after the first two seconds of the event as they adjust to the change in vehicle behaviour. As for turning events, it is notable that Stress levels are more confined during the later stage of the event, suggesting that (some) participants feel more comfortable after the first two seconds of the event.

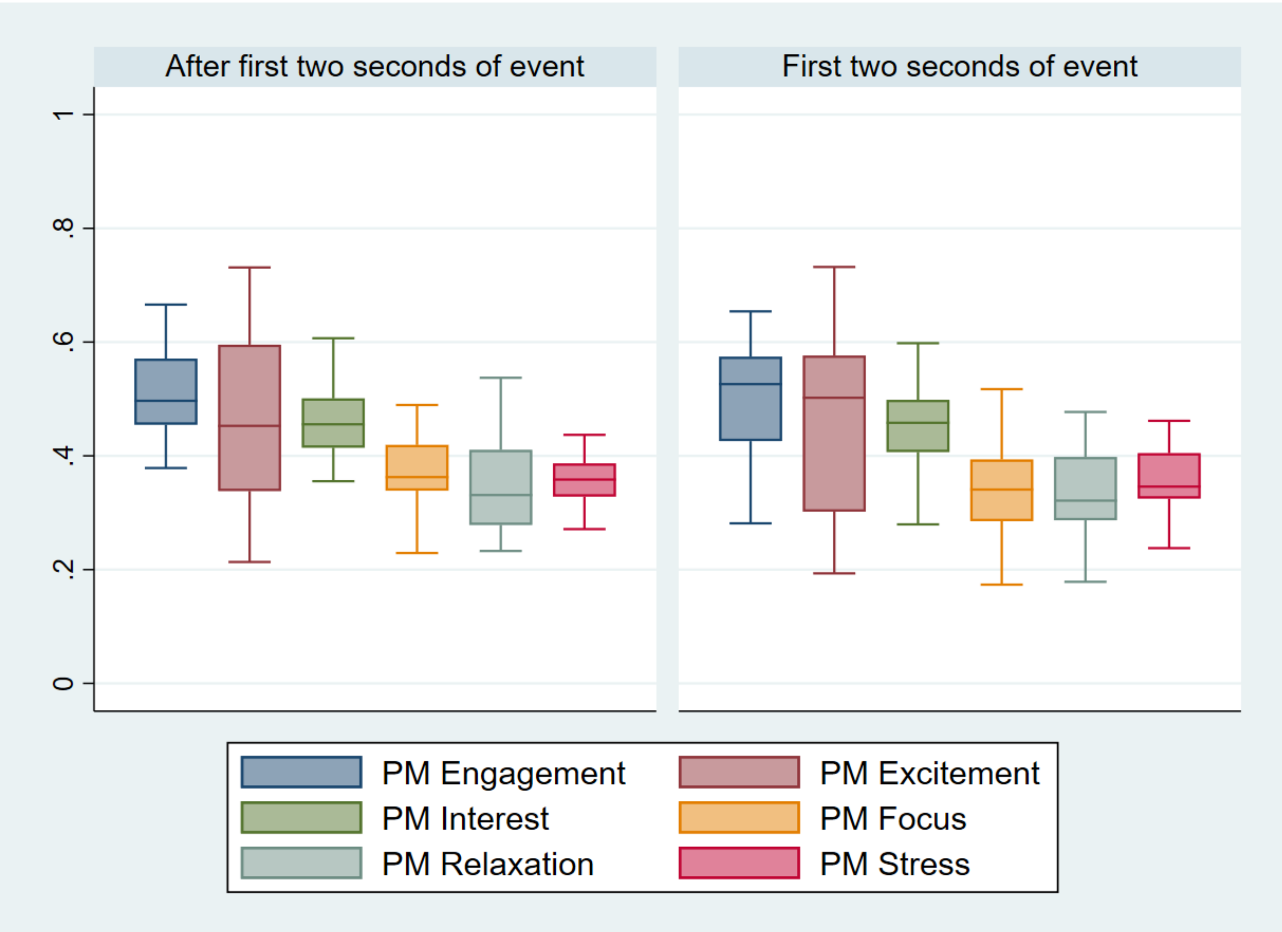

Figure 41. EEG readings during acceleration event. First two seconds versus final two seconds of the event.

To further assess the acceleration events, box plots were generated to see whether gender differences may play a role. Figure 42 and Figure 43 display the effects for male and female participants. The following findings can be derived:

- Kolmorogov-Smirnov test suggest that the distributions for Stress and Excitement are significantly different between the first two seconds and the latter moments during a turning events for males.
- Kolmorogov-Smirnov test suggest that the distribution for all Performance Metrics apart from Engagement are significantly different between the first two seconds and the latter moments during a turning events for females.
- Pairwise t-tests suggests that there are no significant differences for males between the Performance Metrics.
- For females, the pairwise t-tests suggest a significant drop in Focus (from 40% to 35.7%), Interest (from 46.7% to 45%) and Stress (from 38% to 36) between the first two seconds and the latter stage of the acceleration event.

- As for the average differences between the first two seconds of the event and latter stages, there is a shift in the median value for Excitement. Interestingly, this has the opposite effect for males versus females, whereby Excitement drops for males (from 50.9% to 47.8%) and increases for females (from 37.7% to 39.2%).
- This suggests that for females there is an initial more negative reaction to the change in vehicle behaviour but this subsides quickly as they become more familiar with the technology. This would be in line with the broader research findings (see The Great Self-Driving Exploration A citizen view of self-driving technology in future transport systems for further details).

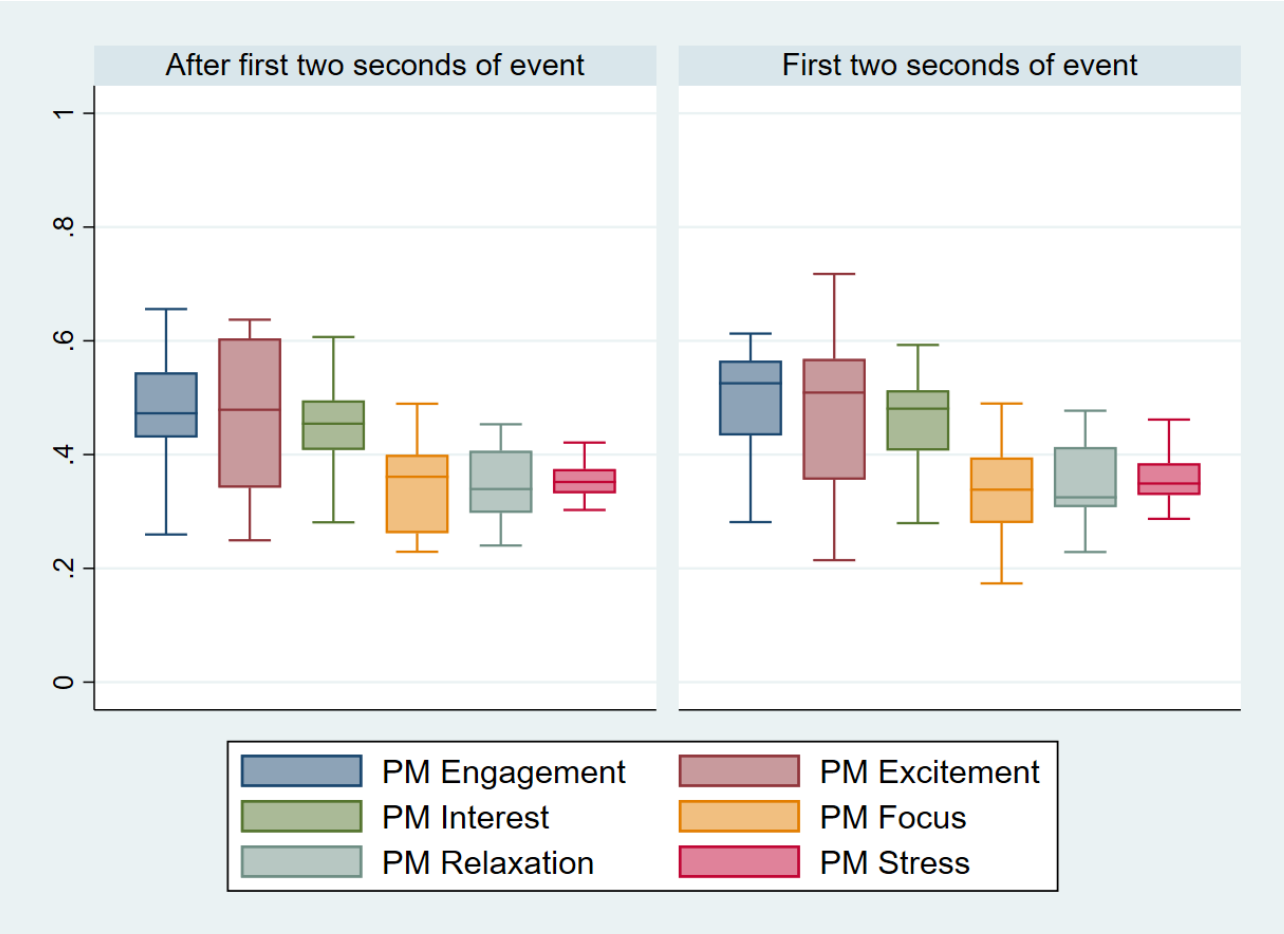

Figure 42. EEG readings during acceleration event. First two seconds versus final two seconds of the event for males

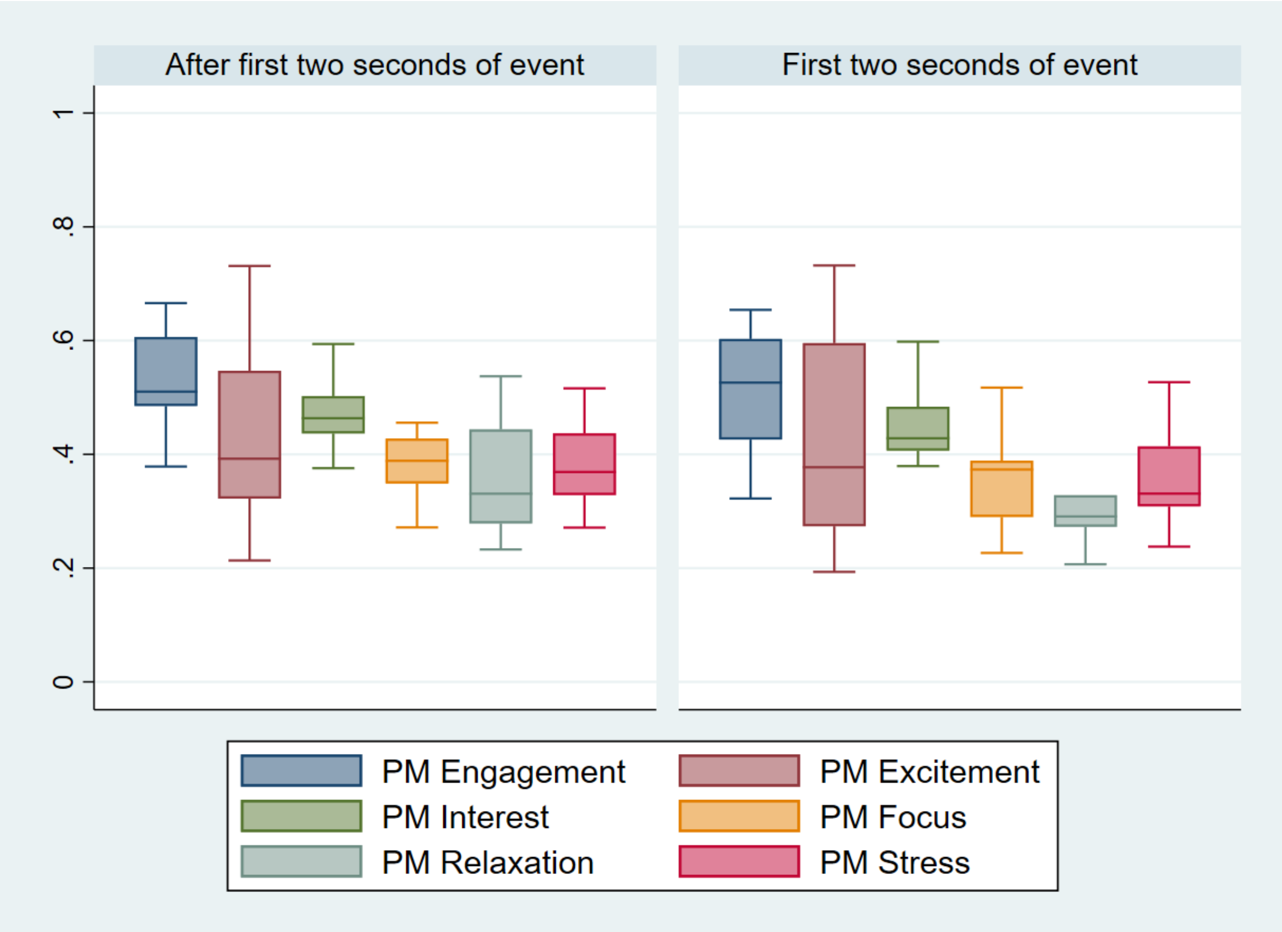

Figure 43. EEG readings during acceleration event. First two seconds versus final two seconds of the event for females.

The impact of vehicle deceleration events was then explored. Deceleration events were identified from the front camera. Timestamps were classed as deceleration events from the moment the vehicle started decelerating, to the moment where the vehicle has a stationary speed or has stopped. On average, 12.4 deceleration events took place during the shuttle rides, with an average duration of 9.8 seconds, and median duration of 7 seconds. Figure 44 displays the Performance Metrics during deceleration events compared to no deceleration events.

- Kolmorogov-Smirnov test suggest that the distribution for each Performance Metric is different apart from Engagement and Stress.
- Pairwise t-tests suggest that levels of Interest are higher for the deceleration event compared to non-decelerating event (46.2% versus 45.5%) whilst Excitement levels are lower during the deceleration events (42.7% versus 44%).
- However, the median for Excitement is higher during the deceleration event (41.2% versus 40.9%). This suggests that participants respond in a heterogeneous way to deceleration events and these underlying patterns are not picked up by the t-test.
- It should be noted that 'No deceleration event' do include events such as acceleration and turning events, which impacts our ability to determine major shifts in performance as these are there own vehicle event

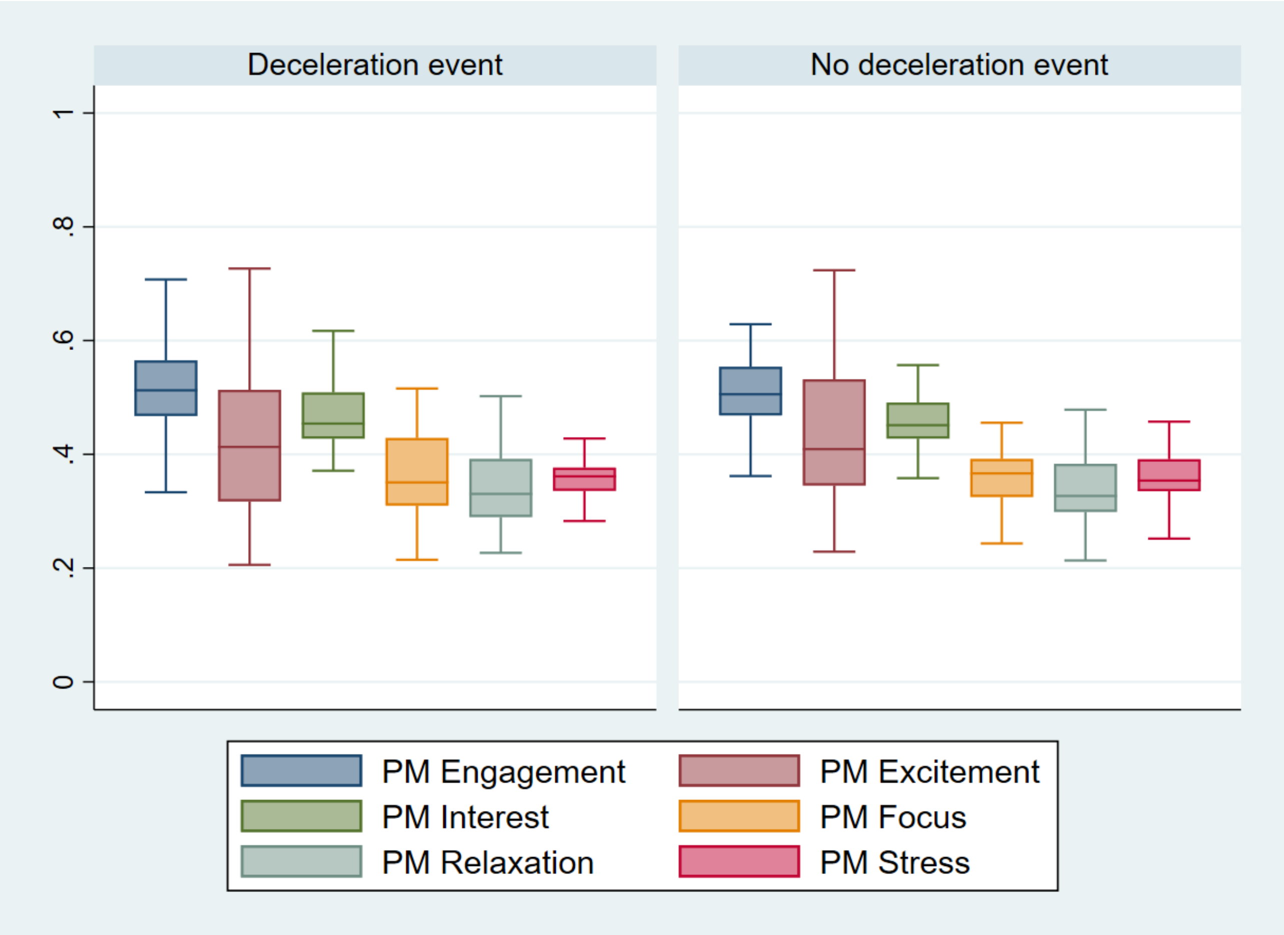

Figure 44. EEG readings, Non deceleration versus deceleration events

As with the other vehicle kinematic events, it was hypothesised that there could be a response at the start of the vehicle kinematic event, whilst later in the duration of this event, certain effects could subside. For this, the Performance Metrics for the first two seconds of the event were compared with the Performance Metrics for the further duration of the event (Figure 45). The findings for this are as follows:

- Kolmorogov-Smirnov test suggest that the distributions for Engagement and Relaxation are not significantly different between the first two seconds and the latter moments during a turning events.
- Pairwise t-tests suggests that Excitement increases during the deceleration event (42.7% during the first two seconds compared to 44% during the later stage of the deceleration event).

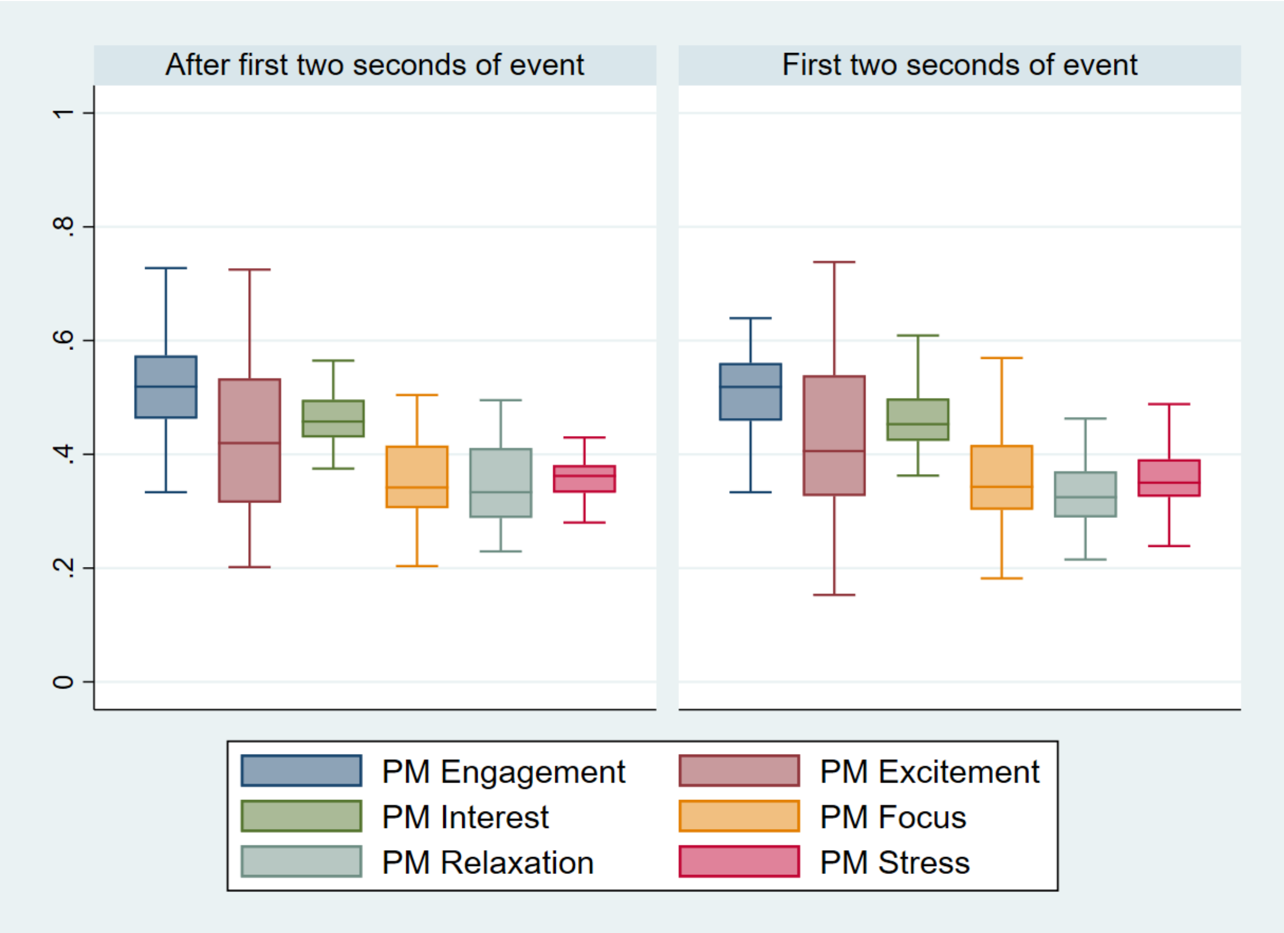

Figure 45. EEG readings during deceleration, first two seconds versus further seconds during event

To further assess these deceleration events, box plots were generated to see whether there are any differences between gender. Figure 46 and display the effects for male and female. The following findings can be derived:

- Kolmorogov-Smirnov test suggest that the distribution for Engagement, Excitement and Interest are significantly different between the first two seconds and the latter moments during deceleration events for females.
- Kolmorogov-Smirnov test suggest that the distribution for all Performance Metrics apart from Excitement are significantly different between the first two seconds and the latter moments during a turning events for females.
- The pairwise t-tests suggest that Engagement drops, whilst Excitement increases after the first two seconds for males.
- For females, no significant differences are observed for any of the Performance Metrics.

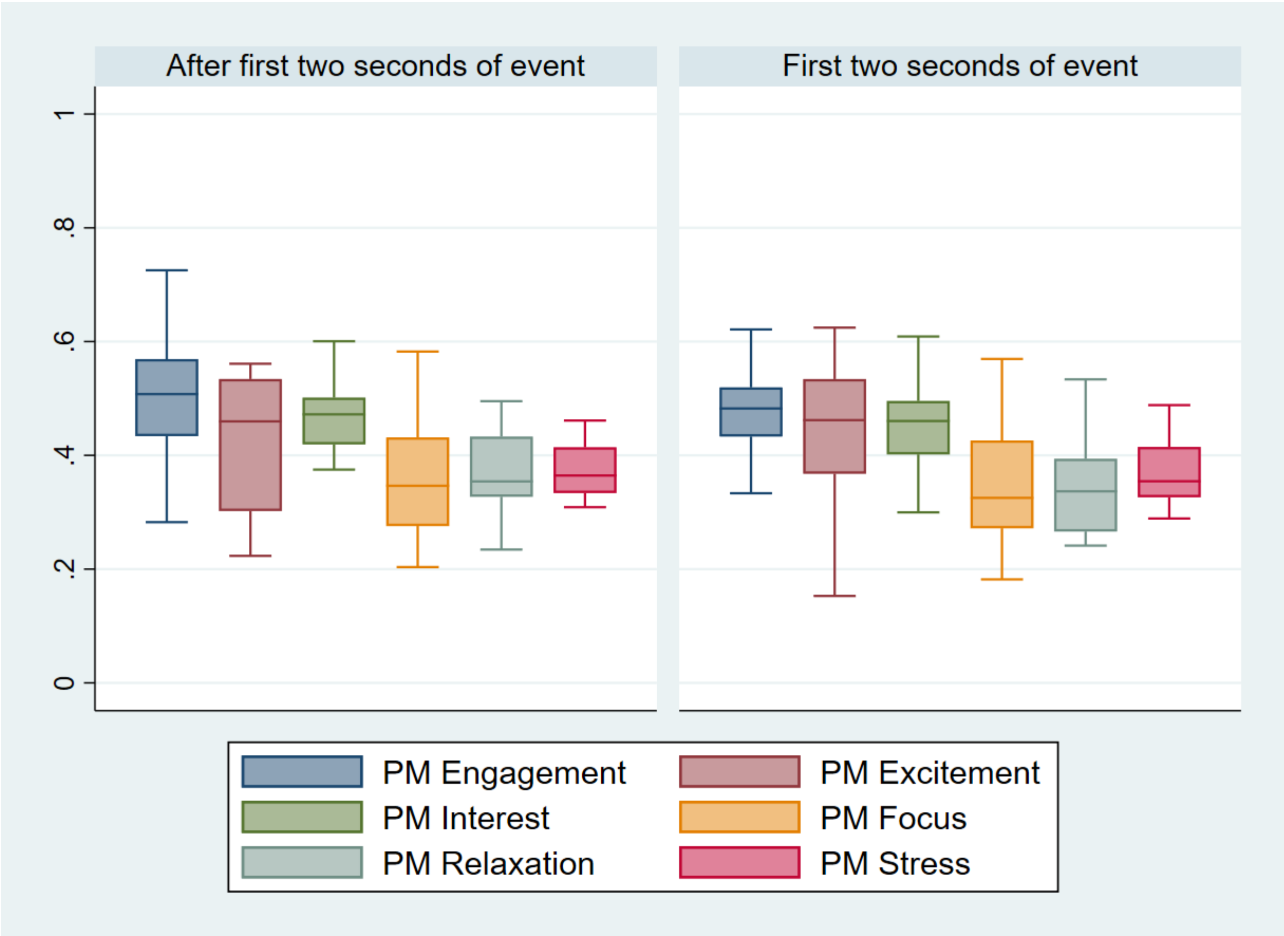

Figure 46. EEG readings during deceleration, first two seconds versus further seconds during event for males

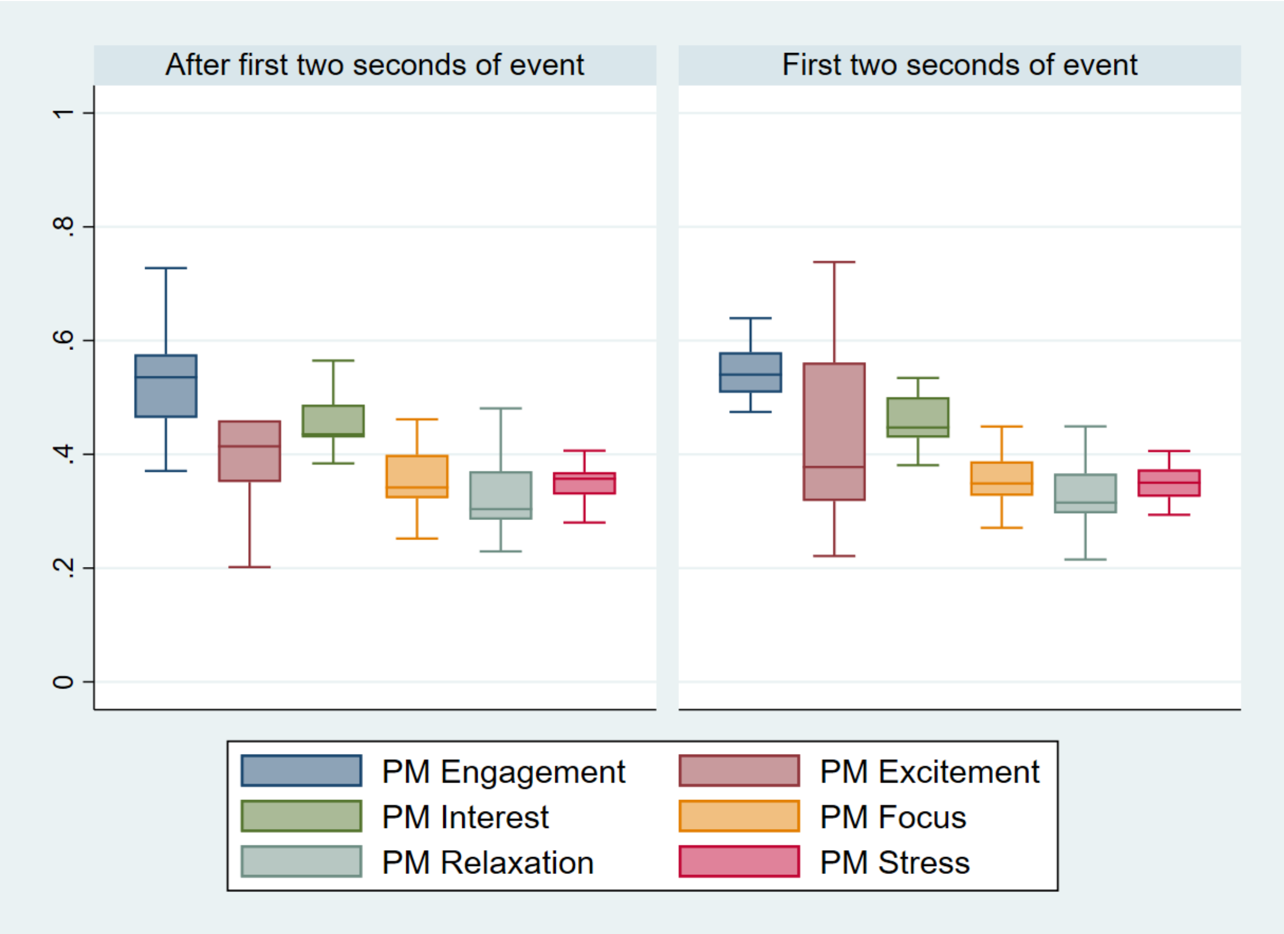

Figure 47. EEG readings during deceleration, first two seconds versus further seconds during event for females

Analysis results: Pod

This section presents the findings for the pod ride. The pod ride took place across all three locations but data was only obtained from the town and the city. The journeys lasted on average 8 minutes in both the town and city. Recordings were taken from 32 participants, 15 in the town collected over 9 pod journeys and 17 in the city collected over 10 pod journeys.

As with the shuttle journeys, baseline EEG recordings were obtained for all participants taking part in a pod journey. Figure 48 displays the baseline EEG readings for the pod compared to the EEG readings during the pod ride. The main findings are as follows:

- As with the shuttle, there is a signifcant dispersion for most Performance Metrics, suggesting a degree of heterogeneity between participants. This goes for the baseline EEG readings as well as for the EEG shuttle readings.
- For Focus and Stress, the dispersion is more limited, suggesting a limited degree of heterogeneity. This goes for the baseline EEG readings as well as for the EEG shuttle readings.
- The Kolmogorov-Smirnov test suggests that for all the Performance Metrics, the distributions are significantly different.

- The pairwise t-tests suggests that Interest (43.8% versus 48.1%) and Excitement (35.7% versus 43.2%) are significantly higher during the pod rides relative to the baseline EEG readings.
- For the baseline EEG readings and the EEG readings, the highest median scores are visible for Engagement, Interest and Focus. As with the shuttle ride, this suggests that participants are alert, with a degree of being immersed in the moment and have a degree of affinity with the task.
- For the baseline EEG, Excitement is generally low (Excitement can be described as an awareness or feeling of physiological arousal with a postiive value). For the pod ride, Excitement is significantly higher.
- Stress levels are generally low during the pod ride, suggesting that the experience did not cause adverse emotions.

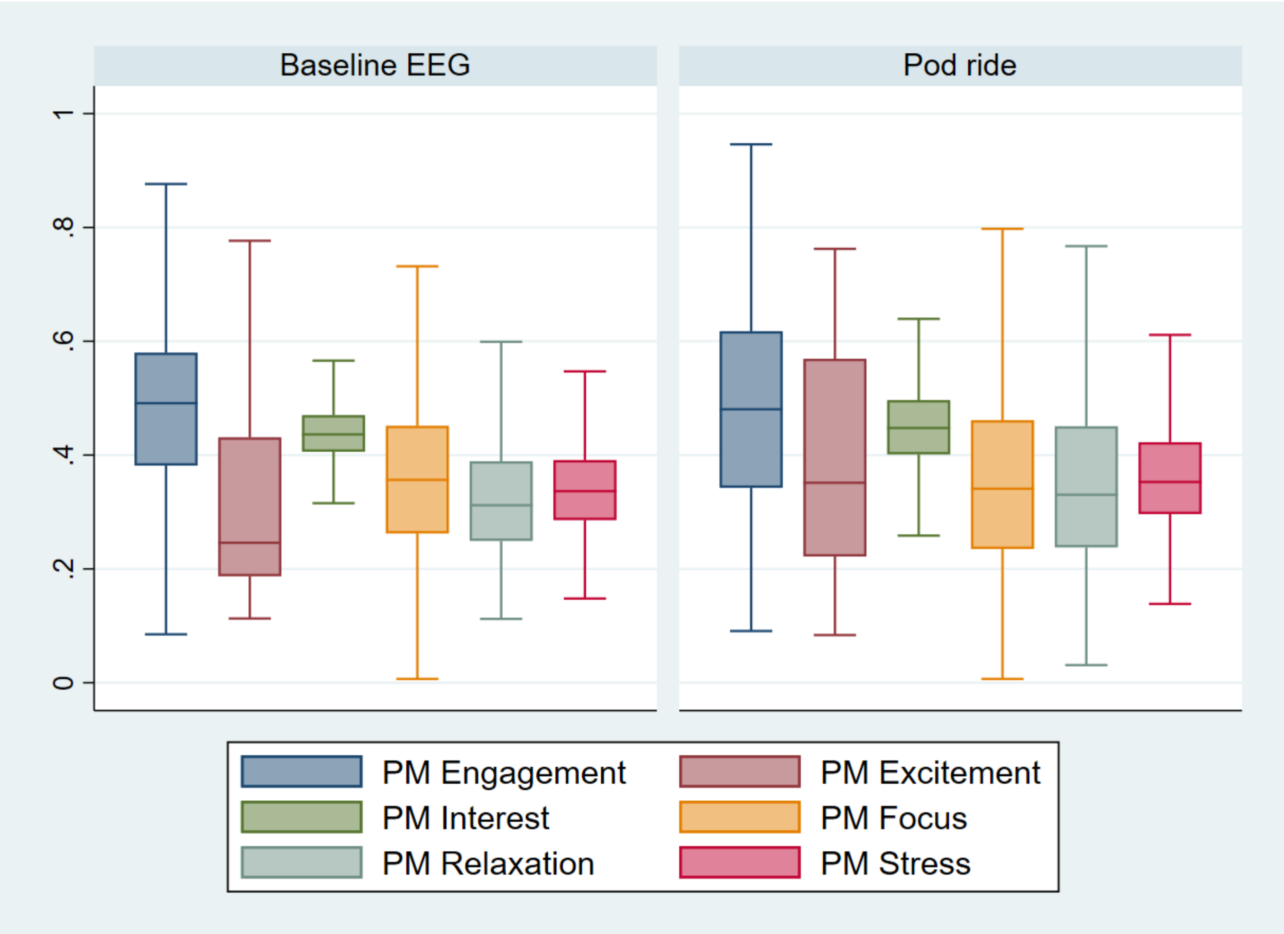

Figure 48. Baseline EEG versus EEG readings during pod ride

Regarding gender differences in the Performance Metrics for the baseline EEG readings compared to the pod ride in Figure 49 and Figure 50, the following conclusions can be drawn:

- For both males and females, there is a significant dispersion for most Performance Metrics, suggesting a degree of heterogeneity between participants. This goes for the baseline EEG readings as well as for the EEG pod readings.

- For both males and females, the Kolmogorov-Smirnov test suggests that for almost all the Performance Metrics, the distributions are significantly different. This however is not the case for Relaxation for females
- The pairwise t-test suggests that there are no significant differences between the baseline EEG and shuttle EEG readings for males.
- For females, Interest (42.5% versus 48.2%) and Excitement (35.5% versus 45%) are significantly higher during the pod ride and significantly higher than for males. This suggests that the pod ride was more enjoyable for female participants compared to male participants.
- For females, there is a larger increase in Excitement compared to males, but for both, Excitement is significantly higher. This is in contrast with the shuttle, whereby Excitement was much higher for males relative to females.

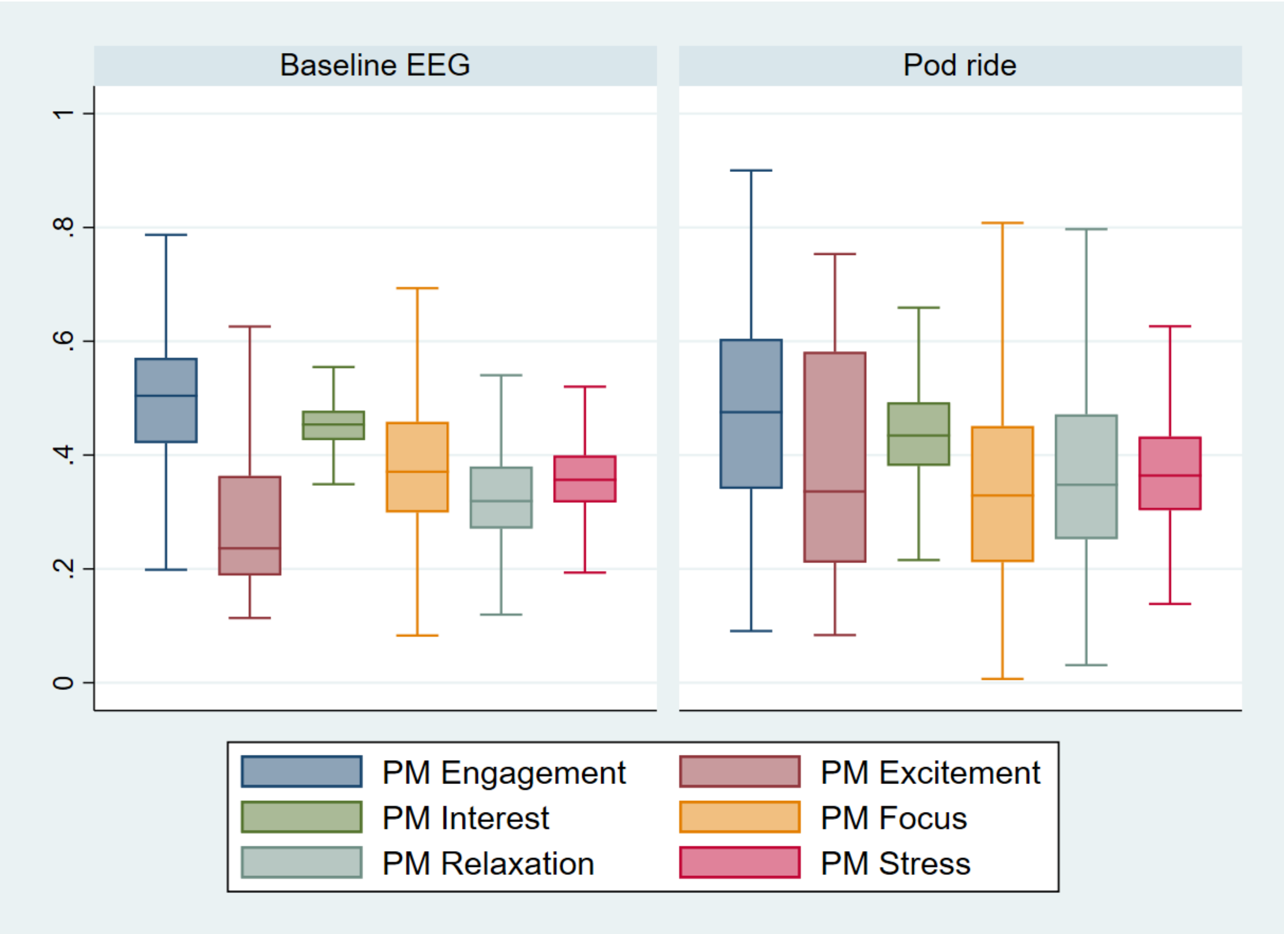

Figure 49. Baseline EEG versus EEG readings during pod ride for males

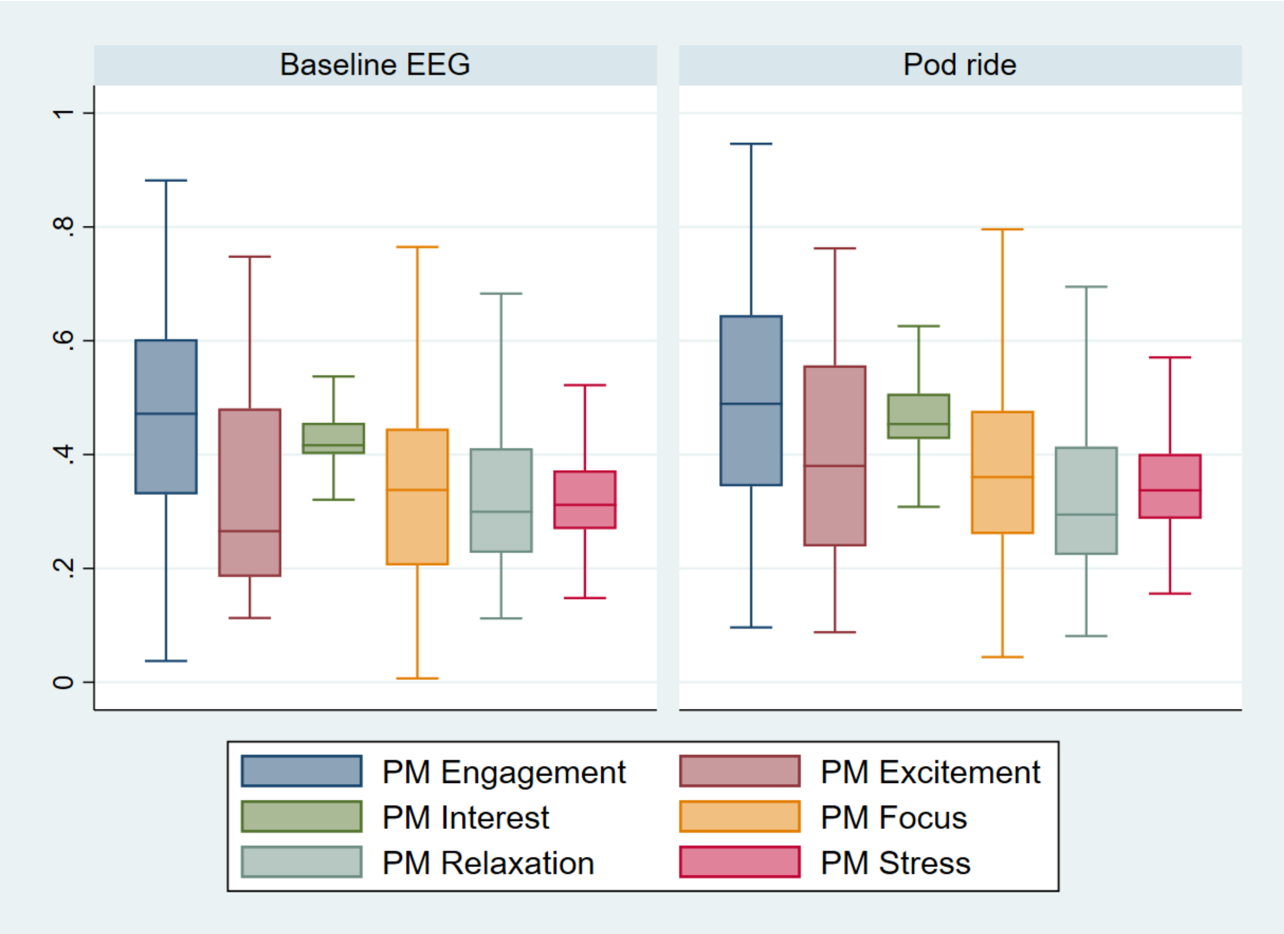

Figure 50. Baseline EEG readings versus EEG readings during pod ride for females

Regarding differences based on social grades (A and B versus C1, C2, D and E) on the average Performance Metrics for the baseline EEG readings compared to the pod ride in Figure 51 and Figure 52, the following conclusions can be drawn:

- For both social grade categories, there is a signifcant dispersion for most Performance Metrics, suggesting a degree of heterogeneity between participants. This goes for the baseline EEG readings as well as for the EEG pod readings.
- For both social grade categories, the Kolmogorov-Smirnov test suggests that for all the Performance Metrics, the distributions are significantly different.
- The pairwise t-test suggests that Engagement (44.8% versus 55.4%) and Interest (44.5% versus 49.6%) are significantly higher for participants in social grade A and B. The levels of Excitement (31.8% versus 40.5%) are also higher but not significantly and is likely due to the low number of participants in social grades A and
- For participants in social grade C1, C2, D or E, Interest (43.5% versus 47.5%) and Excitement (37% versus 44%) are significantly different between baseline EEG and pod ride EEG.
- Participants in social grade A and B are significantly more 'Engaged' compared to participants in social grade C1, C2, D and E (55.4% versus 48.4%). The levels of Excitement are significantly higher in social grades C1, C2, D and E versus A and B (44% versus 40.5%).
- This suggests that participants in social grade A and B are perhaps more inquisitive and have a more considered response to the pod, whilst participants in lower social

grades are more likely to have a more intense emotional or physical response to the experience.

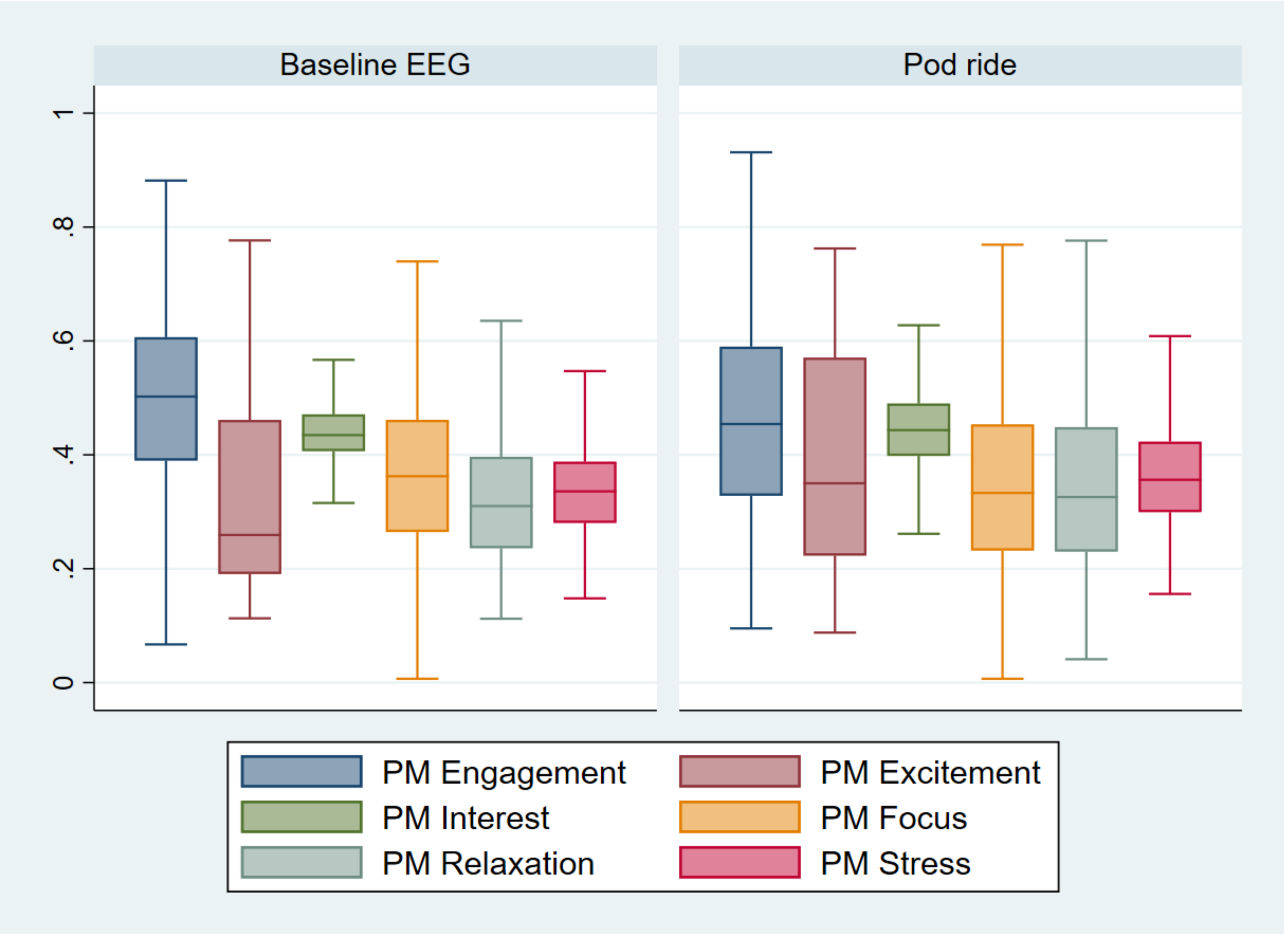

Figure 51. Baseline EEG versus EEG readings during pod rides. Social grades C1, C2, D and E.

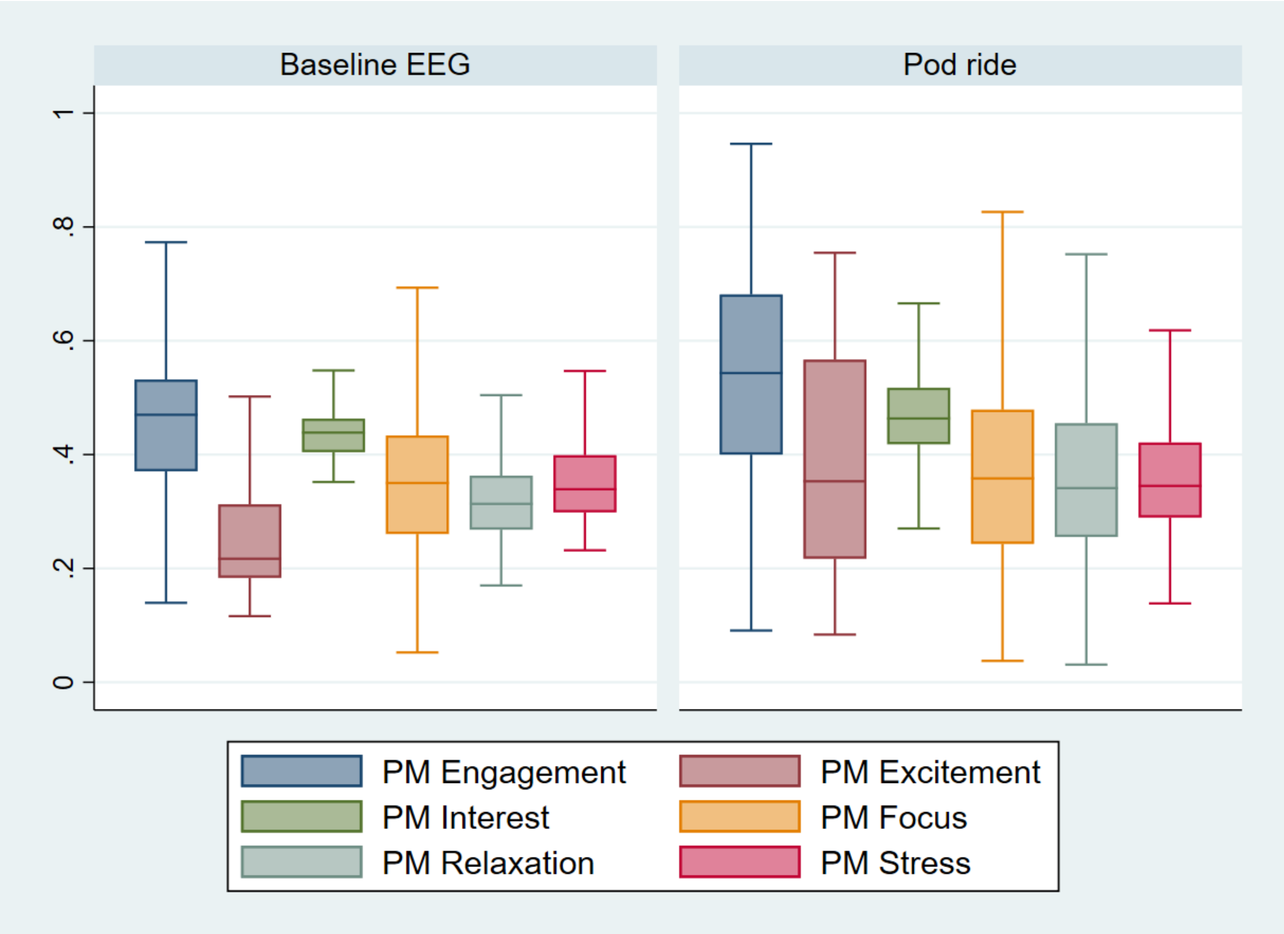

Figure 52. Baseline EEG versus EEG during pod ride. Social grades A and B.

Regarding age based differences in the Performance Metrics for the baseline EEG readings compared to the pod ride in Figure 53, Figure 54 and Figure 55, the following conclusions can be drawn:

- For all age categories, there is a significant dispersion for most Performance Metrics, suggesting a degree of heterogeneity between participants. This goes for the baseline EEG readings as well as for the EEG pod readings.
- For Focus and Stress, the dispersion is more limited, suggesting a limited degree of heterogeneity. This applies to the baseline EEG readings as well as for the EEG pod readings.
- For all age categories, the Kolmogorov-Smirnov test suggests that the distributions are significantly different for all the Performance Metrics.
- The pairwise t-tests suggest that for the participants aged under 31, Engagement (44% versus 52.2%) is significantly higher during the pod ride. For Excitement, there was also an observed increase but this was not signifcant and this was likely due to the low sample size for this group.
- For participants aged between 31 and 55, Excitement (35.8% versus 44.3%) is significantly higher during the pod ride.
- For participants aged 56 years and over, Interest (44.8% versus 51.5%) is significantly higher during the pod ride. As with the younger ages groups there is a notable increase in excitement but this is not signficant.

- There is an increase in Excitement across all age groups but the lowest increase can be seen for those aged 56 and over and the highest levels of Excitement for those aged 31 to 55.

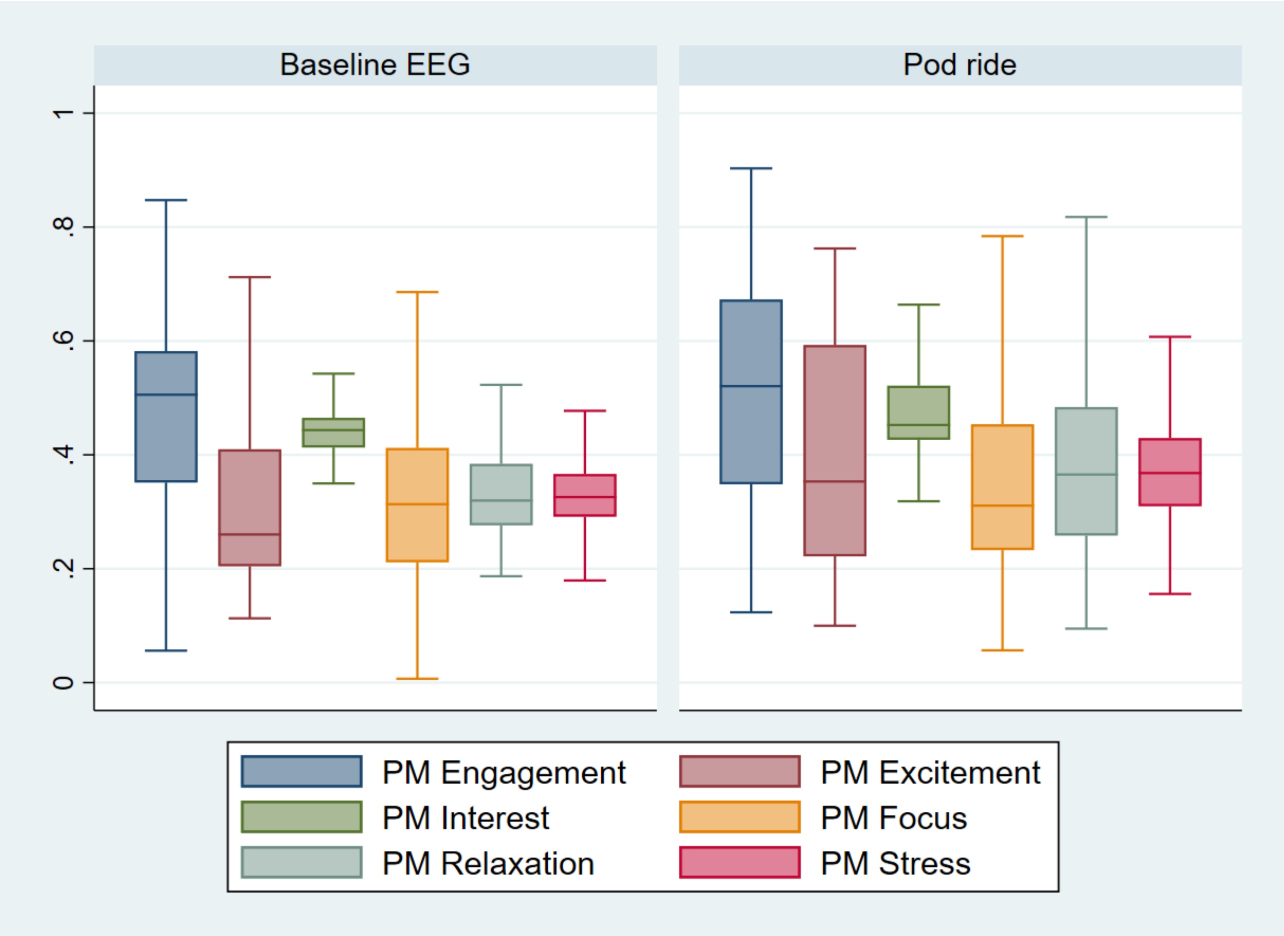

Figure 53. Baseline EEG versus EEG readings pod ride. Participants aged under 31 years

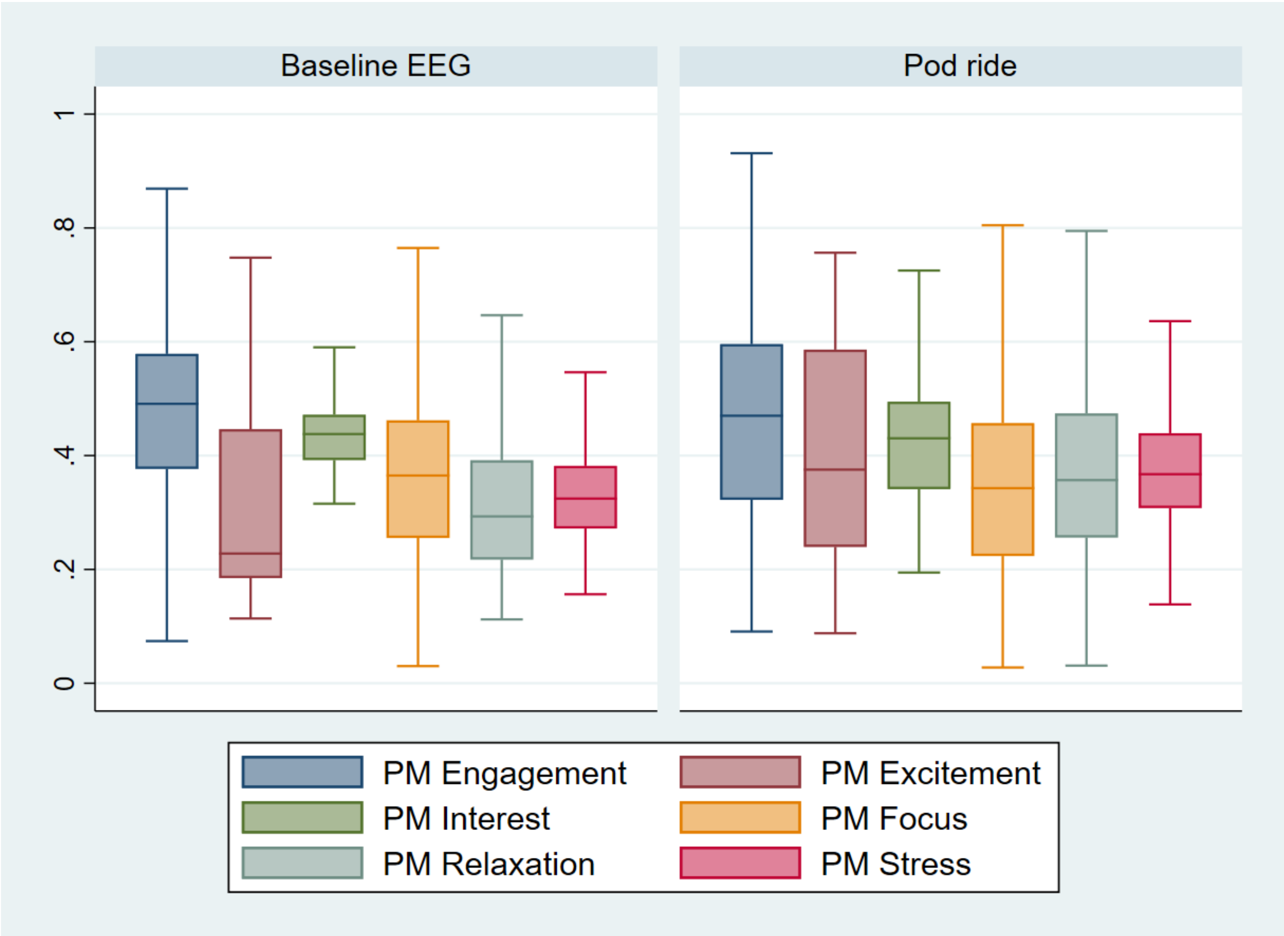

Figure 54. Baseline EEG versus EEG readings pod ride. Participants aged between 31 and 55 years

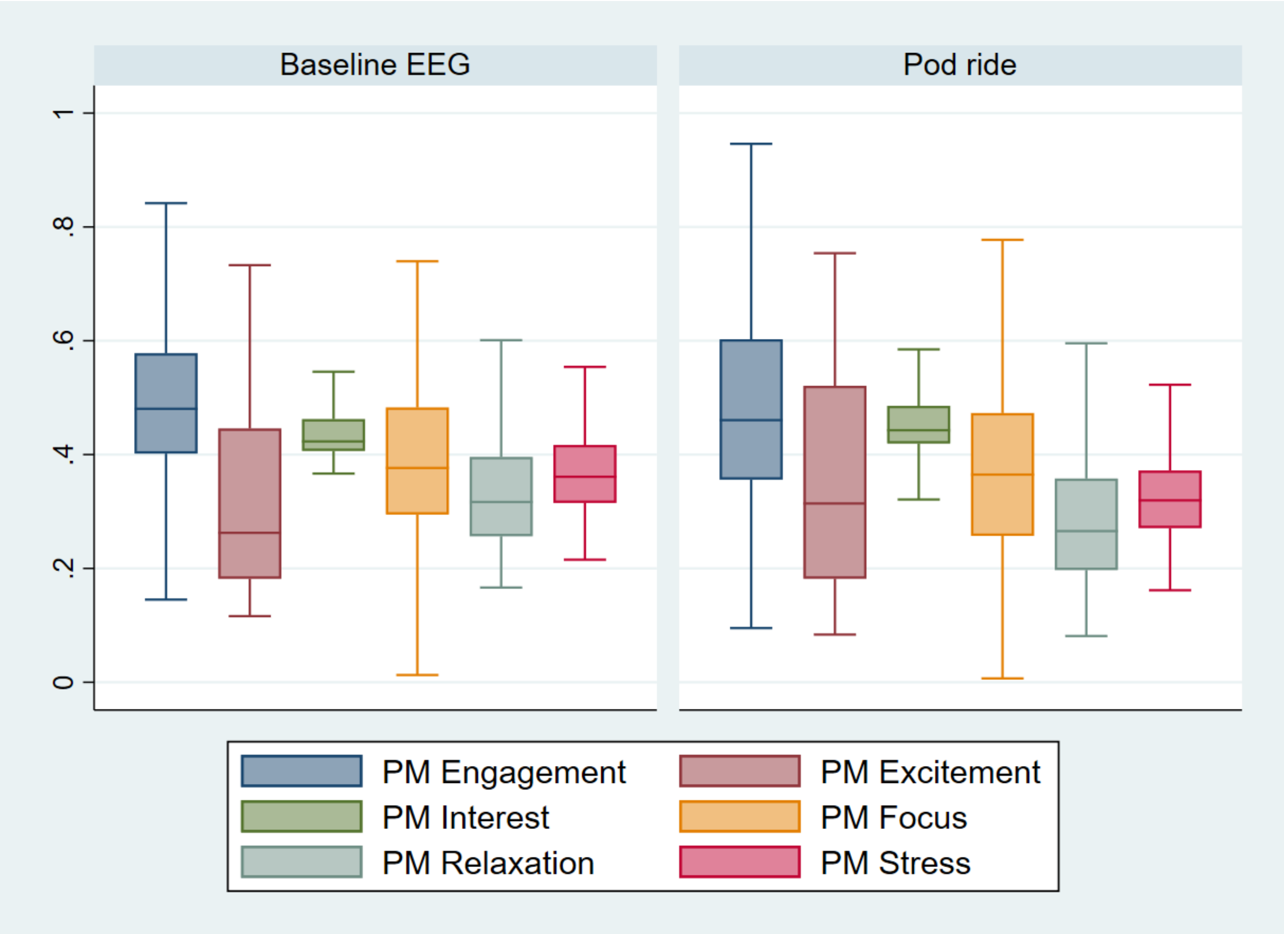

Figure 55. Baseline EEG versus EEG readings pod ride. Participants aged 56 years and over.

Regarding location based differences in the Performance Metrics for the baseline EEG readings compared to the pod ride in Figure 56 and Figure 57, the following conclusions can be drawn:

- For both locations, there is a significant dispersion for most Performance Metrics, suggesting a degree of heterogeneity between participants. This goes for the baseline EEG readings as well as for the EEG shuttle readings.
- For Focus and Stress, the dispersion is more limited, suggesting a limited degree of heterogeneity. This goes for the baseline EEG readings as well as for the EEG shuttle readings.
- For both town and city, the Kolmogorov-Smirnov test suggests that the distributions are significantly different for all the Performance Metrics.
- The pairwise t-test suggests that both Excitement (28.9% versus 41.8%) and Interest (45.8% versus 50.2%) are significantly higher for participants in the city. For the town, a similar effect is found for Interest (41.6% versus 45.7%).
- For the Town there is no significant difference in Excitement between baseline EEG and pod ride EEG (43.4% versus 44.8%) which contrasts with the findings from the shuttle ride.

Despite the significant increase in Excitement for participants in the city,those in the town still had higher levels of Excitement during baseline EEG readings and during the pod ride. However, for both the levels were still lower than levels of Excitement observed for the shuttle. A few things may have contributed to this. Firstly, it must be noted that the ordering of the vehicles was different across both locations with participants in the city experiencing the pod after the shuttle and this might have impacted how the journeys were experienced. It is possible that for participants in the city, Excitement was dampened as participants became more familiar with the technology. Additionally, the ordering of the vehicles would explain the significant increase in Interest and overall increase in Excitment for participants in the town for whom this was their first experience of self-driving technology.

This difference could also have been a result of the environment and the vehicle's route through the town and the city. In the town, the vehicle was operating in a public park with higher levels of pedestrians, cyclists and other obstacles whilst in the city, the vehicle was operating around a stadium with much lower footfall. Once again, the more complex town environment could explain the higher levels of Interest and Excitement at seeing the vehicle navigate this varied environment.

This would also explain the differences in Excitement levels with the shuttle. In both locations the shuttle operated in more complex environments but as described earlier, the route followed in the town was more diverse (navigating narrow roads, mixed traffic compared to a dual carriageway in the city location). The higher levels of Excitement observed in the city could be attributed to the novelty of the experience which then reduced upon trialling the pod in a less complex environment as well as becoming more familiar with the technology. On the other hand, the greater levels of Excitement in the town could be due to experiencing self-driving technology in a more complex setting that reflected a potential real-world service (please see The Great Self-Driving Exploration A citizen view of self-driving technology in future transport systems for further detail). This suggests that the specific characteristics of a route and the level of familiarity to the exposure may impact emotional states.

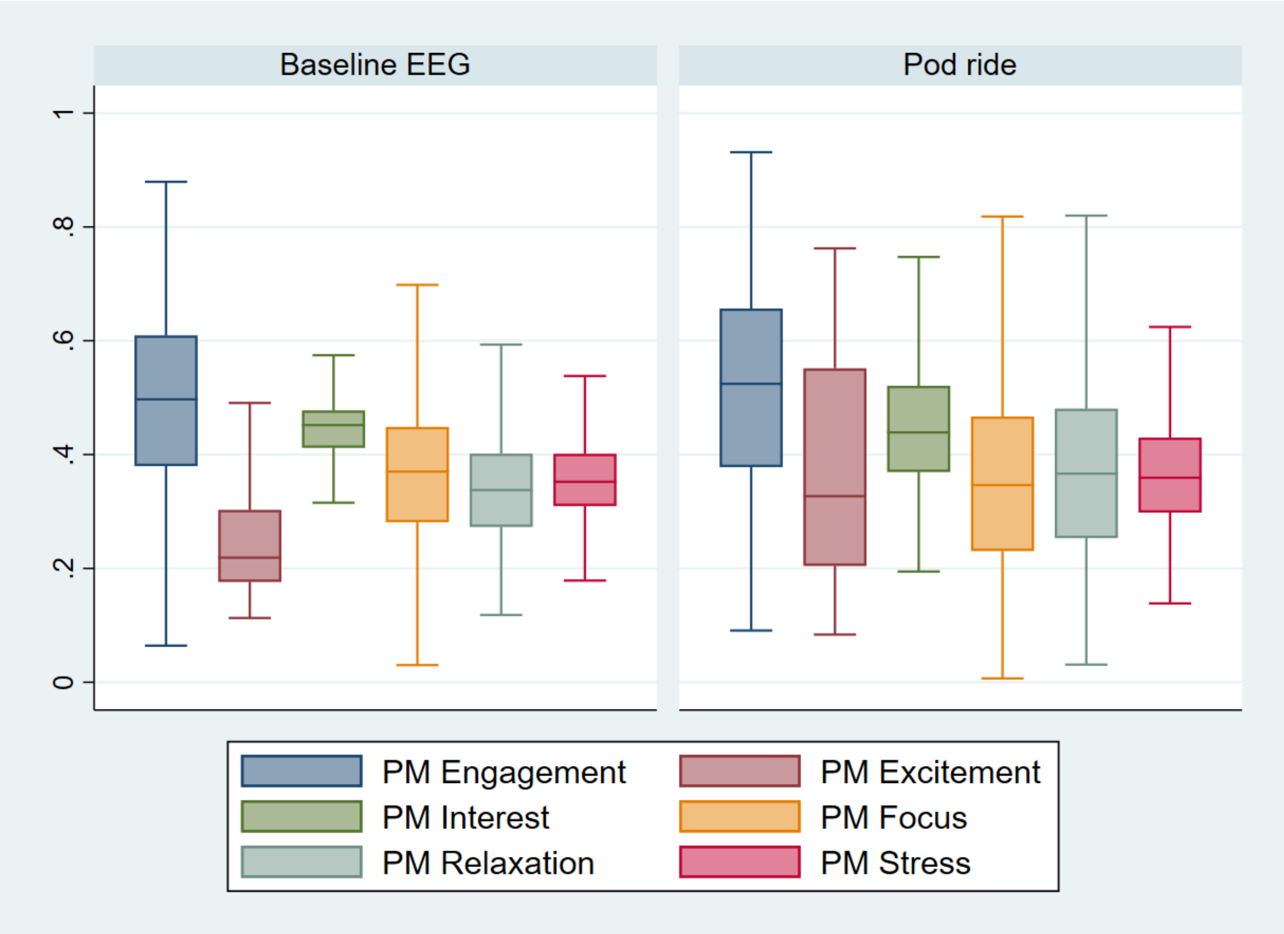

Figure 56. Baseline EEG versus pod EEG readings for the city

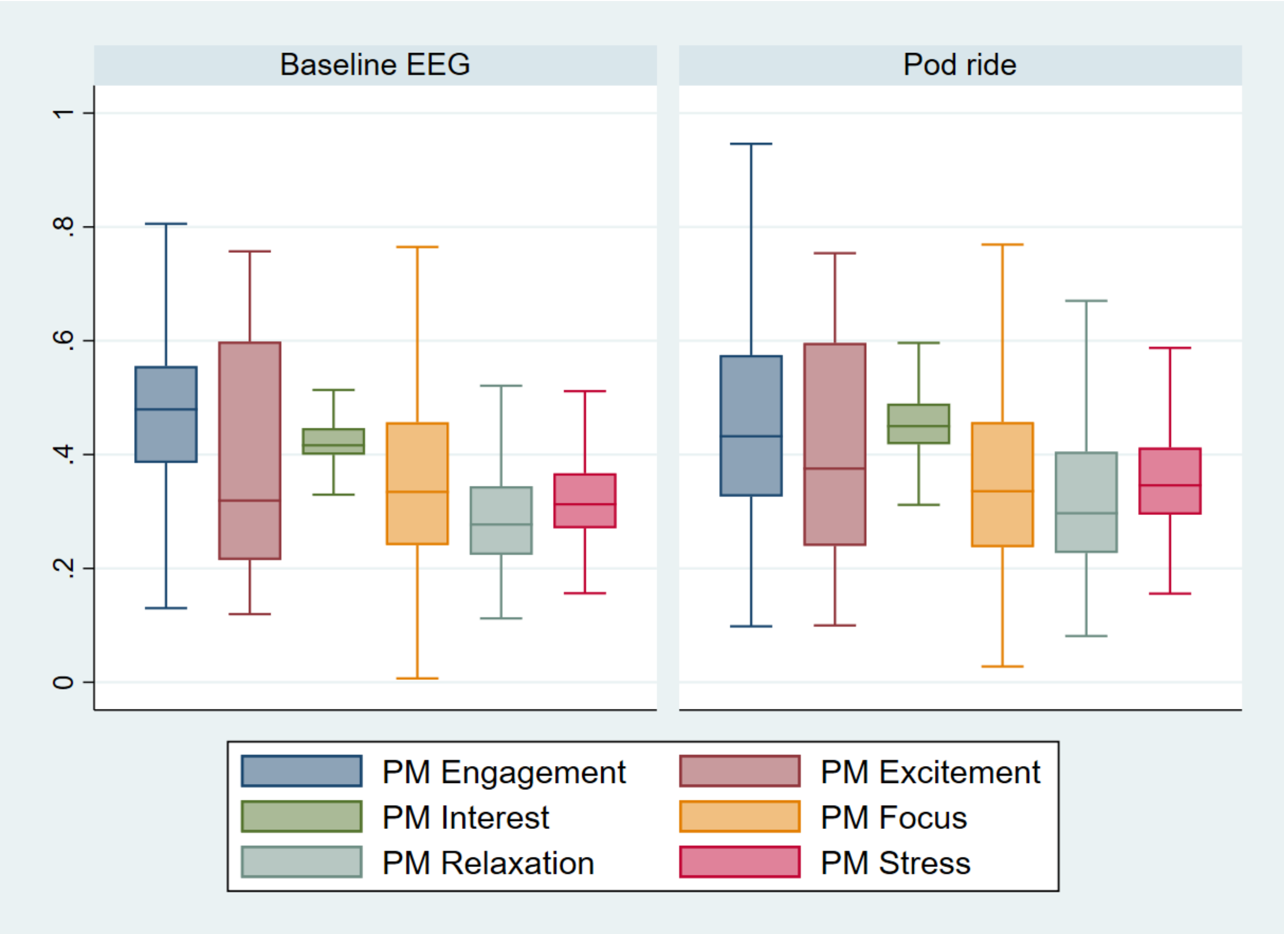

Figure 57. Baseline EEG readings versus pod EEG readings for the town

Pod EEG results versus shuttle EEG results

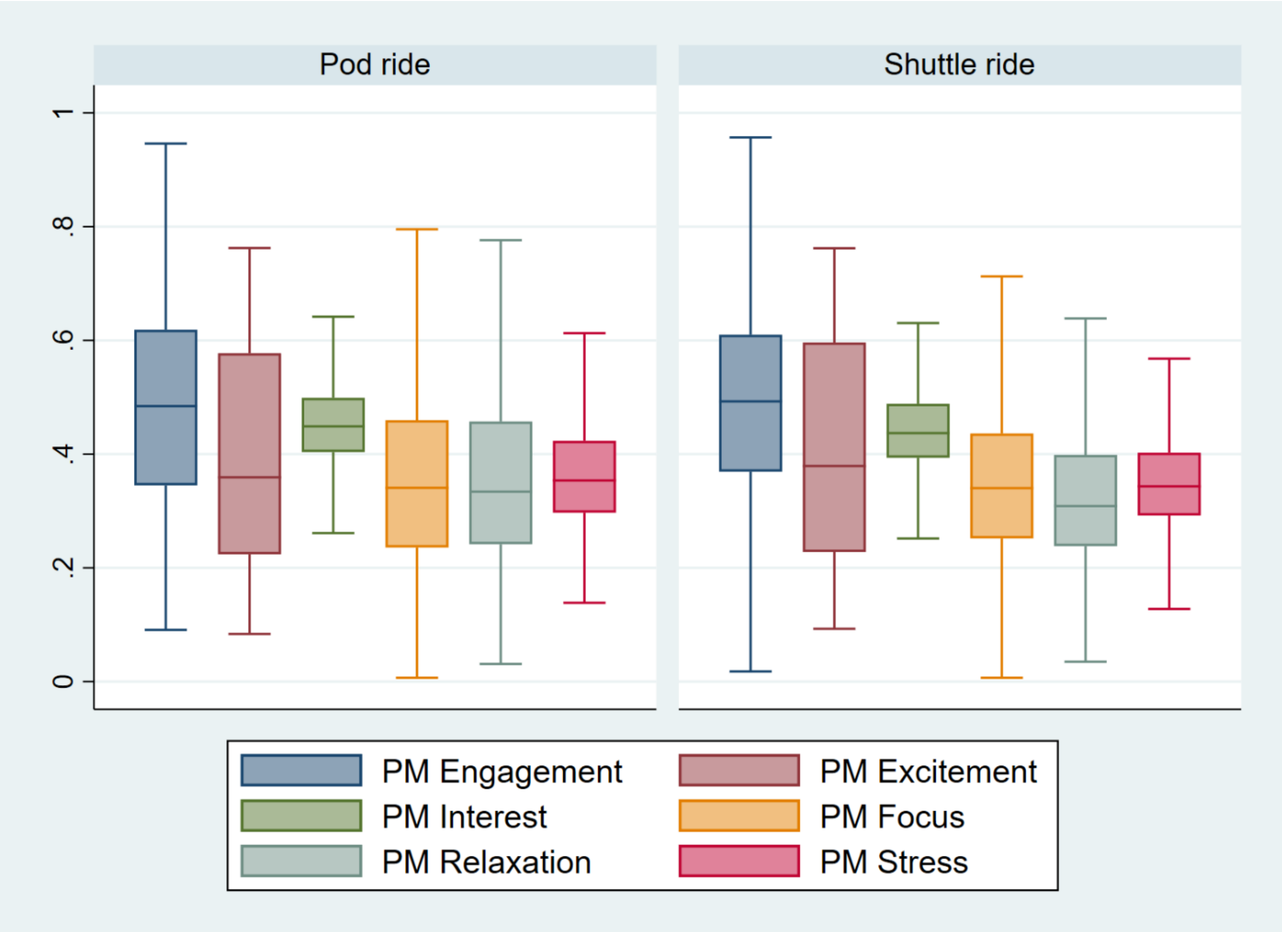

Figure 58. EEG readings during pod ride versus shuttle-bus ride

EEG measurements between the pod and the shuttle journeys can be compared to understand the variations in the emotional state of participants across the two vehicles. Figure 58 displays the EEG readings during the full shuttle ride compared to the full pod ride. The patterns observed between the two vehicles are very similar. One difference is that the Performance Metric Excitement has a somewhat higher median during the shuttle ride. Given that the ordering in which the vehicles were experienced varied across the town and city location this may have impacted the overall distributions in Performance Metrics (e.g. the intial excitement or stress of experiencing a new technology could have been balanced out due to the changes in ordering).

Interestingly, there is a marked difference for the shuttle and pod ride when comparing the first two minutes (Figure 59). It seems that the Performance Metric Excitement is significantly higher for the shuttle ride compared to the pod ride during the first two minutes of the ride. This could be due to initial excitement and interest regarding the vehicle or technology itself, as none had ever experienced self-driving vehicles prior to the research. However, the initial Excitement quickly reduces as participants become familiar with the vehicle and it's novelty wears off. This is in line with the broader research findings whereby participants described the shuttle as a smoother and more comfortable journey to the pod, with some reporting that as the journey progressed they started to feel relax or even bored.

This has a number of potential implications suggesting that it does not take long for participants to become more comfortable, or for the intensity of any initial emotional reactions to subside, allowing more cognitive led responses to form. This is in line with the changes observed in the broader research programme (see The Great Self-Driving Exploration A citizen view of self-driving technology in future transport systems with these new technologies for more detail) where as participants became more familiar with the technology they were able to develop more informed views (i.e. reduced uncertainty and increased comfort towards the technology). These insights demonstrate the importance of providing members of the public with the opportunity to trial the technology to allow for more informed views, both positive or negative, to be shared and embedded into the design of future services that may use self-driving vehicles.

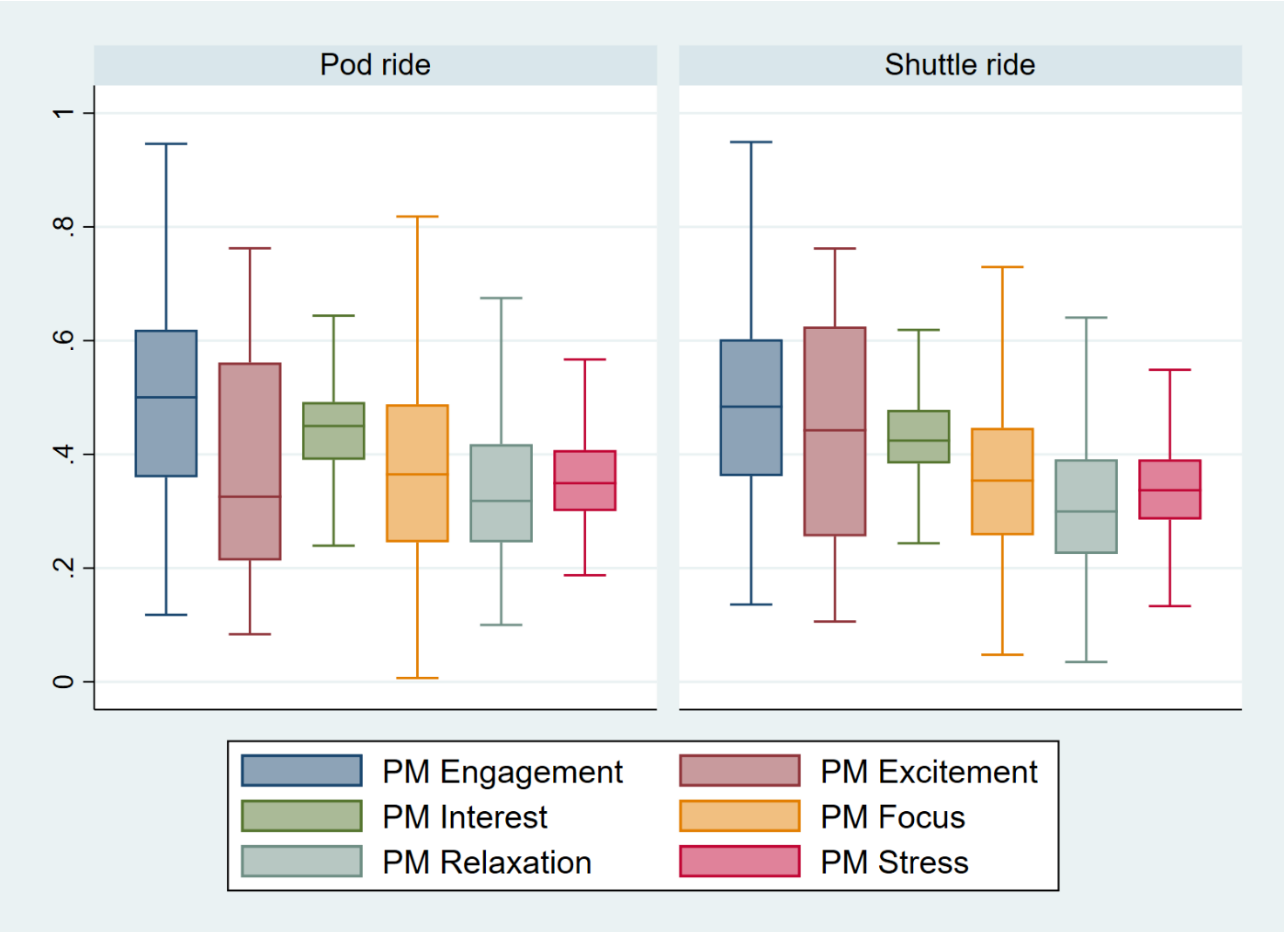

Figure 59. EEG readings, pod ride versus shuttle ride during first two minutes.

Pre- and post-trial survey and relationship with EEG data

This section presents the outcomes of the pre-and post-trial survey. Then, some conclusions are drawn based on the relationship between the EEG readings for participants, and their self-reported emotional states through the surveys.

The purpose of the pre-and post-trial survey was to contextualise the findings from the EEG data. To achieve this, the survey collected participants' self-reported emotional state.

This was done by presenting participants with 15 statements about their emotional state, whereby they could rank their level of agreement with the statement through a five-point Likert scale (with 1 being strongly disagree and 5 strongly agree). Table 1 presents the average scores for each of the emotional statement across all participants.

Based on the findings presented in Table 1, it is clear that the negative emotions, such as 'I feel sad', 'I feel annoyed', generally have a low level of agreement. In contrast, positive statements, such as 'I feel happy', 'I feel confident' generally have a high level of agreement. This indicates that most participants were in a positive state of mind. After having trialled the self-driving vehicles, these more positive emotions have higher levels of agreement, whilst there are slightly lower levels of agreement with negative emotions post ride. For the following items, there were statistically significant differences for the pre-and post-trial survey:

- Significant increase in 'I feel safe'
- Significant increase in 'I feel content'
- Significant increase in 'I feel confident'
- Significant increase in 'I feel surprised'
- Significant increase in 'I feel in control of things'
- Significant reduction in 'I feel worried'
- Significant reduction in 'I feel irritated'

For the following statements a large change was noticed between the pre and post ride surveys but these changes were not statistically significant:

- Increase in 'I feel pleased'
- Reduction in 'I feel melancholic'

Table 1: Mean scores for pre-and post trial survey

Emotional statements	Mean value pre ride (n=63)	Mean value post ride (n=63)
I feel sad	1.60	1.46
I feel scared	1.72	1.53
I feel happy	4.25	4.28
I feel alert	4.26	4.20
I feel active	3.93	4.02
I feel irritated	1.91	1.58
I feel confident	3.96	4.19
I am worried about what people think of me	2.04	1.85
I feel in control of things	3.55	3.85
I feel motivated	3.96	4.05
I feel safe	4.25	4.37
I feel bored	1.82	1.73
I feel content	4.04	4.18
I feel annoyed	1.55	1.43
I feel pleased	3.98	4.15
I feel melancholic	1.63	1.54
I feel amused	3.82	3.81
I feel surprised	3.20	3.46

To contextualise the EEG data, and to assess the relationship between the EEG readings and the self-reported emotional state, Spearman correlation coefficients were computed. This was first done for the pre-trial survey and the average baseline EEG readings for the Performance Metrics and can be seen in Table 2. This was followed by the post-trial survey and the average shuttle ride EEG readings for the Performance Metrics and are displayed in Table 3. To assess the statistical significance of the correlations, a confidence interval of 10% was used, and these coefficients are displayed in bold in the tables.

Table 2: Spearman correlation coefficients for pre-trial survey versus baseline EEG Performance Metrics

Emotional statements	Engagement	Excitement	Interest	Focus	Relaxation	Stress
I feel sad	0.10	**-0.41**	0.16	-0.22	**0.26**	0.12
I feel scared	0.21	-0.14	0.08	**0.29**	0.06	0.02
I feel happy	**-0.27**	**0.28**	-0.10	-0.08	0.02	0.01
I feel alert	-0.23	0.14	-0.08	-0.04	0.01	-0.04
I feel active	-0.19	0.19	-0.17	0.10	-0.21	-0.14
I feel irritated	0.11	-0.13	-0.09	-0.04	-0.11	-0.16
I feel confident	**-0.30**	0.27	-0.10	-0.18	0.11	0.07
I am worried about what people think of me	0.10	**-0.48**	0.02	-0.06	0.06	-0.01
I feel in control of things	-0.22	0.05	-0.13	**-0.32**	0.01	-0.04
I feel motivated	**-0.28**	0.05	-0.16	-0.09	0.05	0.06
I feel safe	-0.20	0.30	-0.16	-0.18	0.09	0.11
I feel bored	-0.01	-0.05	-0.10	-0.03	-0.01	-0.09
I feel content	-0.27	**0.34**	-0.05	-0.18	0.12	0.14
I feel annoyed	0.15	**-0.34**	0.17	0.17	0.09	0.02
I feel pleased	-0.18	0.16	-0.09	-0.05	-0.18	0.04
I feel melancholic	0.13	-0.18	0.09	-0.07	0.14	0.08
I feel amused	0.11	0.17	-0.06	0.18	-0.13	-0.15
I feel surprised	0.09	**0.23**	0.07	0.10	-0.01	-0.04

Table 3: Spearman correlation coefficents for post-trial survey versus shuttle EEG Performance Metrics

Emotional statements	Engagement	Excitement	Interest	Focus	Relaxation	Stress
I feel sad	-0.08	**-0.22**	0.03	0.14	0.07	0.14
I feel scared	-0.09	-0.20	0.02	**0.29**	0.18	**0.22**
I feel happy	-0.05	0.11	-0.14	**-0.23**	-0.12	-0.13
I feel alert	-0.04	0.16	**-0.25**	-0.15	0.00	-0.08
I feel active	-0.19	**0.31**	-0.1	-0.11	0.02	0.02
I feel irritated	-0.06	-0.07	0.07	**0.29**	0.13	0.21
I feel confident	0.10	0.13	**-0.27**	0.00	0.00	-0.09
I am worried about what people think of me	-0.07	**-0.30**	0.04	-0.01	0.09	0.10
I feel in control of things	-0.20	**0.26**	**-0.30**	-0.09	-0.08	**-0.18**
I feel motivated	0.08	0.20	-0.08	-0.06	0.01	-0.06
I feel safe	0.04	**0.21**	-0.05	-0.17	0.03	-0.02
I feel bored	0.03	**-0.25**	0.04	0.11	**0.27**	0.10
I feel content	-0.03	0.17	-0.15	-0.16	-0.01	-0.10
I feel annoyed	0.10	-0.14	0.07	**0.25**	0.20	0.08
I feel pleased	0.09	**0.24**	0.02	-0.19	0.01	-0.03
I feel melancholic	-0.12	-0.17	0.12	0.14	0.19	**0.23**
I feel amused	-0.20	**0.37**	0.00	-0.1	0.15	0.10
I feel surprised	-0.10	**0.22**	-0.07	-0.18	0.06	0.10

Based on the findings in Table 2 and Table 3, several conclusions can be drawn. Firstly, that there not many significant correlations between the EEG data and self-reported emotions but there are some notable patterns observed. Given that the values for the Performance Metrics vary between the pre-and post-trial survey (whereby the baseline EEG was correlated with pre-trial survey results, and shuttle EEG with post-trial results), the absence of very strong correlations is not surprising.

The most notable patterns are found for the Performance Metric Excitement, which has a positive relationship with self-reported statements that relate to positive emotional states (e.g., 'I feel happy', 'I feel content'), and negative relationship with negative self-reported emotional statements (e.g., 'I feel sad', 'I am worried what other people think of me'). Given that Excitement is defined as an awareness of feeling with physiological arousal with a positive value this finding is expected. Moreover, it suggests that participants emotional state whilst riding in a self-driving vehicle are in line with their self-reported emotions and that these emotional statements could be used as good indicators of Excitement in future research.

For the other Performance Metrics, correlations are often less strong and vary between the pre-and post-trial survey. This is the case for Engagement. For the pre-trial survey, Engagement negatively correlates with statements relating to a more positive state of mind and for the post-trial survey no significant correlations are found. Given that Engagement is defined as alertness and the conscious direction of attention towards task-relevant stimuli, which measures the level of immersion in the moment, it is possible that the statements presented to participants do not relate to this this Performance Metric. There was no relationship between Engagement and 'I feel bored' and 'I feel alert' which might have been expected given what Engagement represents. This suggests that Engagement simply refers to a more 'functional' or 'cognitive' state, rather than an emotional state for participants and therefore that the emotional statements used may not be suited to measure Engagement in future research.

Further, the Performance Metric Interest also has limited correlation but a relationship is seen with 'I feel in control of things', 'I feel confident' and 'I feel alert'. Interest is defined as a measure of attraction or aversion to the stimuli experienced by the participant. To further assess whether any relationships exist, the differences in the mean value for Interest were tested for all 15 emotional statements, whereby two groups were created one where participants agreed with the statement and one group where participants disagreed. After this, t-tests were performed to assess whether differences were statistically significant. Given the definition of Interest, the expectation is that the mean of Interest should be significantly higher for participants that are in agreement with the more positive statements. The findings support this and show statistically significant relationship between high levels of Interest and statements such as 'I feel happy', 'I feel active', 'I feel alert' and 'I feel pleased'. There was also a positive relationship with 'I feel in control of things' but this was not statistically significant. This suggests that participants emotional state whilst riding in a self-driving vehicle are in line with their self-reported emotions and that these measures could be used as a good indicator for Interest in future research.

For the Performance Metric Focus, negative correlations are seen with statements such as 'I feel sad', 'I feel happy', and 'I feel in control of things'. Focus is also positively related with 'I feel scared', 'I feel irritated' and 'I feel annoyed'. This seems to indicate that higher levels of Focus are associated with emotional states that are more negative or anxious. The Performance Metric Focus is described as a measure of fixed attention to one specific task, and it could be that the more negative or anxious emotional states are associated with a slightly higher task-specific attention span. This could also be due to the novelty of the task whereby participants were more focused on the task due to concerns around the vehicles capabilities as none had ever experienced a self-driving vehicle before. This would be in line with self-reported findings (see The Great Self-Driving Exploration A citizen view of self-driving technology in future transport systems for more details) whereby some participanst were unsure about the vehicles ability to operate safely in mixed traffic and will have taken those concerns with them when trialling the vehicles. Given this more research is required to determine whether these metrics would be good indicator of Focus in future research, or whether these patterns could be due to the novelty of the task.

For the Performance Metric Relaxation, positive correlations exist for the statements 'I feel bored' and'I feel scared'. The strongest effect is found for 'I feel bored', which is expected as the Performance Metric Relaxation is defined as a measure of an ability to switch off and recover from intense concentration. This suggets that the emotional statement 'I feel bored' could be used as a good indicator for Relaxation in future research.

Finally, for the Performance Metric Stress, there are positive correlations for 'I feel scared' and 'I feel melancholic'. A negative correlation exists for 'I feel in control of things'. Given that the Performance Metric Stress is described as a measure of comfort with the current challenge, these relationships are expected. This suggests that participants emotional state whilst riding in a self-driving vehicle are in line with their self-reported emotions and that these measures could be used as a good indicator for Stress in future research.

5. Conclusions and implications

This report presents the findings from the electroencephalography (EEG) strand of the Great Self-Driving Exploration project which aimed to provide a set of quantitative data on physiological response to self-driving technology. To do so, EEG data was collected to assess the emotional state of participants whilst using a self-driving vehicle as well as pre- and post-trial surveys assessing self-reported emotional states. This study is the first of its kind to monitor the emotional responses of participants on a self-driving vehicle in real-time, and the data collection has resulted in a sizeable quantitative dataset on physiological responses to self-driving technology.

The main findings from the EEG data indicate that participants generally have the highest median scores for Engagement (52% for the shuttle ride, 50% for the pod ride), Excitement (45% for the shuttle ride, 43% for the pod ride) and Interest (45% for the shuttle ride, 48% for the pod ride) with lower scores for Focus (35% for the shuttle ride, 35% for the pod ride), Stress (36% for the shuttle ride, 37% for the pod ride) and Relaxation (33% for the shuttle ride, 36% for the pod ride).

Given the relatively high scores for Engagement, Interest and Excitement across the sample, it can be concluded that participants tended to be alert, immersed in the moment, have a degree of affinity with the task and tended to have more positive emotional responses to the technology. Equally, the lower average scores for Focus, Stress and Relaxation suggest that participants were not fixing their attention to a single task and were relatively comfortable with the experience despite its novelty. It also suggests that the experience of riding in a self-driving vehicle did not cause adverse emotions.

The analysis does show that there are large variations between participants for Engagement and Excitement during the shuttle and pod ride. This suggests that there are greater differences in individuals experience for these two measures. Additional analysis on the socio-demographics suggest that these variations are in part due to age, socio-economic status, gender, and the specific vehicle route adopted.

The findings suggest that males tend to show higher levels of Excitement than females when on the shuttle whilst the opposite is seen for the pod where females have higher rates of Excitement. In addition, women tend to have higher levels of Interest for the pod ride as well. These differences could also be explained by the specific journeys and the characteristics of the vehicles as well as attitudinal differences that were observed throughout the broader research programme. For instance, in the pod participants could see out the front of the vehicle and through the use of the in-vehicle screen see how the vehicle's software and sensors detected and responded to obstacles. We know from the broader research (see The Great Self-Driving Exploration A citizen view of self-driving technology in future transport systems for more details) that women were more uncertain and had lower levels of comfort regarding self-driving vehicles at the start of the research. This additional information was reported as 'reassuring' and may therefore have impacted the level of Interest for females who were initially more uncertain about the vehicles. Males on the other hand reported higher levels of comfort from the beginning of the research and therefore this information may not have had the same level impact. However, operating on more complex and mixed roads may have further empahsised that overall interest in the technology especially for those who were maybe more comfortable in regards to the technology, such as men.

Younger participants had much lower levels of Engagement compared to the older age categories suggesting that they were maybe less focused or concentrated on the specific task. This would also align with the lower levels of Excitement seen with this group. For socio-economic status, participants from socio economic groups C1, C2, D or E showed higher levels of Excitement compared to those from higher socio-economic groups.

Moreover, there was also notable differences across locations with those in the town location showing higher levels of Excitement for the shuttle ride than the other trial locations. This could be due to some of the socio-demographic differences discussed as well as broader attitudinal differences but could also be attributed to the specific journey. Indeed, as previously discussed the journey in the town location was more complex (i.e., a busy high street, narrow streets and high levels of mixed traffic) and seeing this new technology safely operate in a complex environment may have had a positive impact on Excitement. These findings would be in line with the broader research findings (see The Great Self-Driving Exploration A citizen view of self-driving technology in future transport systems for more details).

Finally, another important main finding is that for both the pod rides and the shuttle rides, the scores for Excitement are significantly higher compared to baseline readings (30% during baseline EEG reading versus 45% for the shuttle ride, whilst for other Performance Metrics, shifts are much less dramatic (and only statistically significant for Engagement and Focus). For this shift, there is also significant heterogeneity between participants, whereby the shift in Excitement is much less pronounced for female participants, younger participants and participants from the city.

Further analysis was done on how the emotional state changes during the ride. This was done by analysing the Performance Metrics during the first five minutes of the shuttle ride and comparing them with the Performance Metrics for the rest of the journey. For males, levels of Excitement subside as the journey progresses, whilst for females, levels of Focus subside and there is also a decrease in levels of Stress, although this is less strong. A similar effect is found for participants from higher socio-economic groups. As described earlier this suggests that as participants become more familiar with the technology the more immediate and emotional reactions subside. The higher levels of Excitement and Focus could be attributed to the novelty of the experience and an apprehension of trialling a new technology on complex roads for the first time triggering more emotional reactions. The differences in emotion type could be due to observed gender differences in underlying attitudes towards technology and self-driving vehicles specifically, with females reporting higher rates of uncertainty and lower rates of comfort than their male counterparts prior to trialling the vehicles. However, the experience of the vehicle operating and interacting with other road users as any other vehicle would do, works to appease these initial more emotional reactions, both positive or negative. This pattern follows the dual processing theories (Epstein, 1994) that suggest that individuals can respond to situations through two different routes: one that is linked to more immediate and spontaneous reactions and are driven by underlying attitudes, habits and emotions (also known as experiential systems, heuristic processing or automatic processing) or a more considered route that is driven by more deliberative thought and is possible when individuals have sufficient time, cognitive resources and motivation to engage in more rational deliberation (rational system, systematic processing or deliberative processing) (Gawronski & Creighton, 2013). As participants trialled the technology for the first time their responses tended to be led by this more spontaneous route, but it is possible that as they became more familiar with the technology these emotions subsided allowing them to start to move towards the more systematic processing. This is in line with the changes observed in the broader research programme (see The Great Self-Driving Exploration A citizen view of self-driving technology in future transport systems with these new technologies for more detail) where as participants became more familiar with the technology they were able to develop more informed views (i.e. reduced uncertainty and increased comfort towards the technology).

The analysis exploring changes in emotional state in response to vehicle kinematics suggested that males generally have higher levels of Excitement during the first two seconds of acceleration and turning, and lower excitement during the first stages of deceleration. Stress levels seem to lower after the first two second of a turning or acceleration event particularly for females. These findings are in line with those previously explored suggesting that as familiarity increases those initial emotive reactions (positive for males and more negative for females) subside.

Finally, the pre-and post-trial survey was analysed to contextualise the EEG findings. Correlation analysis was performed to see how the EEG readings relate to the self-reported emotional state pre- and post-trial. The patterns in the relationship between the EEG readings and the emotional statements are in line with expectations and in line with what is being observed for the baseline EEG readings and the shuttle EEG readings. For instance, the EEG readings suggest an increase in Excitement between the baseline EEG and shuttle EEG readings, whilst the surveys contain a trend towards more positive feelings in the post-trial survey. This suggests that both methods can be seen as providing a reliable indicator of the actual emotional state of participants.

It should be noted that there are limitations to this study that should be considered as interpreting the findings. As noted in 'The Great Self-Driving Exploration: A citizen view of self-driving technology in future transport systems' with these new technologies participants in this sample tended to have higher levels of technology optimism (as compared to the national control group surveyed as part of this research) and therefore may not be representative of the population at large. This could explain the high observed rates of Excitement and lower Stress levels and more research on an even broader sample will be required to see if these findings apply to those who may have lower levels of technological optimism. Furthermore, while the study has a relatively large sample size compared to the broader EEG literature, the sample sizes for each sub-group is low. This makes it difficult to observe statistical patterns in the data between sub-groups. For this reason, a more lenient confidence interval of 10% was considered, rather than the more common 5% confidence interval.

All in all, the findings demonstrate that participants respond in a positive way to the experience of riding the shuttle and the pod and that feelings of anxiousness and/or stress were generally low. There are differences between groups in the emotional state experienced during the journey and how these emotional state develop throughout the ride or under the influence of vehicle kinematics, particularly based on gender. These differences will have implications on both engineering and policy choices to help mitigate certain emotional states if self-driving vehicles become more widespread. The changes in emotional state observed throughout a journey also suggest the value of providing members of the public with the opportunity to trial the technology. This should be done with a diverse representation of the public both to address concerns and normalise the idea of self-driving technology as well as provide opportunities for participants to progress from more automatic, or emotion led reactions, to more deliberated or informed views that can be embedded into the design and development of future self-driving vehicles.

6. Appendix

Consent form for all Core Deliberative Locations

Consent form | Self-Driving Research

Project on behalf of the DfT | 11191671 CD | LOCATION 2022

You are being invited to take part in a research project for the Department of Transport (DfT) about self-driving vehicles.

Before you decide to take part, it is important for you to understand why the research is being done and what participation will involve, so that you can give your informed consent. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information and then take time to decide whether or not you wish to take part.

What is the project's purpose?

This research has a number of key objectives for DfT, who wish to:

- Understand what the public think about self-driving vehicle technologies and what they want from this technology in the future.
- Explore what the public already know about self-driving vehicles and how to use them, as passengers and other road users
- Learn how best to communicate with people about self-driving vehicles and self-driving features that might become available soon and how to use them
- Learn about what might need to happen, and what the DfT could do, to enable self-driving vehicles to be introduced successfully

The research will be carried out on behalf of DfT by a research consortium of; BritainThinks, an independent research organisation who will be running the workshops; University College London (UCL) who will advise and run part of the research; and Aurrigo, a company that designs and manufactures self-driving vehicles, which they will provide for you to trial.

Why have I been chosen?

You have been chosen to take part as you fit certain demographic and transport-based criteria from the screening questions asked by our network of recruiters.

Do I have to take part?

Participation in this research is entirely voluntary and you may withdraw from the research at any time during the span of the project, although you may forfeit your right to any / part of any incentive or benefit being offered.

What will happen if I take part?

The research consists of three workshops taking place over three weeks. We will also ask you to complete a 15 minute survey both before the first workshop, and after the final workshop. You will be provided with a ‘thank you’ payment for each workshop paid via the secure incentive payment platform Ayda. Catering will also be provided free-of-charge at each workshop.

Each workshop will have approximately 64 members of the public participating and involve discussions in smaller groups (of around eight people). In workshops 1 and 3 you will be discussing your thoughts and feelings about the technology and provided with easy-to-understand information to respond to. You will also be asked to complete short pre and post questionnaires so we can capture your thoughts at the start and end of the process.

In the second workshop you will be invited to trial a self-driving vehicle, although this is voluntary, and you are free to withdraw from participation in the trial at any time during the span of the project.

Aurrigo will provide the vehicles you will ride in, all of which are fully tested and licensed to operate in the UK. To ensure that the trial is carried out safely Aurrigo produced a safety case (a type of risk assessment) which has been independently reviewed and verified. In addition, some participants can opt into wearing EEG equipment (a lightweight and unobtrusive headset) to measure physical responses during the trials of the self-driving vehicles – you can read more about this below, and are free to choose whether or not to take part in this element of the research, at any time including on the day.

After 6 and 12 months we will contact you by email or post with another short survey to see if your views have changed in the meantime.

How will my information and data be handled if I take part?

Your personal data will be treated with confidentiality, this means that no one outside of the research teams will know you have taken part, and none of the results we publish will have your name or other personal details included. Please note that assurances on confidentiality will be strictly adhered to unless evidence of wrongdoing or potential harm is uncovered. In such cases the research team may be obliged to contact relevant statutory bodies / agencies.

Both your data and personal information will be held by BritainThinks for 12 months after which it will be securely deleted, except for this record of your consent which will be kept indefinitely. We will produce a report about the research which will be published, but which will not identify you personally. We will also produce a fully anonymised data set that includes notes from all of the discussions (GDPR compliant) following the completion of the project that will be published to the Data Archive. This is to ensure that other researchers can use the data we collected. There will be no way to identify you through this data.

BritainThinks and University College London will act as the data processor for the research, with the Department for Transport acting as the data controller. BritainThinks privacy policy can be found below. The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk

By signing below, I confirm the following:

I agree to take part in this research.

I understand that BritainThinks adheres to the Market Research Society Code of Conduct, meaning that personal data I provide will not be passed on to any third party without my express consent. However, I understand that if I say anything which gives a BritainThinks researcher reason to think that I or someone else is at risk of harm, BritainThinks may be legally obliged to pass on this information to the relevant authorities.

- I understand that I am not required or obliged to take part in this research, and that I can opt out at any time during the span of the project by contacting a member of the BritainThinks research team (info@britainthinks.com / 0207 845 5880), though I may forfeit my right to any / part of incentive or benefit being offered.
- I agree to having my name and contact information held by BritainThinks for a period of up to 12 months for their internal quality monitoring purposes only. I agree to have this record of my consent be kept on file by BritainThinks indefinitely.
- I consent to having my name and email address shared with the incentive payment platform Ayda (previously known as Particity), so they can contact me to process any incentive being offered. I understand that I must collect my incentive payment within 6 months of it being released to me.
- I am aware that the research data may be published (using an anonymised dataset) to the Data Archive in a manner that is GDPR compliant.
- I understand that BritainThinks might be interested in contacting me again to hear my thoughts or ask me to take part in further research. I consent to being re-contacted by BritainThinks within the next 12 months for research related to this project and I understand that I will not be obliged to take part.
- I am aware that this research may be attended by a client in an observational capacity only.

FILM / MEDIA

- I understand that the workshops will be filmed / photographed and agree for this footage / these photographs to be used by BritainThinks, DfT, UCL, Aurrigo and the venue for research purposes including but not limited to:
- For security at the workshops, e.g. CCTV

- As research data e.g. analysing video footage of the vehicle trials
- To communicate the findings of the research internally within the research consortium listed

To agree to the above, please enter your **FULL NAME** below.

To view the BritainThinks privacy policy, please go to www.britainthinks.com/privacy

To view the Ayda privacy policy, please go to www.helloayda.com/privacy-policy

Additional Consent – Film and Media

Some elements of the research may also be filmed / photographed by professional videographers and potentially some national media outlets.

This footage may be publicly broadcast, and used in media formats including, but not limited to social media / the internet / television in order to communicate the findings of the research and publicise the research.

This consent is optional, and you can still take part in the research and receive the full incentive being offered if you do not consent to this.

Please indicate below if you consent to being filmed for this research, and for that footage to be used in the public sphere.

Additional Consent – Riding in a self-driving vehicle

During Workshop 2 you will be invited to experience a short journey of about 10mins in a self-driving shuttle and / or a 3-4mins in a self-driving pod.

The vehicles are self-driving but there will be trained safety operators in the vehicles at all times when they are in transit. You will be given full information on the day when you are invited to ride in the vehicle.

This consent is optional, and you can still take part in the research and receive the full incentive being offered if you do not consent to this. If you would like to ride in a self-driving vehicle at the workshop you will be provided with a waiver to sign on the day.

Additional Consent – EEG headsets

During the trial we will invite some participants to wear EEG equipment (a lightweight and unobtrusive headset) which will measure the electrical activity in your brain and help us understood more about your reactions to the vehicles.
Specifically, we would like to assess your emotional / cognitive response, which enables us to assess whether you feel anxious, or excited, whether you trust the autonomous vehicle or not. The way in which we want to record your cognitive / emotional response is

through a method called 'Electroencephalography' (EEG). EEG records an electrogram of real-time electrical activity in the brain. EEG is very widely used in research and is very safe. It is a passive method of scanning, which means the headset doesn't emit electricity or anything else, it just picks up the electricity your brain is always producing.

To gather this data, we invite you to wear an unobtrusive headset, which uses five measurement points across the scalp to detect electrical activity in your brain. We would like to link this EEG data with real-time data on the movements made by the autonomous vehicle during the ride (e.g., acceleration, deceleration, turning). Ultimately, this provides us with real-time insight into your cognitive / emotional response to the initial exposure to the vehicle itself, and your response during the ride to the movements made by the vehicle.

You will be asked to wear an unobtrusive EEG headset before boarding the autonomous vehicle, and throughout the ride on the autonomous vehicle. This means that you will be wearing the headset for a duration of roughly 20 minutes. The headset will measure electrical activity in your brain using five sensors which will be placed on your scalp. A member of our team (any team member whom you feel most comfortable with) will help you with setting up the device, and to ensure that the headset fits you comfortably.

The EEG headset requires the use of a saline solution (glycerin, used for eye contact lenses) to the EEG sensors. If you are allergic to glycerin we advise you not to opt-in for this aspect of the research.

In your welcome email we have also included an info sheet on EEG equipment, and on the day you will have the opportunity to see how it works before you take part. You can opt out of this part of the research at any time, including on the day.

This consent is optional, and you can still take part in the research and receive the full incentive being offered if you do not consent to this. Please note that if you select yes, you can still opt out on the day.

Please indicate below if you consent to wearing an EEG headset on the day of the trial event.

References

Epstein, S. (1994). Integration of the cognitive and the psychodynamic unconscious . American Psychologist , 49 , 709–724 .

Gawronski, B., & Creighton, L. A. (2013). Dual process theories. Chicago