# Skilled Motor Learning and EEG with Car Driving Simulation

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**Abstract**

This study investigated changes in electrocortical activity (ECA) associated with motor learning and performance on a driving simulator, and aimed to determine where in the brain and at what frequency does ECA best predict performance. Twenty-nine participants (11 males, 18 females) performed control periods and driving tasks of varying difficulty on an inexpensive driving simulator, comprising a steering wheel, set of pedals, personal computer and "Need for Speed III" driving computer game. Participants' electroencephalogram (EEG), heart rate, and galvanic skin response (GSR) were recorded during each session. Lap times for each driving task were used as a measure of performance. Differences between the ECA across sessions were calculated, as were correlations with measures of performance, and it was found that correlations were more selective. Correlations between ECA and performance were greatest in left front region: F3 at 9-9.5 Hz. Gender differences in ECA were most pronounced at central, temporal and parietal sites at frequencies within the alpha range (8-12 Hz). The development of regression equations and discriminant functions potentially may allow the prediction of performances and performers.

## Introduction

In an article by Sterman and Mann (1995) on pilot workload, decreases in alpha activity were found during simulation flights as workload increased. The high task loads showed the greatest suppression in medial frontal, central, and parietal sites, especially when the flight simulation's weather was changed in terms of visibility, wind, and cloud effects (Sterman & Mann, 1995). Consistent with this, Mills and Cross (2001) showed in a simple motor learning task (PacMan computer game) general suppression of alpha activity in the sensory-motor areas of the brain that was then relieved to some degree once the participants mastered the skill. Furthermore, a correlation between the degree of suppression and task performance was evident in some areas, with the most obvious relationship being expressed in the middle of the sensory-motor area. This study aims to replicate and extend upon the PacMan motor skill study, through the investigation of the changes in EEG activity that occur when participants perform a comparatively complex motor task (playing a computer driving simulation game: Need for Speed III). This study also purports to reveal further existing connections between skilled motor learning, task mastery and EEG output. In this investigation, participants will be using a steering wheel and pedals to respond to changes in the driving course, requiring them to control both their direction and velocity whilst responding to numerous visual cues. It is also believed that a person's state of autonomic arousal may affect skilled motor learning. For this reason, measures of heart rate (HR), heart rate variability (HRV), galvanic skin response (GSR) and galvanic skin response variability (GSRV) were collected and calculated.

### Hypotheses

Performance on the driving simulator will improve as learning occurs.

Brain alpha activity will be suppressed when participants experience the first play condition.

As participants master the game on successive play conditions, suppression of alpha activity will decrease.

An increase in actual task difficulty will lead to increased alpha suppression.

Increases in perceived task difficulty will be associated with increases in alpha suppression.

## Material and Methods

### Participants

Twenty-nine undergraduate psychology students (11 male and 18 female) aged over 17 years volunteered to participate in the study. EEG data from three female participants was later excluded (leaving $N$ = 26). All participants were right handed and reported limited computer game experience, particularly with "Need for Speed".

### Materials and Procedures

The GSR was measured using an in-house instrument with two steel finger electrodes attached to the non-dominant (left) hand, and the signal converted to a voltage, digitised, and stored on a personal computer. Heart rate was measured by attaching a finger pulse monitor and acquired in tandem with the GSR on the same equipment. Durations for each epoch varied according to length of EEG recording. At each stage, heart rate variability, average pulse, GSR, and GSR variability were calculated. EEG data were collected and analysed using a "Brain Atlas" (version 2.3; Biological Systems Corp., Mundelein, IL, USA). Prior to analysis, participants were weighed, measured, and instructed to remove all possible jewellery/hair accessories. "New Prep" abrasive skin gel and "Ten20" conductive EEG paste (both from D. O. Weaver and Company, Aurora, CO, USA), "Electro-Gel" EEG gel and 21 electrode site EEG caps (both from Electro-Cap International Inc., Dallas, Texas, USA) were used to prepare 20 scalp sites, as defined by the international 10–20 system (Jasper, 1958), of each participant (Fpz interpolated). Two linked reference electrodes filled with EEG paste were attached to the ear lobes. EEG gel was injected into each electrode site using a blunt syringe. All impedances were below 5 KOhm and amplifiers (gain 30000) were calibrated prior to recording. Need for Speed was played at two levels of difficulty on the "Lanstrasse" track, easy and hard (as defined by activating the rain weather function). Subjects were seated (in car seat) in front of the computer monitor and asked not to speak. Eleven two-minute sessions followed: Participants were asked to close their eyes (stage 1), then look at the game display (stage 2), then move the steering wheel/pedals (stage 3), then play the easy game where lap times were recorded (stage 4), then repeat stages 3, 4, and 3, then play the hard game where lap times were also recorded, then repeat stages 3, 2, and 1. The session concluded with removal of electrodes and participants being cleaned. Changes from stages 1 to 2 enabled stabilisation of system and physiological validation. Changes observed in the four repeats of stage 3 demonstrated the effect of movement and thus served as control periods. The second easy game was to assess the effect of short-term learning; the difficult game, the effect of increased cognitive load. Data were correlated then displayed using the EEG equipment's program: "Bank Math".

## Results

Mean scores were 12.4 (*SE* = 0.8), 15.2 *SE* = (0.9) and 14.4 (*SE* = 0.7) for the successive plays (Figure 1). Changes in HR, HRV, and GSR are depicted in Figure 2, which appear to coincide rather loosely with the overall activity. Changes in ECA in the alpha range (8-12 Hz) are shown in Figure 3. General suppression of ECA is apparent compared to the resting state in F3, Fz, F4, C3, Cz, C4, T5, T6 P3, Pz, P4, O1, Oz, and O2, whereas none is found compared to movement controls. All site/frequency combinations of combined gender and play groups were correlated to performance (game score), with the highest ($r$ = .47; signed $r^2$ = -22%) at F3 at 9-9.5 Hz. This and the different correlation spectra for each play stage and gender are depicted in Figure 4. Correlational topographies at 9-9.5 Hz are shown in Figure 5. Maximum signed $r^2$ for males was -38% at Fpz, and for females was -14% at T3.

Multiple hierarchical regression was used in keeping with the General Linear Model to economically determine the influence of each variable on the game score. These analyses were significant ($p$ < .05) at each step on the log transformed EEG data of F3 at 9-9.5 Hz ($R^2$ = .200), with HRV ($R^2$ = .239), play stage 1 (vs stages 2 and 3; $R^2$ = .281) and gender ($R^2$ = .425; accumulated, adjusted $R^2$, final $df$ = 81) on the score.

## Discussion

As anticipated, performance, as measured by lap time, improved slightly between the first and second play conditions where learning apparently occurred, followed by a decrease in performance with the

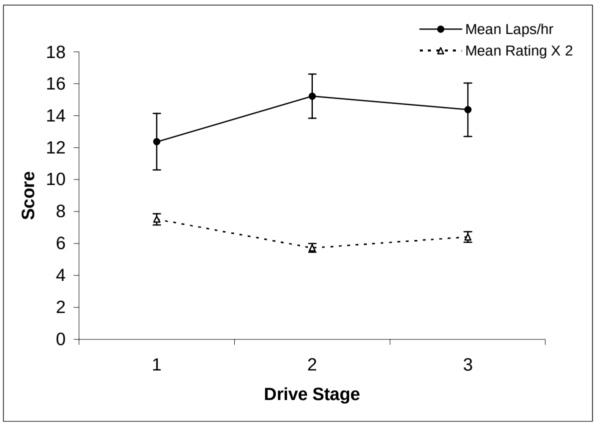


Figure 1: Performance and difficulty rating for each driving stage. Vertical lines depict standard errors of the means.

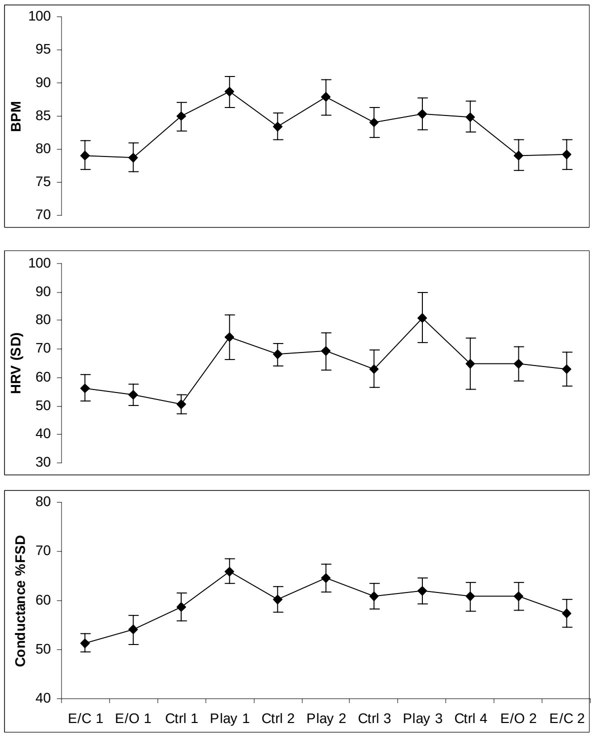


Figure 2: Heart rate, heart rate variability, and galvanic skin response for each session: play, limb movement (Ctrl), and at rest with eyes open (E/O) and eyes closed (E/C). Vertical lines depict standard errors of the means.

introduction of the third and more difficult play condition (Figure 1). General alpha reduction, particularly in the central, parietal and occipital areas, was found for both play and control motor activity relating to unskilled movement. Unlike the simpler Mills and Cross (2001) study, no skill-related alpha suppression was found during any play condition nor a decrease in any suppression evident as the participants improved in the game (Figure 3). The general suppressions are consistent with those Mann, Sterman, and Kaiser (1996) [for F3 , F4, C3, Cz, C4, T5, T6 P3, Pz, and P4], and Schier (2000) [for F3, F4, P3, and P4].

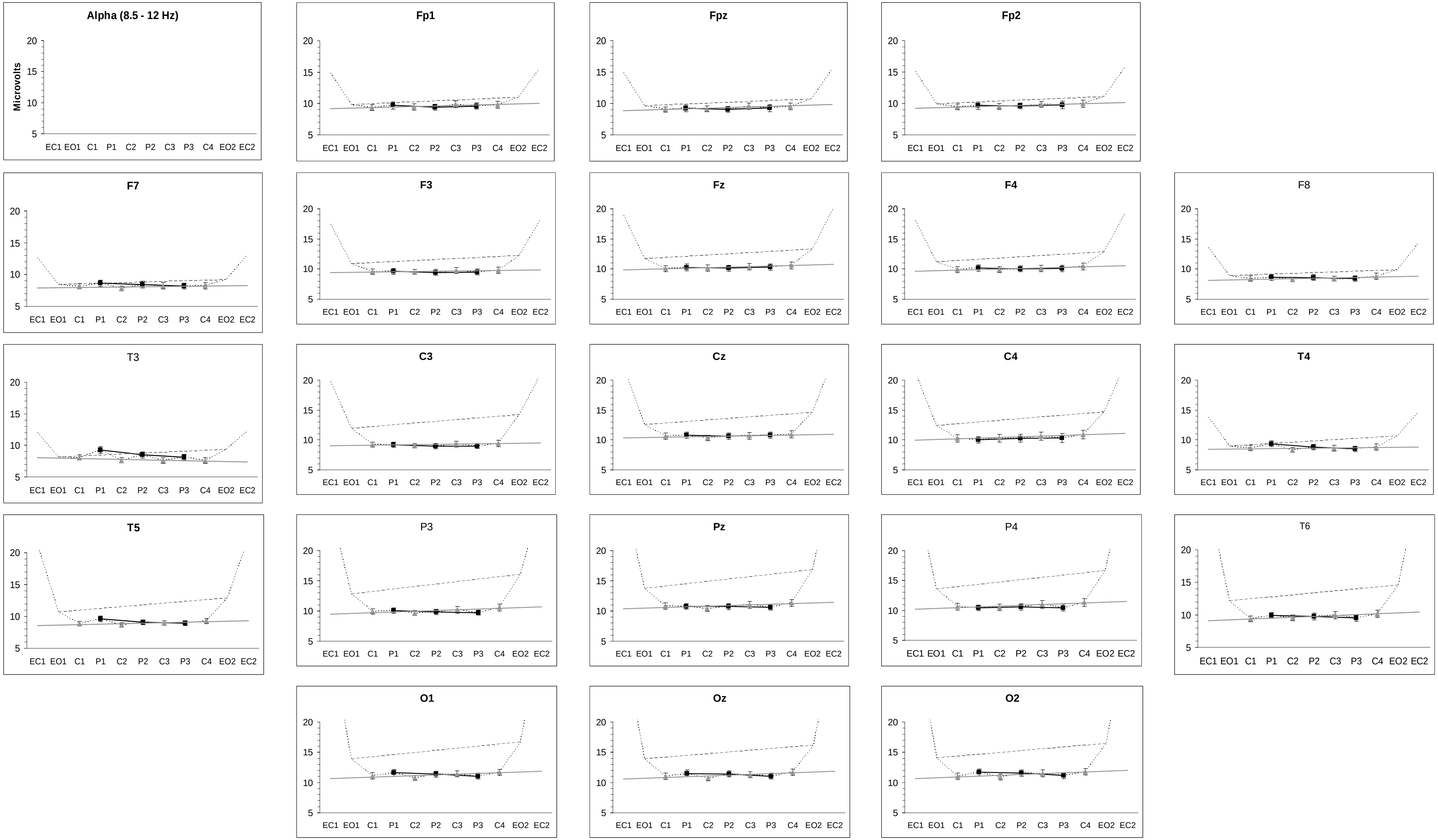


Figure 3: Mean and standard error of electro-cortical activity (μV) at alpha (8-12 Hz) for play (P), limb movement (C), and at rest with eyes open (EO) and eyes closed (EC).

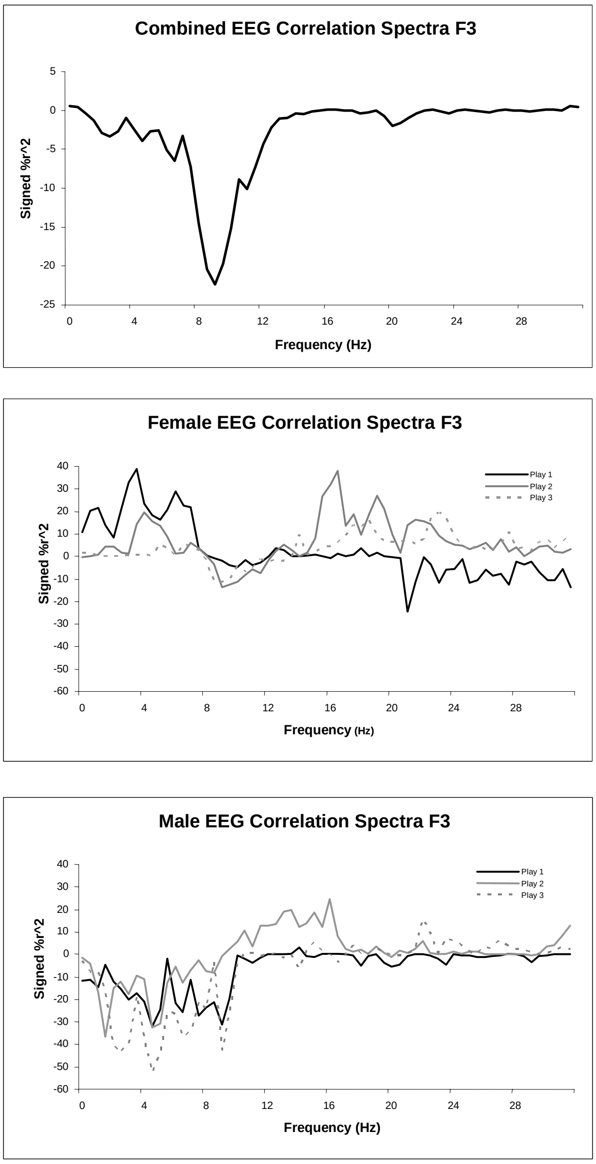


Figure 4: Correlation spectra of combined and separate gender and play event groups of ECA correlated to game score.

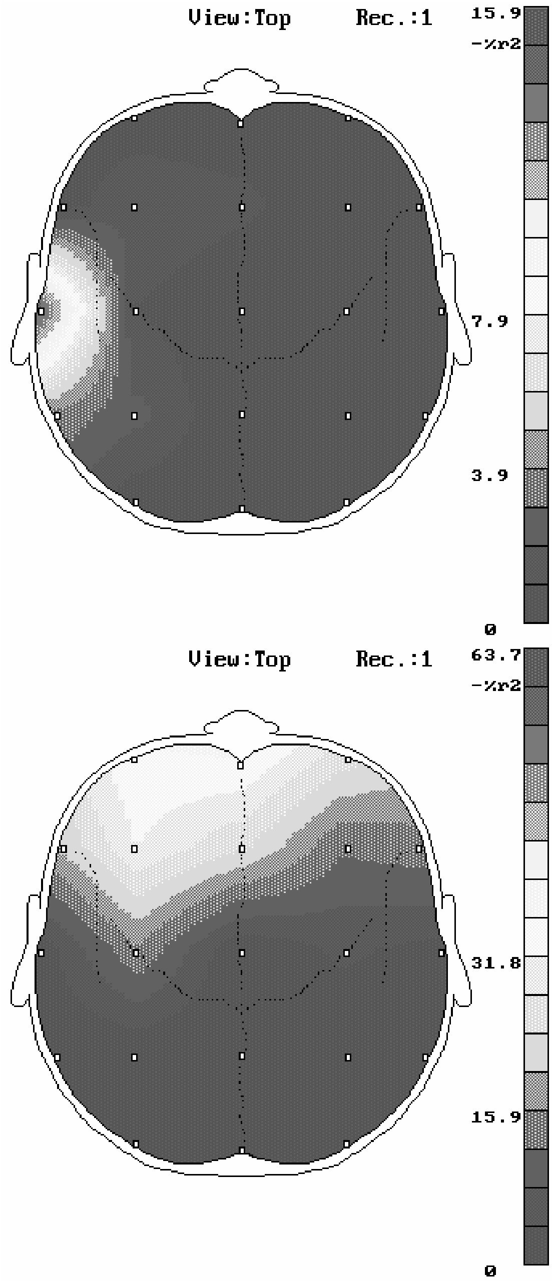


Figure 5: Correlation topographies (signed $r^2$) ECA 9-9.5 Hz correlated to game score of female (upper) and male (lower) for the first play.

There are, however, other psychological factors that may be considered to have contributed toward achieving these results: fatigue, task difficulty, attention, and stress. The subjects evidently found the first play harder than the second, while the increased difficulty was reflected in their ratings of the last game. The sympathetic measures for HR, HRV, and GSR showed an increase while performing, with an overall general decline in stress measures from the first play condition (Figure 2), while a slight increase in HRV was associated with performance. Unlike Mann, Sterman, and Kaiser (1996), who found no change with fewer (21) drivers, the current study agrees with the HR increases in pilots found by Hankins and Wilson (1998). It was anticipated that the third play condition should increase the participants' stress level as task difficulty was increased; however, the measures taken do not fully support this. Both a degree of arousal and attention are necessary to allow for skill mastery. It is therefore considered that the task difficulty may not have been sufficiently increased, or that other factors such as fatigue and learning may be at least partly responsible for opposing this expected change.

Research by Sterman and Mann (1995) showed that alpha activity in pilots is suppressed during performance of difficult tasks mainly at medial areas of the frontal, central and parietal electrode sites; and it decreased over time, presumably as participants learned the task, reflecting the transition to non-declarative memory. Other research by Mann, Sterman, and Kaiser (1996) and Schier (2000) has shown similar patterns of alpha suppression in individuals performing a driving simulation task. As participants became more familiar with the driving or flying task, less attention was required, and the amplitude of alpha activity increased.

Changes in electro-cortical activity of 4-7 Hz (theta) have also been shown to accompany motor activity and motor learning. While Hankins and Wilson (1998) found a decrease in theta under intense actual aircraft landing, a study performed by Laukka, Järvilehto, Alexandrov, and Lindqvist (1995) found that levels of theta activity of the forebrain increased as participants learnt and performed a simulated driving task. However, in the current study, no theta changes were evident, perhaps as it was less demanding cognitively.

Given that gender significantly predicted outcome, inspection of each contribution at F3 shows the inverse alpha and theta correlation is greater in males (Figure 4) while positive theta correlation occurs with females. Males actually had a higher $r^2$ of 38% at Fpz, while for females it was 14% at T3 (Figure 5). Gender differences in electro-cortical activity have been found by Rescher and Rappelsberger (1996) in the EEGs of males and females performing a tactile discrimination task. The potential remains to make performance predications from larger sets of such data, but this group is rather small, which would limit its generality.

## Conclusions

Performance on the driving simulator improved as learning occurred.

No suppression of alpha activity could be seen when participants experienced the first play condition.

As participants mastered the game on successive play conditions, no decrease in any suppression of alpha activity could be seen.

No increases in actual or perceived task difficulty lead to increased alpha suppression.

While correlation to performance was found in many sites, the maximum was found in the left frontal area, consistent with the motor association cortex controlling the right hand and leg that were used.

Gender was an important predictor of performance, these males performing better (faster), even when factoring previous experience.

Males used a different part of the brain than females.

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