

Skilled Motor Learning and EEG with PacMan

Malcolm Mills (millsm@usq.edu.au)

Don Brinkworth

Department of Psychology, University of Southern Queensland, QLD 4350 Australia

Abstract

The brain activity changes that accompany motor learning in both the skill and the cognitive development stages were monitored at 21 locations on the scalp by the electroencephalograph (EEG) during the playing of a simple "PacMan" computer game. As predicted, the maximum changes in the electrocortical activity occurred along the sensory motor strip reflecting finger movement and the frontal and temporal areas reflecting cognitive learning in the initial play phase. As familiarity with the task improved with practice there was a reduction in activity in frontal sites and a change in the dominant frequency bands along the sensory motor strip that indicated the basic skills had been learned. Further, increased mastery of the task during latter play stages were preceded by a further temporary engagement of frontal and temporal areas suggesting a modification of cognitive strategy. Predictors of these changes were also found in theta, alpha, and lower beta frequencies. Low beta is associated with focused awareness while associated reduction of activity was noted in the alpha band (disengagement) to coincide with increased activity in the beta bands (engagement). Not only was it possible to predict changes in performance scores from the changes in cortical activity, but also it should be possible to predict whose would give the better performance.

Introduction

The purpose of this study is to investigate the connection between skilled motor learning, task mastery and EEG output. During skilled motor learning, states of attention, cognitive load and autonomic arousal may be involved. Aside from basic knowledge considerations, there is a growing recognition of the importance of understanding human motor performance (both learned ability and attention to task) in transport safety ~ particularly when tiredness or overload occur as well as in video game performance (Baba, 1993; Cross, 2002; and Mills and Cross, 2003). It would be useful to show EEG changes as a predictor of performance. An article by Sterman and Mann (1995) revealed a measurable suppression of "alpha" activity in the 8 - 12 Hz spectrum, corresponding to the post-reinforcement synchronisation in cat, in aircraft pilots manoeuvring for in-flight refuelling and with flight simulator landing sessions. A well-established cellular understanding of EEG synchronisation as generated by the thalamus has been reviewed (Steriade et al 1990). This study starts by looking at a very simple motor task (playing a computer "PacMan" game: PAC PCII), which requires minimal motor activity: using the four arrow keys of a keyboard in response to a slow moving target moving in two perpendicular dimensions. In addition, performance was measured by the game score

achieved. (In practice this was somewhat arbitrary, given the random nature of "bonus points" being only occasionally available). The performance was repeated after five minutes: hence short-term learning was examined.

Heart rate (HR) and heart-rate variability (HRV) and skin conductance, as measures of autonomic arousal, were also taken to assess sympathetic or stress changes as shown (with heart) by Backs, Lenneman and Sicard (1999), and Hankins and Wilson (1998). The HRV calculations are an alternative indicator of sympathetic activity that can be more specific in some conditions than heart rate.

Event related EEG changes can be assessed by determining if EEG differences occur during play/no-play conditions; performance related EEG effects can be made from correlations of EEG with the game score – and are consequently more specific, as incidental, unproductive activity can occur during the event.

Aim and Hypotheses

The aim was to determine which sites and frequencies best predict performance, that these sites and frequencies will change with different task difficulty levels (slow and fast speed), and that these changes will indicate that learning (how to obtain a high score) has taken place. Predictions as to who will perform best should also be possible.

The hypotheses proposed are:

There is a relationship between event-related changes in EEG magnitude at frequencies and sites with PacMan performance scores.

It should be possible to identify what frequency and location would be expected to best predict stages of performance.

The sites and frequencies that best predict performance will change with changes in task difficulty (levels of game speed).

Material and Methods

Nineteen subjects (aged 17 – 35), 17 female, 2 male, were asked to sign consent in participation. All were psychology students; five were on electro-physiologically benign medication. All but one were right handed (as defined by preferred operating hand). All reported limited experience with computer games generally and this game specifically in the past 20 years (17 less than 50 hours, one 50 - 500 hours and one 500 - 3000 hours). The galvanic skin response (an index of sympathetically generated sweating) was measured with a "Relax Plus" instrument (Ultramind Limited, London, UK). Two steel GSR electrodes were placed on the

first and third fingers of the non-dominant (usually left) hand. The computer displayed readings, in arbitrary units, were recorded manually every 30 seconds. Heart rate was measured from the second finger of the non-dominant hand by a wrist pulse monitor (supplied by the Department of Nursing, USQ, Australia) connected remotely and taped to an adjacent bench. These readings were recorded manually every 30 seconds and means taken for the stages five minute epochs. Heart-rate variability (standard deviation of heart rate) was also calculated for each stage. EEG recordings were made with a "Brain Atlas" device (Bio-Logic Systems Corp., Mundelein, IL, USA). Subject scalps were exfoliated with "Newprep" skin gel (D. O. Weaver and Company, Aurora, CO, USA), and "Electro-Gel" electrode paste (Electro-Cap International, Inc., Eaton, OH, USA) used for conductivity. A 21 lead cap was selected for best fit (using the nasion toinion method) and this was connected to the isolated amplifier and computer interface. EEG was recorded from 20 scalp sites using Ag/AgCl electrodes embedded in an electrode cap (Electro-Cap International Inc., Dallas, TX, USA). These sites were: Fp1, Fp3, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, O2 of the International 10-20 system (Jasper 1958). Fpz was calculated by interpolation and for the first slow game Oz was used for event marking only in two subjects or with the signal in seven more subjects. All resistances were below 10 KOhm and amplifiers (gain 20,000) were allowed to calibrate automatically prior to recording. A 37 Hz high filter, 0.3 Hz low filter and 50 Hz notch filter were used. The game was played at a slow speed (n=9) or a fast speed (n=10). Subjects were seated in a dentist's electro-mechanical adjustable chair in front of a computer monitor and the room was darkened. Seven stages followed of five minutes each: Subjects were asked to close their eyes and to avoid talking; then to look at the computer monitor showing the moving game target; then to also move their fingers on the arrow keys (only two minutes for the fast game); then to play the game while game scores were recorded; then to repeat stage 3; to repeat stage 4; and finally to repeat stage 3. This was repeated either immediately (fast game) or the following week (slow game) having spent an hour practising at the fast speed. The session then concluded with the electrodes being removed and the subjects cleaned up. The change from the first to second stage allowed immediate physiological validation as well as giving time to allow the system to stabilize. The change between the next two stages allowed to check the effect of moving fingers, which served as the control period and which bracketed the experimental periods to control for any systematic change over the remaining session. The second play period was to assess any short term learning effect. Raw data were subjected to Fourier transformation (with Hanning window enabled) and expressed as μV . Delta 0 – 3.5 Hz, theta 4 – 7.5 Hz, alpha 8 – 11.5 Hz, beta 12 – 15.5 Hz frequency bands were used. Eye activity was designed to be very similar over stages 2-7

where the target was continually tracked. However, a manual artifact reduction was performed off-line, as conducted by Sterman and Mann (1995).

Results

Game scores are shown in Figure 1. Most improvement was found after the second game at both speeds (difficulty level), while the faster game showed lower scores.

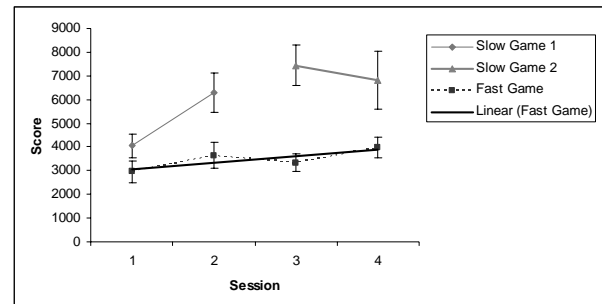


Figure 1: Scores (and SE) for groups playing the slow and fast game. A week elapsed between play 2 and 3 in the slow game.

Alpha suppression was evident for the play condition for both game speeds, and more so in the fast game (Figure 2, 3a & 4a). This is reduced after practice (Figure 3b). High correlations were found at Cz at 9 Hz and Fz at 2 Hz as shown in Figures 4b and 5. To normalize, the data were transformed into their natural logarithm after Sterman, Mann, Kaiser, and Suyenobu (1994). Sequential multiple regression analysis provided progressive increases in the adjusted coefficient of determination for Cz at 9 Hz ($R^2 = .137$), heart rate ($R^2 = .325$), speed ($R^2 = .410$), play 1 vs plays 2-4 ($R^2 = .506$) and log Fz at 2 Hz ($R^2 = .583$; final $df = 55$, all at $p < .01$). In this model, all predictors provide appreciable (more than about 8%) of the variance.

Discussion

Subjects evidently learn the PacMan game as their scores progressively improved (Figure 1). The differences between playing and not appear more posterior than the sensory-motor strip (Figures 2, 3a and 4a). It seems alpha suppression from playing reduced from week 1 to 2 (Figure 2, slow game), although a general increase in alpha is evident in each daily session. Initial slow game playing shows suppression of parietal-occipital alpha (Figure 2) and "learning" (play 4 vs play 1) shows a reversal of posterior alpha suppression (Figures 2 and 3b). In the fast game anterior and posterior alpha suppression is seen (Figure 2), but the correlations (for both the first and best predicting play and the combination of all fast plays) are seen to the centre and anterior especially at Cz and Fp1 (Figures 4b and 5). Spectral analysis of the

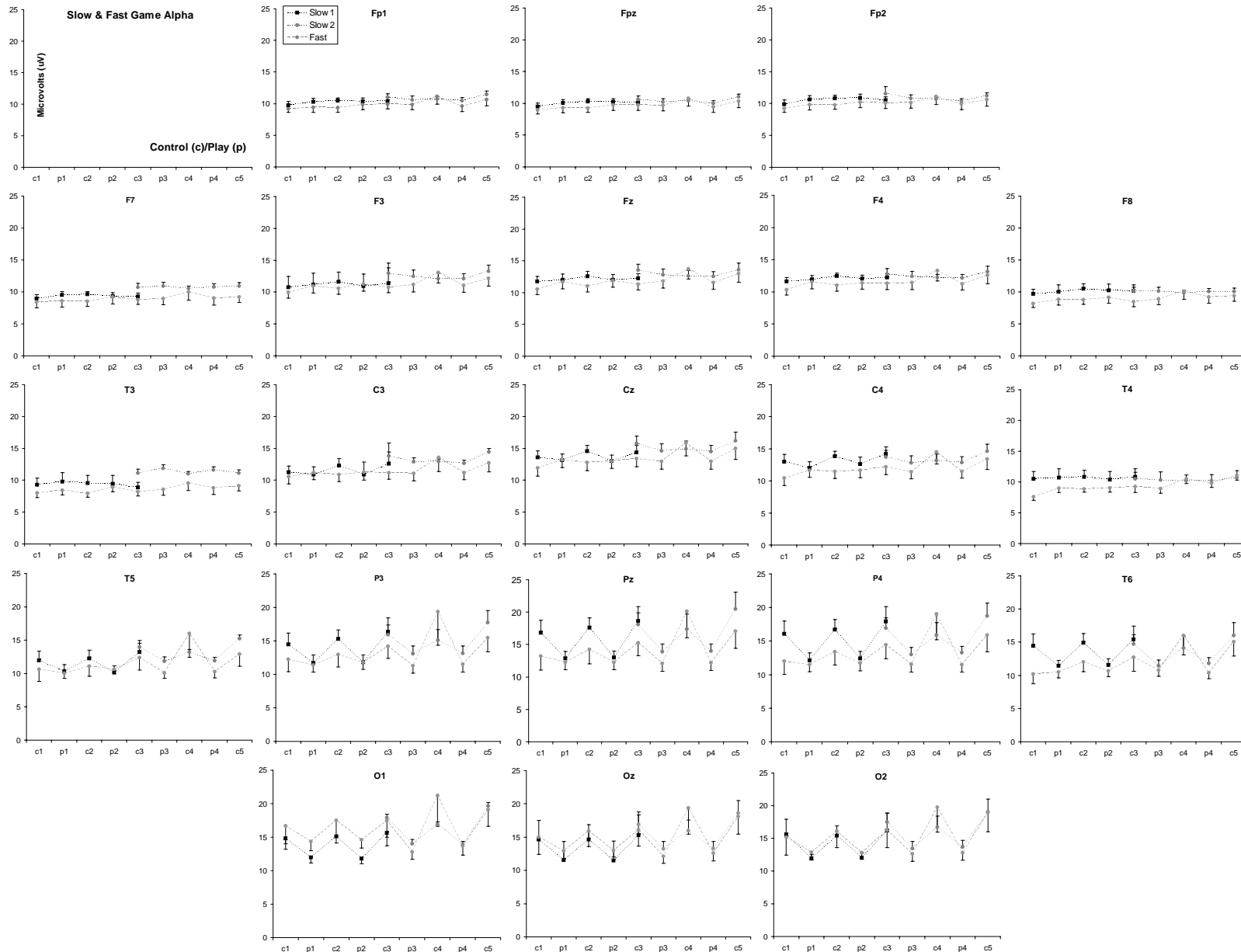


Figure 2: Fast Fourier transformed electro-cortical activity (μV) for each play and control session at alpha (8-12 Hz)

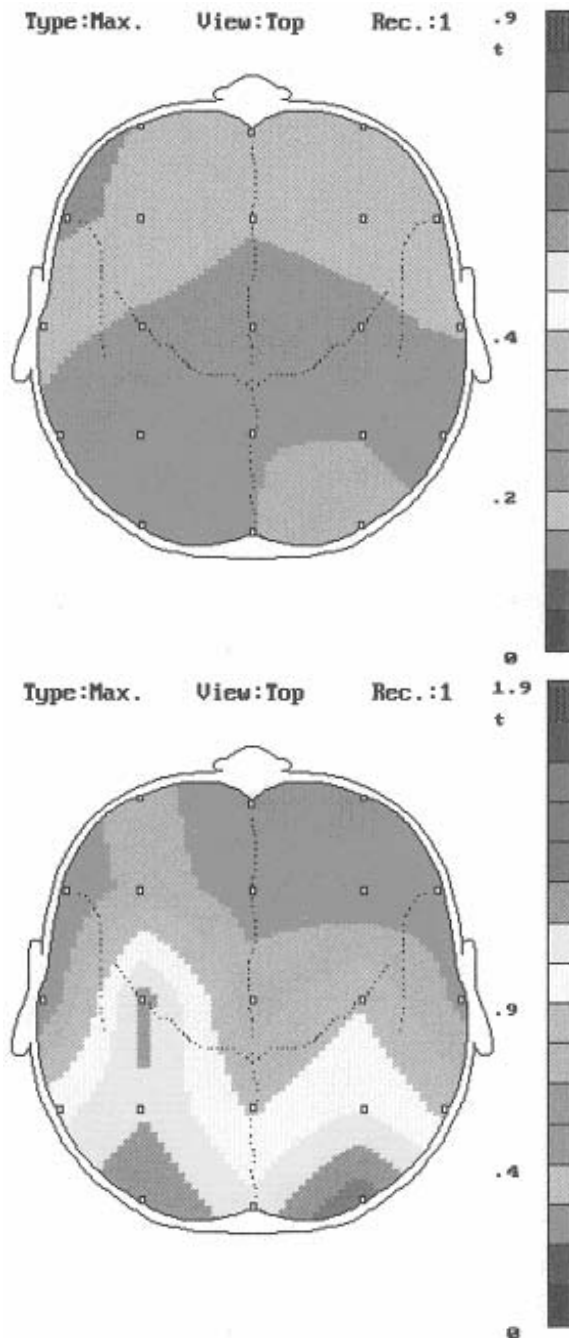


Figure 3: Slow game alpha (8-12 Hz; t-scores):
3a, control vs play 1; 3b play 4 vs play 1.

correlation to game score for these shows peaks in the 9 Hz for Cz and 2 Hz for Fz. These correlations and suppressions correspond to increased (9-13 Hz) somatosensory parietal “cortical alpha rhythm” and (11-13 Hz) motor/pre-motor sensory-motor rhythm, where sensory encoding occurs with reduced “high alpha” (11-15 Hz) and cognitive processing with reduced alpha (8-12 Hz; Serman and Mann 1995). The general posterior alpha suppression was indicative of general visual sensory engagement: attention; however, the skill factor revealed by the regression seems more anteriorly focused at Cz and Fz in the supplementary motor cortex

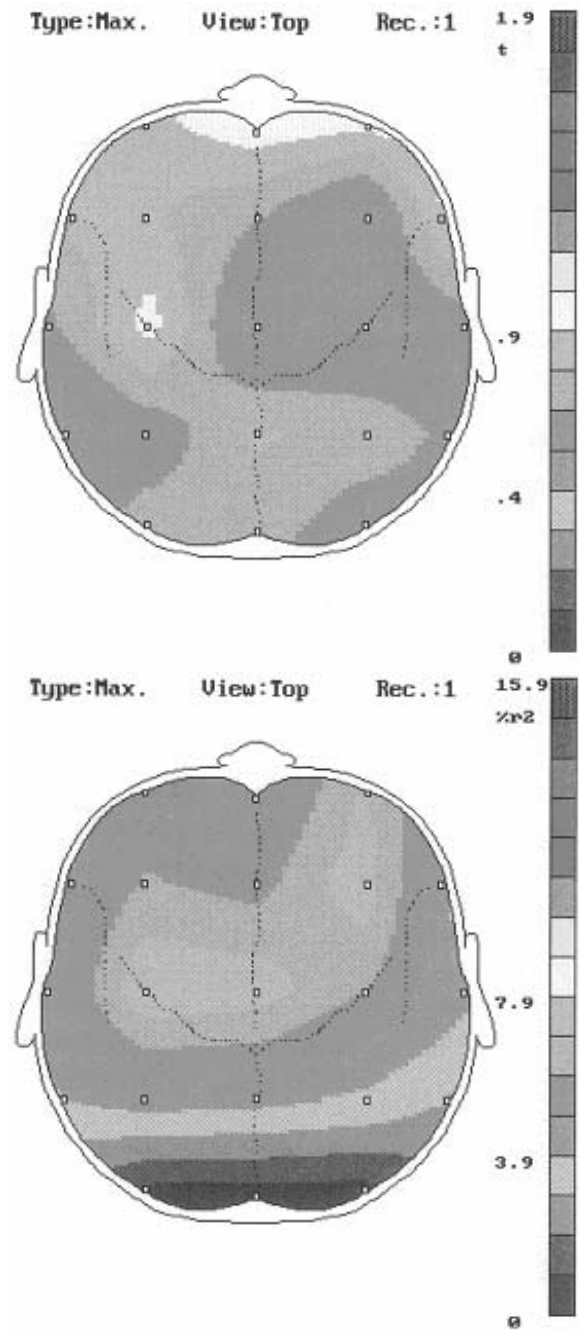


Figure 4: Fast game alpha (8-12 Hz): 4a, control vs play (t-scores); 4b, play 1 percent squared positive correlation to game score.

(as with Hikosaka, et al, 1996): 58% of this variance being predictive of score. Finally, the fast game physiology differed from the slow game, which was generally considered very easy. The superiority of correlational versus differential analysis is exemplified here: the prediction comes from the frontal, not posterior area. There are several psychophysiological states worth considering with this type of motor learning study: attention, focused concentration, arousal, and stress. A significant stress level is evident in this regression model, with HR better than the other two sympathetic measures: heart rate variability and

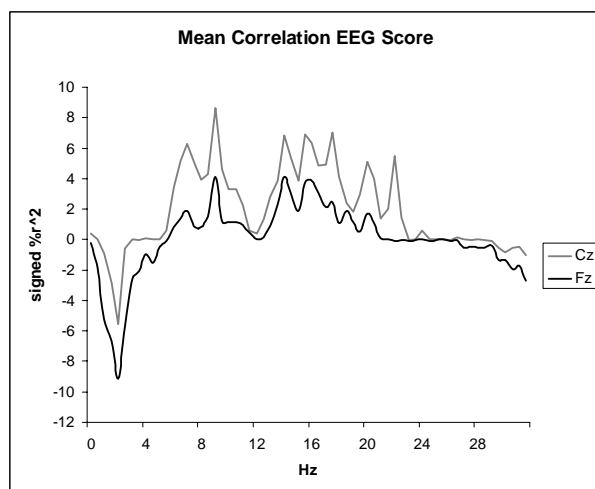


Figure 5: Correlational spectra of Cz and Fz electrode sites with maxima of 9 Hz (Cz) and 2 Hz (Fz).

galvanic skin resistance (which monitors sweating). A degree of arousal would be necessary to perform this task, while attention would be vital, but would change from declarative to procedural learning. Another aspect relates to cognitive overload, and a similar profile to stress and performance would be expected, where a bell shaped response to task-demand and performance would appear from the Yerkes-Dodson Law (1908). Changes in EEG magnitude at certain frequencies and sites may well also predict who will perform best.

Conclusions

Score improved (as subjects learn);
 Several electrode sites' μV are suppressed with play;
 This suppression was reduced with learning;
 The electrode potential at Cz (9 Hz) and Fz (2 Hz) and HR were able to predict PacMan scores.

Acknowledgments

Thanks to David Lalor for demonstrating and help in setting up and recording with the EEG equipment and Ross Bool for technical assistance.

References

Baba, D. (1993). Determinants of video game performance. In J. L. Starkes & F. Allard (Eds.), *Cognitive Issues in Motor Expertise*. New Holland, Amsterdam: Elsevier Sciences.

Backs, R. W., Lenneman, J. K., & Sicard J. L. (1999). The use of autonomic components to improve cardiovascular assessment of mental workload in flight simulation. *The International Journal of Aviation Psychology*, 9 (1), 33-47.

Cross, N. Y. B. (2002). Electroencephalograph (EEG) as predictor of motor performance. Unpublished manuscript.

Hankins, T. C. & Wilson, G. F (1998). A comparison of heart rate, eye activity, EEG and subjective measures of pilot mental workload during flight.

Aviation, space and Environmental Medicine, 69 (4) 360-367.

Hikosaka, O., Sakai, K., Miyauchi, S., Takino, R., Sasaki, Y., and Puetz, B. (1996). Activation of human presupplementary motor area in learning of sequential procedures: A functional MRI study. *Journal of Neurophysiology*, 76, 617-621.

Jasper, H. (1958). The ten twenty system of the International Federation. *Electroencephalography and Clinical Neurophysiology*, 10, 371-375.

Mills, M. H. & Cross, N. (2003). *PacMan and the seat of learning*. Poster session presented at the 4th International Conference on Cognitive Sciences, Sydney, Australia.

Steriade, M., Gloor, P., Llinas, R. R., Lopes da Silva, F. H., & Mesulam, M. M. (1990). *Brain mechanisms of cerebral rhythmic activities*. *Encephalography and Clinical Neurophysiology* 76, 481-508.

Serman, M. B., & Mann, C. A. (1995). Concepts and applications of EEG analysis in aviation performance evaluation. *Biological Psychology*, 40, 115-130.

Serman, M. B., & Mann, C. B, Kaiser, D. A. and Suyenobu, B. Y. (1994). Multiband topographic EEG analysis of a simulated visuomotor aviation task (1994). *International Journal of Psychophysiology*, 16, 49-56.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit formation. *Journal of Comparative and Physiological Psychology*, 18, 459-482.