THE NEUROPSYCHOLOGICAL MEASURE (EEG) OF FLOW UNDER CONDITIONS OF PEAK PERFORMANCE

by

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DECLERATION

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I declare that **THE NEUROPSYCHOLOGICAL MEASURE (EEG) OF FLOW UNDER CONDITIONS OF PEAK PERFORMANCE** is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

5 June 2014

F.G. DE KOCK DATE

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ABSTRACT

Flow is a mental state characterised by a feeling of energised focus, complete involvement and success when fully immersed in an activity. The dimensions of and the conditions required for flow to occur have been explored in a broad spectrum of situational contexts. The close relationship between flow and peak performance sparked an interest in ways to induce flow. However, any process of flow induction requires a measure to trace the degree to which flow is in fact occurring. Self-reports of the flow experience are subjective and provide ad hoc information. Psycho-physiological measures, such as EEG, can provide objective and continuous indications of the degree to which flow is occurring. Unfortunately few studies have explored the relationships between psycho-physiological measures and flow. The present study was an attempt to determine the EEG correlates of flow under conditions of peak performance.

Twenty participants were asked to perform a continuous visuomotor task 10 times. Time taken per task was used as an indicator of task performance. EEG recordings were done concurrently. Participants completed an Abbreviated Flow Questionnaire (AFQ) after each task and a Game Flow Inventory (GFI) after having finished all 10 tasks. On completion, performance times and associated flow scores were standardised where after the sample was segmented into a high flow - peak performance and a low flow - low performance level. Multi-variate analysis of variance (MANOVA) was conducted on the performance, flow and EEG data to establish that a significant difference existed between the two levels. In addition, a one-way analysis of variance between high and low flow data was conducted for all variables and main effects were established. Inter-correlations of all EEG data at both levels were then conducted across four brain sites (F3, C3, P3, O1). In high flow only, results indicated increased lobeta power in the sensorimotor cortex together with a unique EEG pattern showing beta band synchronisation between the prefrontal and sensori-motor areas and de-synchronisation between all other areas, while all other frequencies (delta, theta, alpha, lobeta, hibeta, and gamma) remained synchronised across all scalp locations. These findings supported a theoretical neuropsychological model of flow.

Key words

Psycho-physiological; Flow; Performance; Power; Synchrony; De-synchronisation; EEG correlates; EEG marker; Visuomotor task.

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CHAPTER 1

GENERAL ORIENTATION

1.1 INTRODUCTION

Peak performance is often associated with an optimal state of mind which in sporting terms is better known as ‘the zone’ or ‘the groove’. In this mind state body and mind are working together in a super-efficient manner. In psychological terms, this phenomenon is called ‘flow’. In sport psychology, flow is associated with high intensity, strong focus, superior performance (Young, 2000), and peak experience (Murphy & White, 1995), which are accompanied by heightened awareness and intrinsic motivation (Frederick-Recascino & Morris, 2004). Young and Pain (1999) reported that ‘the zone’ or flow state is a universal phenomenon associated with peak performance across sporting codes. Flow is associated not only with sport performance but also with performance in general, and so is an important aspect of coaching, training, and consulting at the individual and group level. It applies to sport and to the commercial and leisure environments.

Flow theory, developed by Csikszentmihalyi (1975), has been studied for more than 30 years, mostly from a positivistic paradigm, in many situational contexts, such as computing (Trevino & Webster, 1992; Webster, Trevino, & Ryan, 1993; Chen, Wigand, & Nilan, 1999); occupational therapy (Jacobs, 1994; Emerson, 1998); family interaction (Csikszentmihalyi & Rathunde, 1993); leisure (Csikszentmihalyi & LeFevre, 1989; Graef, Csikszentmihalyi & Gianinno, 1983); schooling (Carli, Delle Fave & Massimini, 1988; Clarke & Haworth, 1994; Moneta & Csikszentmihalyi, 1996); sports (Jackson & Roberts, 1992; Stein, Kimiecik, Daniels, & Jackson, 1995; Kowal & Fortier, 1999;); and video gaming (Cowley, Charles, Black & Hickey, 2008). The body of evidence from the above research indicates a strong positive relationship between flow and peak performance.

Csikszentmihalyi (1975) defined flow as the mental state of operation in which the person is fully immersed in what he or she is doing, characterised by a feeling of energised focus, full involvement, and success in the processing of the activity. He also defined it as an experience of being completely immersed in an activity such that heart, will and mind are in harmony. According to him, the value of flow is that it pushes people to increasingly higher levels of performance. Following flow people report subjective experiences of challenge-skills balance, concentration on the task at hand, action-awareness merging, sense of control, loss of self-consciousness, transformation of time, and autotelic experience (Csikszentmihalyi, 1997).

Peak performance is defined as “behaviour which exceeds one’s average performance” (Privette, 1982, p. 242) or as “superior functioning” (Privette, 1983, p. 1361), whilst Jackson and Roberts (1992, p. 156) viewed it as a “prototype of superior use of human potential”, including physical and mental involvement. Performance is also closely related to learning or practice, and follows an identifiable “S” curve which expresses the relationship between performance (as learning output) and efficiency. Fitts and Posner (1967) found that the learning process is sequential and that the learned skill eventually becomes automatic, involving little or no conscious thought or attention, but displaying the ability to self-correct and make minute adjustments. This autonomous phase of skill acquisition mirrors action-awareness merging, also described as absorption or immersion, characteristic of flow and considered one of the clearest indications that someone is experiencing it (Csikszentmihalyi, 1975; Jackson & Wrigley, 2004).

Contrasting flow and peak performance, Jackson and Wrigley (2004, p. 426) postulate that peak performance refers to an outcome or achievement of superior functioning rather than to an internal experience of optimal feelings and perceptions. Optimal experience (flow) describes an inner psychological state while engaged in an effortful and challenging activity, whereas peak performance refers to outcome or accomplishment as a consequence of a person’s effort and sustained concentration. In summary, ‘peak performance’ refers to an outcome rather than an experience, whilst ‘flow’ refers to the psychological experience accompanying the peak performance. The flow experience motivates people to re-engage the same activity, but in order to re-experience flow, performance has to be raised to a new, higher level.

Flow is measured by means of post-hoc questionnaires drawing on the subjective experience of behaviours during performances. It cannot be directly evaluated or observed by others, whereas peak performance is objectively quantifiable by observations through direct measurement and comparison to previous or other performances. Reflecting on the above comparison, Kimiecik and Stein (1992) argued that peak experience and flow are subjective in nature, whereas peak performance is about objective results. Csikszentmihalyi (1993) postulated that flow is tangentially related to peak performance, indicating that both phenomena can occur at the same time, or perhaps as two sides of the same coin.

Since flow is so closely associated with peak performance it becomes an important aspect of performance, irrespective of activity, and an attractive concept for utilisation by coaches, trainers and supervisors in pursuit of consistent, top-level performance with the added advantage of experiencing enjoyment and satisfaction from the performance.

However, the dilemma for the consultant or coach is that since flow is invisible to direct objective observation or measurement it is extremely difficult to teach people to enter it, to know how long they have been in it, or whether they were in it at all. It is therefore important to find a mechanism through which flow can be observed in real/humanly measured chronological time, objectively and accurately. If this is possible it will facilitate clearer links between flow, behaviour, and performance and thus improvements in the design of empirical, measurable behavioural/psychological skills to induce, sustain, and tap its value.

Having an objective measure of flow will also enable researchers to provide answers to questions such as:

(1) Is the occurrence of flow limited to peak performances only or is it also possible during lower levels of performance?
(2) Is flow influenced by learning and experience?
(3) Is there a neuropsychological correlate for peak performance and, by implication, for flow?

In search of an objective measure for flow, the author reverted to neurophysiological measures, such as the electroencephalogram (EEG), to determine a set of EEG correlates that can be used as a neurophysiological marker and objective measure of flow. Since technology has evolved to such a level that EEGs are being recorded using laptop computers, wireless applications and headsets with electrodes, EEG technology can be used in the consulting and coaching environment as an indicator of flow.

However, using neurophysiological means to measure behavioural aspects has its own challenges. According to Chalmers (1995), there is an explanatory gap between matter and sensation that has not yet been satisfactorily bridged, whether by neuroscience, cognitive science, neuropsychology, phenomenology, or systems theory. Chalmers states that "the hard problem [is] the question of how physical processes in the brain give rise to subjective experience", that is, how the physical and mental faculties interact.

Werner (2008) proposed that a 'state space' approach be adopted in viewing the brain's states as neural patterns in a two-dimensional space. In state space, reconfiguration of the neurological system is expressed as a change in the correlation function between micro-system elements. Flow is purported as an altered, heightened state of consciousness, which implies that, from a cognitive- and neuropsychological perspective, it is possible to identify a unique network of neural structures and processes under conditions of peak performance that represent the flow state.

From a neuropsychological perspective, consciousness is considered hierarchically ordered, with the pre-frontal cortex at the top of the hierarchy, representing the neural basis of higher order cognitive functions, supported by the temporal, occipital, and parietal cortices (TOP), and limbic structures, which together provide the lower order or primary neural circuitry for consciousness (Dietrich, 2003). The dorsolateral pre-frontal cortex (DLPFC) is considered the higher order seat, and the thalamus the lower order seat of central processing (Fuster, 2000; Dietrich, 2003). Sensory information is fed into the thalamus and distributed to other centres (including memory) for encoding, then to the DLPFC for higher order processing, which then returns the information to the thalamus for action responses. The thalamus processes information, presumably in 'bottom-up' fashion, through a two-track circuit, one for cognitive processing, via the hippocampal formation and TOP cortices, which are mainly linked to perception and long-term memory; and one for emotional processing, via the amygdala, anterior cingulate cortex and the ventromedial pre-frontal cortex (Damasio, 1994). Emotional processing involves the computation of information in a non-algorithmic, skilled-based manner associated with self-discipline, achievement, self-esteem and confidence (Churchland, 2002). Each system keeps a record of its activity so that emotional memory is part of the emotional circuitry and perceptual and conceptual memory is part of the cognitive circuitry.

Although there are multiple connections at various levels between the two information processing systems, full reintegration of emotional and cognitive information does not appear to happen until both types of computations converge back on the DLPFC (LeDoux, 1996). In addition to the type of information (emotional or cognitive), the brain also operates two distinct information processing systems to acquire, memorise, and represent knowledge. Once information has entered the sensory system and is coded with a cognitive and/or emotive tag it is further processed, presumably by the DLPFC in ‘top-down’ fashion, by either or both the explicit or implicit information processing system that contains both cognitive and emotional information. The explicit system is rule-based, with its content able to be expressed by verbal communication, and it is tied to conscious awareness (Dietrich, 2004). In contrast, the implicit system is skill or experience-based, with its content not able to be verbalised but only conveyable through task performance. It is inaccessible to conscious awareness (Ashby & Casale, 2002; Dienes & Perner, 1999).

The process of skill acquisition starts as a conscious process during which attention is focussed on the goal of acquiring explicit knowledge regarding the composition and execution of the skill (Fitts & Posner, 1967). The pre-frontal cortex (PFC) and anterior cingulate cortex (ACC) are strongly engaged early in the learning cycle, when stimulus-response mappings are actively being established (Jenkins, Brooks, Nixon, Frackowiak, & Passingham, 1994). During this phase performance is low and conscious effort is put into learning. As learning progresses through repetition, explicit knowledge becomes entrenched and transformed into implicit knowledge, whilst performance improves because fewer errors are made and therefore conscious attention is progressively freed up for other use. In later stages of learning, once contingency mappings have become consolidated, the frontal structures (PFC and dorsal ACC) exhibit a reduction in activity, while the posterior regions (basal ganglia circuit, including parietal, posterior cingulated, and parahippocampal cortices) demonstrate and increase in activity (Chein & Schneider, 2005; Luu, Tucker & Stripling, 2007; Toni & Passingham, 1999). An internalised (skilled) motor pattern is controlled entirely by this basal ganglia circuit and little pre-frontal activity is required; unconscious, effortless execution of the skill is achieved, which is characterised by a perception of ‘automaticity’. However, Toates (2006) argues that the link between conscious (explicit) and unconscious (implicit) processes is not entirely functionally severed following the progression to automaticity. Automatic processes are thus modulated by conscious intentions (such as goals, objectives or strategies), pointing to joint control and thereby integration between implicit and explicit controls, which highlights the importance of goal setting as a precondition for flow, linking focussed conscious attention and unconscious intrinsic motivation to peak performance.

It is postulated that during peak performance skill execution is implicitly controlled by posterior structures through the application of repertoires of automated reflexes and skilfully tweaked by input from explicit conscious adjustments by the fronto-limbic structures made in response to dynamic external changes in the task environment. This joint implicit/explicit control is supported or maintained by unambiguous dynamic feedback from the sensory system. When task efficiency is achieved by little or no correction from the explicit system, a perception of being controlled by ‘auto-pilot’ (a flow trait) is experienced. Since attention is fully and consciously invested (by the PFC) in the task environment, loss of self-consciousness (a flow trait) is experienced. Also, since the implicit system contains both cognitive and emotional information processing, the achievement of flow will include not only logical, time and spatial motor responses, but also emotional responses (for example, joy, happiness) associated with motivational and task behaviour.

A neuropsychological model for peak performance, and thus flow, is characterised by a neurological pattern representing a change in motor functioning from explicit to implicit control, as indicated by a shift in neural activity from the frontal networks to the posterior networks during peak performance. This neurological pattern is supported by neurological studies using EEG technology which suggest that superior performance is marked by mental economy, particularly of analytical associative processes, and that pruning of excessive cortico-cortical communication between such processes and motor regions underlies enhancement and consistency of psychomotor performance (Hatfield & Hillman, 2001).

Recent experimental evidence indicates that in later stages of skill acquisition or visuomotor performance, once contingency mappings have become consolidated, frontal structures (as indexed by F3/F4) exhibit a reduction in activity, while posterior regions (as indexed by P3/P4) demonstrate increased activity. Shifts in neural control occur as a function of practice so that the details of a motor task become gradually controlled by the basal ganglia circuit, which includes the supplementary motor cortex, the motor thalamus, and the hippocampus (indexed by P3/P4). Beta de-synchronisation and phase lags between different cortical areas are reported once a motor skill is completely internalised and controlled entirely by this basal ganglia circuit (indexed by P3/P4), and little pre-frontal activity is required, freeing up working memory and allowing executive attention (indexed by F3/F4) to fill its premium computational space with other environmentally relevant content that requires higher order processing (Logar et al., 2008).

Individuals performing at peak levels will therefore exhibit improved executive control over the fronto-limbic circuit through modulation by the dorsolateral pre-frontal cortex (F3). Consequently, individuals will experience decreased activation of the amygdala (less anxiety) and increased activation of the hippocampus (smoother motor control) in the limbic system (P3) (Janelle & Hatfield, 2008). In terms of EEG data, theta oscillations have been reported to represent a basic resonance phenomenon mediating the information flow through the hippocampus, thalamus, and frontal/temporal neocortex. Theta power is expected to decrease in the frontal region (F3). The resultant emotional reactivity, in turn, will lead to alpha synchrony, particularly in the left temporal (T3) and parietal (P3) regions, along with decreased cortico-cortical communication between these regions and the motor planning centres (Fz) (Deeny, Hillman, Janelle & Hatfield, 2003). Decreases in power in the lower alpha band have been linked to higher task demands and attentional processing. The EEG at T3 will thus show higher levels of alpha power (8–12 Hz) (lower task demand) as well as lower levels of beta and gamma power at Fz, implying less explicit (conscious) and more implicit (unconscious) attention to task execution (Haufler, Spalding, Santa Maria & Hatfield, 2000; 2002). This interpretation is consistent with the well-established notion of ‘automaticity’ during skilled motor performance in which advanced performers are unconscious of the details of their performance as they execute “in the moment” (Fitts & Posner, 1967; Schneider & Chein, 2003). The above regulation of the cerebral cortex will lead to consistent input to the motor loop, resulting in consistent cortico-spinal output and motor performance.

Synchronous gamma activity, associated with organising the brain, promoting learning, and allowing for mental sharpness, will occur in the thalamus and frontal (F3/F4), auditory (T3/T4), visual (O1/O2), and motor (C3/C4) and association (P3/P4) cortices, and likely contribute to the ‘binding’ of diverse information into a single coherent percept. All of these may well be associated with selective attention, transient binding of cognitive features, and conscious perception of visual objects (Hughes, 2008). Synchronous gamma activity is expected in all regions during peak performance.

Using the above model, it is hypothesised that individuals performing at peak levels, and thus experiencing flow, exhibit increased frontal (F3) and parietal (P3) theta power, increased sensori-motor (C3) and parietal (P3) alpha power, and decreased frontal beta and gamma power, as well as increased alpha synchrony between the sensori-motor (C3) and parietal (P3) regions along with beta rhythm de-synchronisation between the frontal (F3), sensori-motor (C3) and parietal (P3) areas.

Following the state space approach, peak performance and accompanying flow, can be investigated through the observation of changes in correlation between the various areas of the brain during task performance. The EEG correlates of peak performance can be used as objective measure of flow during a motor task. These correlates can be used as input for neurofeedback training or monitoring of flow in a consulting situation.

In light of the above, this study was undertaken to add to the body of research on flow and the neuropsychological properties of flow under conditions of peak performance, using EEG technology. An objective measure of flow is deemed to be valuable in coaching, training, and self-development because flow is associated with peak performance and flow induction may increase performance in the workplace, sports field and leisure activities. An objective measure of flow, such as EEG, can be used to monitor flow during performance since it provides more accurate information than subjective behavioural measures.

1.2 THE AIM OF THE RESEARCH

This study aims to determine the EEG correlates of flow under conditions of peak performance in order to establish an objective measure, or neurophysiological marker, for flow.

1.3 THE HYPOTHESES

Based on these postulations, the following hypotheses were formulated and tested in the study:

H1: There is a relationship between peak performance and psychological flow.

H2: There is an increase in PFC (F3) EEG Theta power in high flow.

H3: There is an increase in PPC (P3) EEG Theta power in high flow.

H4: There is an increase in PPC (P3) EEG Alpha power in high flow.

H5: There is an increase in SMC (C3) EEG Alpha power in high flow.

H6: There is a decrease in PFC (F3) EEG Beta power in high flow.

H7: There is a decrease in PFC (F3) EEG Gamma power in high flow.

H8: There is an increase in Alpha synchrony between C3 and P3 in high flow.

H9: There is a decrease in Beta synchrony between C3 and P3 in high flow.

H10: There is a decrease in Beta synchrony between F3 and P3 in high flow.

H11: There is a decrease in Beta synchrony between F3 and C3 in high flow.

1.4 THE RESEARCH

The research is broken down into the following components.

1.4.1 Literature study

In-depth literature study was conducted into flow theory and its relationship with performance. With regards to EEG studies of flow and performance, only two limited flow related studies were found (Holcomb, 1976; Kramer, 2007), an indication that this study contributes towards filling a gap in the psychological literature on flow. Following a brief overview of brain anatomy, flow and performance were explored from a neuropsychological perspective leading to a proposed neuropsychological model for flow. Thereafter, neurological functioning and EEG technology were reviewed, followed by EEG studies of visuomotor functioning under peak performance conditions. Finally, a neurophysiological model for flow under conditions of peak performance was proposed.

1.4.2 Research methodology and techniques used

Following an extensive review of the literature and the subsequent formulation of a theoretical neurophysiological model for flow under conditions of peak performance, a laboratory-type study was designed to collect both behavioural and EEG data within a cross-sectional timeframe, from 20 male respondents over the age of 16. A computer-based visuomotor task was set and subjects were given 10 trials to enable them to reach their peak performance at some stage during the session. Each subject provided feedback on their experience, or otherwise, of flow after each race by completing a short questionnaire (AFQ). On completion, performance times and associated flow scores were standardised, after which the sample was segmented into two sub-samples reflecting two levels of the flow variable per subject, namely a high flow - peak performance level and a low flow - low performance level. The first race completed by each participant was used as a ‘baseline’ (and indicative of a low flow state) for comparison with their own personal fastest race/highest flow score combination, indicative of the high flow state. This was required to extract the EEG data associated with each level for further statistical analysis and interpretation.

The relationship between flow and EEG was expressed in terms of the difference between the two levels. EEG power scores were compared (mean differences) by site and frequency, as well as the EEG patterns (correlates) between sites and by frequency. It was expected that the EEG patterns on the lower end of the flow measure (low flow - low performance condition) should differ from the EEG patterns on the higher end (high flow - peak performance) of the flow measure. The EEG patterns on the high end were qualitatively compared with the patterns on the low end, as well as the predictions from the theoretical model.

1.5 THESIS OUTLINE

The thesis is arranged into the following chapters:

Chapter 1: General orientation

Chapter 2: Theoretical conceptualisation of flow and performance

Chapter 3: The neuropsychology of flow and performance

Chapter 4: EEG research findings on flow and performance during visuomotor tasks

Chapter 5: Research design and methodology

Chapter 6: Research results and findings

Chapter 7: Conclusions, limitations, and recommendations.

1.6 TERMINOLOGY

The following key terms are clarified here as they are understood during the thesis:

EEG – An electroencephalogram (EEG) is a visible record of the amplified electrical activity generated by the nerve cells of the brain. According to its Greek etymological roots the word means electro (electrical) encephalo (brain) gram(ma) (picture) (Tyner, Knott & Mayer, 1983).

EEG biofeedback, or neurofeedback, is a sophisticated form of biofeedback based on specific aspects of cortical activity. It requires the individual to learn to modify some aspect of his/her cortical activity. This may include learning to change the amplitude, frequency and/or coherence of distinct electrophysiological components of one's own brain. The goal of neurofeedback training is to teach the individual what specific states of cortical arousal feel like, and how to activate such states voluntarily. For example, during neurofeedback training the EEG is recorded and the relevant components are extracted and fed back to the individual using an online feedback loop in the form of audio, visual or combined audio-visual information (Vernon, 2005).

1.7 CONCLUSION

This chapter outlined the aim of the study and the research hypotheses under investigation. Key terms were explained, and a brief overview of the chosen research methodology was given. The following chapter presents a historical overview of the flow phenomenon and its relation to performance.

CHAPTER 2

THEORETICAL CONCEPTUALISATION OF FLOW AND PERFORMANCE

2.1 INTRODUCTION

This chapter reviews the origin, establishment, conceptualisation, and theoretical underpinnings of the flow phenomenon and its relationship to performance.

2.2 BIRTH OF THE FLOW CONCEPT

The concept of flow, or the “flow experience” was coined by Mihaly Csikszentmihalyi, who conceptualised the phenomenon during the early 1970s. He first observed it while researching motivational aspects of work with a group of artists in the late 1960s, as a state of immersion and total absorption in the act of painting, without any clear motivation for doing so, and then questioned what could probably account for the deep fascination that painting had for the artists (Csikszentmihalyi, 1975).

Observing the artists’ efforts, Csikszentmihalyi found that their work was characterised by intense involvement, which he described as “enthralled” and “trancelike”. At that time, motivational theories advocated external rewards as impetus for this kind of behaviour. Observations of the artists’ involvement revealed that they were not propelled to complete their work to satisfy any external need, but by their connection to and enjoyment of the activity. These experiences subsided as soon as their work was completed. Csikszentmihalyi (1975) concluded that the activity was self-contained and became an end in itself, with no need for any additional rewards.

Csikszentmihalyi came to the conclusion that the motivation for their total dedication might be within the activity, in other words, intrinsically the creation of the painting was the reward for their efforts and not some external motive or driver. The end product (creation) was assessed by the creator in terms of his own goals and standards (performance criteria) and would lead to a subjective experience (emotion) of happiness (satisfaction), pride, disappointment (dissatisfaction), frustration or failure.

In his search for explanations, especially in the line of intrinsic motivation, he investigated Abraham Maslow's (1968) desire for "self-actualisation" in "peak experiences", the "enjoyment" factor in play from researchers such as Piaget (1952), Sutton-Smith (1997), and others; the "optimal arousal hypothesis" by Daniel Berlyne (1960), and others; and autonomy and self-determination by Deci and Ryan (1985), and Lepper and Green (1978). Following the above research, he argued that it was mostly laboratory oriented and did not account for the quality of the subjective experience (feeling) that made a behaviour intrinsically rewarding.

2.3 FLOW THEORY

Csikszentmihalyi started to conceptualise a flow theory.

2.3.1 Defining flow

Continuing his search for an acceptable explanation, in the early 1970s Csikszentmihalyi initiated studies about the quality of subjective experience in intrinsically motivated behaviour by investigating athletes, chess masters, rock climbers, dancers, basketball players, and composers of music. The main conclusion from the latter study indicated that respondents felt an autotelic, or self-rewarding (happy and satisfied), experience after their expectations were met during an activity.

Csikszentmihalyi and Csikszentmihalyi (1988) observed that when people from all walks of life describe their experiences after doing something worth doing "for its own sake" they use terms that were interchangeable in the smallest detail. He argued that this unanimity suggests order in consciousness, which produces a very specific experiential state, so desirable that one wishes to replicate it as often as possible. This state he termed "flow" since it was the term that many respondents used in their interviews to describe what the optimal experience felt like.

Csikszentmihalyi (1990, p. xi and p. 1) states that the concept of flow was borne out of "decades of research on the positive aspects of human experience – joy, creativity, the process of total involvement with life I call flow." He goes on to suggest that, as Aristotle concluded about 2,300 years ago, more than anything else, men and women seek happiness and that all goals are pursued with the expectation that it will lead to happiness. He postulates that, like success, happiness cannot be pursued, it is a by-product of effort, and is achieved by a "circuitous path that begins with achieving control over the contents of our consciousness (Csikszentmihalyi, 1990, p. 2)." He links happiness to a feeling of exhilaration and enjoyment, which he calls "optimal experience" and which people experience after taking control of their actions.

2.3.2 Consciousness and contents of consciousness

In his book, Finding flow – the psychology of engagement with everyday life, Csikszentmihalyi (1997) describes the contents of consciousness by virtue of emotions, intentions, and thoughts. He states that psychologists have identified up to nine basic emotions that can reliably be identified by facial expressions among people living in very different cultures. According to him, all emotions share in a basic duality: they are either, positive and attractive, or they are negative and repulsive.

2.3.2.1 Emotion

According to Csikszentmihalyi (1997), emotions refer to the internal states of consciousness. Negative emotions, such as sadness, fear, anxiety or boredom, produce "psychic entropy" in the mind, that is, a state in which attention cannot be used effectively to deal with external tasks, because it is needed to restore an inner subjective order. Positive emotions such as happiness, strength, or alertness are states of "psychic negentropy", as attention is not needed to ruminate and feel sorry for oneself, and psychic energy can flow freely into whatever thought or task one chooses to invest it in. In other words, emotions are linked to producing either positive or negative energy, which in turn will produce a positive or negative attitude that will influence the economy of attention utilisation.

2.3.2.2 Attention

Csikszentmihalyi (1990) argues that information enters consciousness either because the intention is to focus attention on it or it is the result of attentional habits based on biological or social instructions. It is attention that selects the relevant bits of information from the potential millions of bits available, references it with memory, evaluates it and then makes an appropriate decision. Control of consciousness, because of the mind’s limited processing capacity, constitutes the ability to focus attention at will, to be oblivious to distractions, to concentrate for as long as it takes to achieve a goal, and not longer. The multiple involvement and functions of attention liken it to psychic energy. Further, he argues, that attention to a task, for example, leads to the forming of an intention or set goal and that the intensity of the effort to achieve it is a function of motivation. Intentions, goals and motivations are, therefore, also manifestations of psychic negentropy, in that they focus psychic energy, or attention, establish priorities and thus create order in consciousness.

Csikszentmihalyi (1990) argues that psychic entropy is at its highest when people feel that what they do is motivated by not having anything else to do. Thus, both intrinsic motivation (wanting to do something) and extrinsic motivation (having to do something) are preferable to the state in which one acts without having any kind of goal to focus attention. Intentions focus psychic energy in the short run, whereas goals tend to be longer term.

The third content of consciousness involves cognitive mental operations, such as thinking, whereby psychic energy is ordered by linking cause and effect into logical causal sequences. This also refers to the ability to make rational decisions through the use of intelligence. Without focus (attention) or concentration (focussed attention), consciousness is in a state of chaos. Conflicting desires or motives, intentions, and thoughts, jostle each other in consciousness and cause distraction, anxiety and erratic behaviour. Optimal experience depends on the ability to control what happens in consciousness, based on individual efforts and creativity, and requires concentration. When attention is focussed on information (stimuli) that are congruent with the achievement of set goals, psychic energy will flow effortlessly.

2.3.2.3 Control

The notion of control is centred in Csikszentmihalyi's (1997, p. 117) construct of autotelic personality. The word 'autotelic' is composed of two Greek roots: *auto* (self) and *telos* (goal). Reflecting on the meaning of the word, flow theory defines an autotelic individual as one who does things for his or her own sake, rather than in order to achieve some external goal, that is a person who controls attention by focusing on significant activities with the intention or expectation of achieving self-reward. An autotelic person has a strong tendency to find intrinsic motivation and flow in daily activities.

According to Csikszentmihalyi (1997), following a flow experience, the organisation of the self becomes more complex, in other words, growth has taken place. Complexity is the result of differentiation and integration, the former implying a movement toward uniqueness or separation (individuality), the latter referring to the opposite, a union with other people, feeling part of the social network (communality) or experiencing harmony. A complex self is one that succeeds in combining these two opposites. Investing equal amounts of psychic energy into differentiation and integration, while avoiding both selfishness and conformity, leads to increasing complexity, or growth, and self-actualisation.

2.3.3 The flow zone

Literature generally portrays flow as providing people with a sense of discovery and personal growth, pushing them to higher levels of performance and leading them to "previously undreamed of states of consciousness" (Csikszentmihalyi, 1997). In an effort to "contextualise" the flow experience, Csikszentmihalyi (1975) initially illustrated flow as a corridor within various mental states in which optimal experience is more likely to occur. He referred to this zone of optimal experience and arousal as the "flow channel" (see Figure 1), with entry requiring individuals to perceive a balance between their personal skills and the challenges posed by their situation. As a function of the challenge-skill balance, being in this zone is reflected by the absence of the mental states of anxiety, boredom and relaxation.

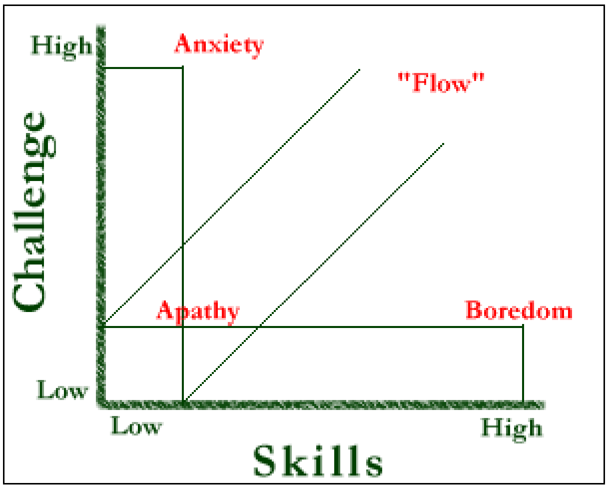


Figure 1. The flow channel (adapted from Csikszentmihalyi, 1990)

Csikszentmihalyi (1990) further concluded that although flow can be experienced in any activity it can only be sustained if the challenges and skills continuously increase in complexity, that is, self-growth or development has to take place. Alternatively, apathy, when challenge and skill requirements are very low; anxiety, when challenge exceeds skill; or boredom, when skill exceeds challenge, will set in.

Csikszentmihalyi (1997) refined the above model by introducing more detail regarding the relationship between challenges and skills and its influence on the quality of the flow experience. The skill/challenge dynamic is illustrated below.

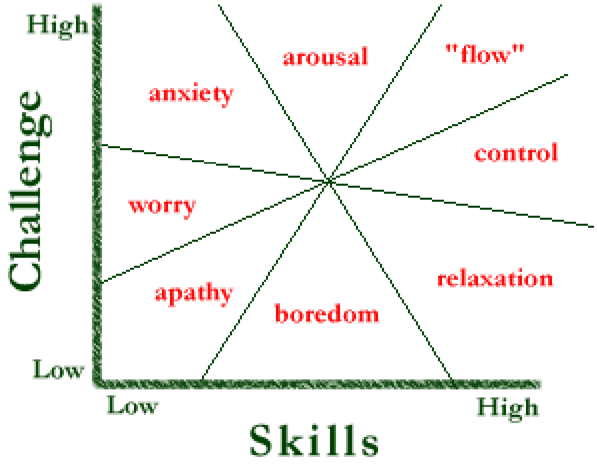


Figure 2. Challenge versus skill (adapted from Csikszentmihalyi, 1997)

The figure above illustrates the following dynamics:

(1) Flow tends to occur when a person's skills are fully involved in overcoming a challenge which is just about manageable, in other words, skills are stretched well above the personal mean (aggregate of skill level relevant to the situation), making the situation a challenge to successfully negotiate.

(2) A person will be aroused or frustrated when the situation is perceived as very challenging at the skill level (level of competency), and may lead to worry and eventually anxiety.

(3) A person will feel in control when the skill level is perceived to supersede the challenge and the challenge is above the person's own mean.

(4) Worry and anxiety will set in when challenge is perceived as being above the personal mean and skill is below.

(5) Boredom and relaxation occur when skill is perceived as being above the personal mean and challenge is below.

(6) Apathy occurs when both challenge and skill are below the personal mean.

According to flow theory, to remain in or re-experience flow one must increase the complexity of the activity by developing new skills and taking on new, tougher challenges. This implies that learning and practising are essential to enabling the flow experience. According to Ellen Langer (1997), the clever approach to any activity involves continuous creation of new ways of organising experience, openness to new information and awareness of different perspectives. From this cognitive viewpoint, finding flow entails engaging in activities that are challenging enough to require new perceptions, perspectives and behaviours without being overwhelmed. According to Pates and Maynard (2000), in flow the subjective or intrinsic experience when achieving the desired performance is the primary reward.

Once flow is experienced, the skill/challenge match is confirmed and the standard has to be raised by setting new goals or standards. Therefore, in order to re-experience flow one has to improve or expand one’s skill level(s). The remaining question however is how to enter the flow state.

2.3.4 Dimensions of flow

Csikszentmihalyi (1975) initially identified four flow components, namely, control, attention, curiosity, and intrinsic motivation. He later replaced them with nine dimensions or general conditions that purportedly facilitate flow experiences (Csikszentmihalyi, 1997). Not all are needed for flow to be experienced.

The nine dimensions are:

(1) Clear goals. Expectations and rules are discernible.

(2) Concentrating and focusing. A high degree of concentration on a limited field of attention, a person engaged in the activity will have the opportunity to focus and to delve deeply into it.

(3) A loss of the feeling of self-consciousness, the merging of action and awareness.

(4) A distorted sense of time – the subjective experience of time is altered.

(5) Direct and immediate feedback. Successes and failures in the course of the activity are apparent, so that behaviour can be adjusted as needed.

(6) Balance between ability level and challenge. The activity is neither too easy nor too difficult.

(7) Sense of personal control over the situation or activity.

(8) The activity is intrinsically rewarding (autotelic), so there is an effortlessness of action.

(9) Action awareness merging. When in the flow state, people become absorbed in their activity, and focus of awareness is narrowed down to the activity itself.

Amongst authors who have re-worked Csikszentmihalyi's version of the flow dimensions, David Farmer (1999) summarises the flow experience as follows:

(1) Completely involved, focused, concentrating - due to innate curiosity or as the result of training.

(2) Sense of ecstasy - of being outside everyday reality.

(3) Great inner clarity - knowing what needs to be done and how well it is going.

(4) Knowing the activity is doable - that the skills are adequate, and the person is neither anxious nor bored.

(5) Sense of serenity - no worries about self, feeling of growing beyond the boundaries of ego. Afterwards a feeling of transcending ego in ways not thought possible.

(6) Timeliness - thoroughly focused on present, not noticing time passing.

(7) Intrinsic motivation - whatever produces flow becomes its own reward.

The nine flow dimensions of Csikszentmihalyi (1997) are discussed in more detail below.

2.3.4.1 Challenge versus skills balance

The challenge-skills balance is probably the pivotal dimension of the flow experience, epitomising the main pre-condition to get into flow. The experience of a balance of challenges and skills is based on individuals' perceptions and their confidence that they can meet the various challenges. Jackson and Csikszentmihalyi (1999) described the interplay of the two dimensions of situational challenges and personal skills on a continuum from high to low, and stipulated that the challenge-skills balance needs to be above average, that is, it occurs in situations of high challenge that require high skill.

If the perception of a match of challenges and skills deviates on either side of the equation the flow state converts into states of boredom, relaxation, apathy, or anxiety. Hence, according to Csikszentmihalyi (2002), low-challenge/high-skill situations, in which performers' skills exceed perceived challenges, lead to states of relaxation or boredom. Those situations lack stimulation, because the demands are relatively low, easy to master, and increase distractibility. Low-challenge/low-skill situations induce feelings of apathy. These situations are not stimulating and the individual lacks the skills or expertise to master them, creating little or no interest. High challenge/low-skill situations provoke states of anxiety, and are perceived as threatening, or, at least, not enjoyable. This is because challenges go beyond personal skills, which are inadequate or insufficient to successfully manage them.

Csikszentmihalyi (1997) illustrated flow as a positive relationship between challenge and skill, which he called the "flow channel". As illustrated in Figure 2 (above), with very high levels of challenge and skill, flow is more likely to occur. If individuals drop out of the flow channel there are two ways to re-attain flow. To get back into flow, individuals can aim for lower challenges that match and stimulate their current skills, or they can seek training in their skill level to meet them.

2.3.4.2 Clear goals

To become involved in an activity, individuals need to have a clear goal of what they wish to pursue (Csikszentmihalyi, 1975). Csikszentmihalyi (2002) maintains that setting goals of low difficulty hardly lead to enjoyment, because the goals are too easy to achieve. Enjoyment and flow will not occur in an activity unless individuals are able to set challenging and attainable goals. Goals also create order in consciousness, providing direction, setting expectations, facilitating structure in terms of execution, and focussing one's intentions. Process goals enhance awareness of what to do next and facilitate concentration and focus on the present, whereas performance goals, such as levels of performance, winning, or outperforming, can increase motivation.

On the other hand, becoming aware of not being able to reach performance-related goals might prevent or decrease flow. To achieve flow, a clearly defined, process-related goal is important to set a specific challenge to strive for, and on which to focus attention (Jackson & Csikszentmihalyi, 1999).

2.3.4.3 Concentration and focussing

Csikszentmihalyi and Csikszentmihalyi (1988) proposed that the most general characteristic of flow is concentration on a limited stimulus field on the task at hand, and referred to attention as a limited resource (1988, 1993). Attention and focus can involve relevant or irrelevant information processing. During flow, which is signified by episodes of total focus on imminent tasks, only selected, task-relevant information is processed (Csikszentmihalyi, 1990). Moran (1996) asserted that a strong task focus would simultaneously block out performance-debilitating thoughts, such as distractions and preoccupations. Therefore, individuals who direct all their focus onto task-relevant information are more likely to experience flow than individuals who lack focus. In addition, Csikszentmihalyi (1993) proposed that total focus on a limited field of stimuli is likely to lead to a merging of body and mind.

Nideffer (1993) proposed that, depending on the sport, attention can vary on a narrow-broad dimension and on an internal-external dimension. For instance, athletes in sports, such as tennis and cricket, players requiring open skills need to shift their attention, more or less rapidly, from a broad-external focus that assesses the situation to a narrow-external focus on performing in the situation. Jackson and Csikszentmihalyi (1999) proposed that athletes' concentration when they are in flow is signified by a rapid, effortless and precise shift in attentional demands, to detect cue information most relevant in the situation.

2.3.4.4 Action-awareness merging

Action-awareness merging signifies that awareness of the self changes through the course of action. During periods of flow, the body and mind are perceived as one unit, with the individual becoming deeply absorbed in the activity. One of the most distinguishing features of this state is that worries, doubts and thoughts concerning the self fade out of awareness. Csikszentmihalyi (1975) advocated action-awareness merging as one of the clearest indications that someone is experiencing flow. Actions appear to be happening spontaneously, effortlessly and automatically, with the individual being on "autopilot". The individual or athlete is mentally and physically at one with their performance. Concentration is fully directed to the activity, while there is a lack of conscious reflection and evaluation of one's actions. The merging of action and awareness on one occasion, as an integrated whole, could be described as 'absorption' or 'immersion' (Csikszentmihalyi, 1975; Jackson & Wrigley, 2004).

Csikszentmihalyi and Csikszentmihalyi (1988) proposed that the unity of body and mind is likely to be the result of another flow antecedent, which he referred to as "concentration on the task at hand". The total focus on one single activity keeps dysfunctional thought processes, such as preoccupations and distractions, out of consciousness and enables individuals to perform at their best.

2.3.4.5 Direct and unambiguous feedback

Besides knowing what to do next, individuals in flow receive immediate and unambiguous feedback on how well actions were executed. There are two distinct ways of evaluating how successfully a person has performed, based on internal and external feedback respectively (Jackson & Wrigley, 2004).

Internal feedback refers to information about bodily movements, including tactile and kinesthetic feedback. External feedback stems from sources outside the body, which are processed as visual, auditory, gustatory, or olfactory. In most activities, internal and external feedback is evaluated in a convergent fashion, providing an overall impression of the performance and results. Progress scores, such as the score on a board, running statistics, lap times, and pulse rates, are sources of direct external feedback. Both internal and external feedback appear to be important in providing information about the quality of performance, which in turn affects the quality of the experience, such as flow.

2.3.4.6 Sense of control

Perceiving a sense of control is accompanied by feelings of comfort, security, relaxation, wellbeing, power, dominance, and predictability. Simultaneously, the absence of a sense of worry and fear of failure is experienced (Csikszentmihalyi, 2002; Jackson & Csikszentmihalyi, 1999). Csikszentmihalyi (2002) stated that in situations with uncertain outcomes, as the possibility of winning or losing, the ability to influence the outcome in their favour will result in athletes experiencing feelings of control. A crucial point is less being in control and more the ability to exercise it in any given situation.

Jackson and Csikszentmihalyi (1999) asserted that the feeling of control is a finely balanced state. Similar to the challenge-skills balance, perceiving a minor sense of control may lead to states of anxiety, whereas the perception of highest levels of control indicates dominance and superior skills over situational challenges, which might induce boredom or relaxation.

2.3.4.7 Loss of self-consciousness

Csikszentmihalyi (1975, 2002) outlined the importance of the self being able to coordinate and integrate its action with other individuals, who are frequently preoccupied with self-reflection and self-analysis of thoughts, as well as with worries and self-doubts. Csikszentmihalyi (2002, p. 64) contended that “loss of self-consciousness does not involve a loss of self, and certainly not a loss of consciousness, but rather, only a loss of consciousness of the self”.

With regard to sport, Jackson and Csikszentmihalyi (1999) asserted that through flow experiences the self expands, by gaining new skills, leading to a more positive self-concept. Csikszentmihalyi and Csikszentmihalyi (1988, p. 370) added that “the strength of the self depends on the cumulative history of positive feedback one gets in high challenge, high-skill interactions”.

2.3.4.8 Time transformation

The transformation of time refers to the aspect of flow that the perception of time within an activity seems to alter, either speeding up or slowing down. Depending on the sport, it might be that athletes experience time passing faster, as during a marathon, or slower, as during a 100-meter sprint. Csikszentmihalyi and Csikszentmihalyi (1988) indicates that time transformation is the consequence of a very deep flow experience and might not be experienced as frequently as other flow dimensions.

Less intense flow states will not have the characteristic of time transformation, and it is possible that the experience of time could vary on the basis of whether performance is only loosely dependent on time measurement, such as in tennis or cricket, or closely dependent on time measurement, such as running, swimming and motor sport.

2.3.4.9 Autotelic experience

Csikszentmihalyi (1975, p. 23) introduced the term ‘autotelic’ to signify that a person can engage fully in an activity and be involved in it for intrinsic reasons, which are inherent in the activity. He defined autotelic experience as a “psychological state, based on concrete feedback, which acts as a reward in that it produces continuing behaviour in the absence of other rewards.”

Intrinsic rewards, for instance, are personal achievement, joy and enjoyment that emerge from an activity. Csikszentmihalyi (1993) proposed that the presence of the other eight flow dimensions turns an individual’s perception into an autotelic experience, meaning that the activity being undertaken becomes self-contained and a goal in itself. The activity is intrinsically motivating, self-rewarding, and a stimulus to participate in the activity for its own sake. The autotelic experience, therefore, could be viewed as a consequence of the other flow dimensions (Jackson & Csikszentmihalyi, 1999). With regard to all flow dimensions, Csikszentmihalyi (2000) reviewed their functions and proposed a distinction between “flow conditions” and “flow characteristics”, the former as crucial to get into flow, the latter dimensions reflecting the phenomenological experience during flow.

According to Csikszentmihalyi (1997), general conditions conducive to flow are based on experiences related to dimensions of challenge-skills balance, clear goals and unambiguous feedback. Characteristics of flow experienced while being in it are dimensions of concentration on the task at hand, action-awareness merging, sense of control, loss of self-consciousness, transformation of time and autotelic experience. Csikszentmihalyi’s distinction between flow conditions and flow characteristics is important for the development of interventions to induce flow.

According to Csikszentmihalyi and Csikszentmihalyi (1988), the ability to enjoy challenges and then master them is a fundamental meta-skill that is essential to individual development and to cultural evolution, yet many obstacles prevent individuals from experiencing flow. These range from inherited genetic malfunctions to forms of social oppression that reduce personal freedom and prevent the acquisition of skills. Understanding how flow works is essential for social scientists interested in improving the quality of life at either the subjective or objective level.

2.3.5 Flow and other theories

Csikszentmihalyi’s concept of flow is closely related to Maslow’s concepts of self-actualisation and peak experiences. Maslow (1962, 1968) developed the concept of self-actualisation as a main component in the humanistic theory of personality. It reflects a drive in human beings with the purpose of realising personal capacities and striving for self-fulfilment. Maslow (1968) introduced a hierarchy of needs model that conceptualises lower and higher-level needs, the former including sleep, hunger, and safety, which are homeostatic in nature. These basic needs have to be satisfied before importance is attached to higher level needs, and a person firstly has to survive physically before he or she can grow psychologically. The latter, higher-level needs, include self-worth, competence, and self-fulfilment. Maslow deemed self-actualisation to be the highest human need, characterised by discovering and extending individual potentialities. In contrast to basic needs, self-actualisation is not subject to homeostatic satisfaction but reflects a continuing need for personal development and growth.

Csikszentmihalyi and Csikszentmihalyi (1988) advocated that flow, like self-actualisation, is detached from homeostatic influences. The purpose of flow is to enable individuals to grow, fully function and make use of one’s potentialities. With regard to homeostasis, Seligman and Csikszentmihalyi (2000) distinguished between enjoyment and pleasure, not universally but with pleasure relating to homeostatic needs, which can arise from satisfying physical needs. Enjoyment and the experience of flow, on the other hand, go beyond homeostasis and include activities such as the active involvement in reading a book, and athletic or artistic performances, which increase individuals’ capacities. Seligman and Csikszentmihalyi (2000, p. 12) added that “enjoyment, rather than pleasure, is what leads to personal growth and long-term happiness”.

As well as the assessment of self-actualisation, Maslow (1968) examined individuals’ peak experiences. Based on qualitative analysis, he found a number of characteristics common to the cognition of people's peak moments during interpersonal, creative, mystic, intellectual, and athletic experiences. He described peak experiences as transcending, unifying, fulfilling, desirable, and egoless, having their own value, achieved in circumstances in which the perception of time is distorted or lost. Furthermore, during episodes of peak experiences, individuals perceived the experience as complete, but detached from expedience, requiring the person's whole attention, and adding to his or her knowledge and growth.

Maslow (1968) concluded that characteristics of peak experience reveal similarities to the experiences of individuals high in self-actualisation. Based on the findings of peak experience, Maslow (1968, p. 97) defined self-actualisation as:

> … an episode, or a spurt in which the powers of the person come together in a particularly efficient and intensely enjoyable way, and in which he is more integrated and less split, more open for experience, more idiosyncratic, more perfectly expressive or spontaneous, or fully functioning, more creative, more humorous, more ego-transcending, more independent of his lower needs.

The phenomenology of Maslow's (1962, 1968) description of self-actualisation and peak experience resembles the experiences that Csikszentmihalyi found in artists. Csikszentmihalyi (1975) reported that his research interest was spurred by trying to understand artists' motivation underlying the extraordinary experiences in their activities. Csikszentmihalyi's work was aimed at exploring how personal and situational characteristics affect these experiences, such as individuals' propensity to have peak experiences, and the intrinsic rewards, such as enjoyment and personal growth, gained from the various activities. This is probably the most obvious differentiation of Csikszentmihalyi's concept of flow from that of Maslow's description of self-actualisation and peak experience.

Csikszentmihalyi's notions of expectation and control (autotelic personality) as applied in his concept of flow and optimal experience is closely related to Rotter's concept of attribution and locus of control. Rotter (1972), whose social learning theory of personality adopts an attribution theory point of view, postulated that people who were more likely to display typical expectancy shifts were those who were more likely to attribute their outcomes to ability, whereas those who displayed atypical expectancy would be more likely to attribute their outcomes to chance. ‘Internals’ tend to attribute outcomes of events to their own control, which is strongly related to the concept of autonomy, whilst ‘externals’ attribute outcomes of events to external circumstances, such as luck, fate, or significant others. In a study regarding locus of control in relation to flow, Taylor, Schepers and Crous (2006) reported that internally oriented individuals are better able to reach higher levels of performance within a shorter space of time, in turn being better able to accelerate the fulfilment of higher-order needs necessary for self-actualisation. Internals reported significantly higher incidents of flow experiences than did externals. Asakawa, (2004), who investigated flow experience and autotelic personality in Japanese College Students, found that the autotelic students reported significantly more positive experiences than their non-autotelic counterparts. Moreover, the autotelic students were significantly more “concentrated” (focused), felt more in control of the situation, and felt more importance for the future than the non-autotelic students, even when watching television and engaging in maintenance activities, which are typically considered unimportant and unworthy of much attention. The above indicates that autotelic persons and persons with an internal locus of control share several commonalities.

The notion of “own choice” (autotelic trait) is also captured in self-determination theory, which relates to the examination of how external factors influence intrinsic motivation. Deci and Ryan (1985, p. 38) defined self-determination as the “capacity to choose and to have those choices, rather than reinforcement contingencies, drives, or any other forces or pressures, be the determinants of one’s actions.” Self-determination theory is based on the notion that human behaviour is motivated by three psychological needs: (i) *autonomy*, as individuals’ perceptions that they are the source of their own actions and behaviours. Autonomous behaviour characterises the expression of the self, with individuals perceiving value and initiation as part of their actions; (ii) *competence*, which refers to individuals’ perceptions of the effectiveness of their skills and capacities with regard to meeting action opportunities; and (iii) *relatedness*, which refers to individuals’ perceptions of connectedness and belongingness to other individuals and the community. This need relates to the security aspect in being with others in the here and now, and does not emphasise the attainment of any future outcome (Deci & Ryan 2002).

According to Ryan and Deci (2000), self-determined actions lead to more intrinsically motivated results, with intrinsic motivation indicating the interest in participating in an activity for its own sake, which offers inherent satisfaction, in other words autotelic behaviour.

From a self-determination perspective, the connection between intrinsic motivation and flow in sport was researched by Frederick-Recascino (2002), and reported that when individuals are in a state of intrinsic motivation they experience "choicefullness" in their behaviour, thereby fulfilling their need for autonomy. Additionally, they are at a level of optimal challenge, which fulfils their competence need. A state of intrinsic motivation is associated with feelings of satisfaction, enjoyment, competence, and the desire to persist at the activity. The above description largely overlaps with the characteristics of flow.

Experiencing flow or being 'in the zone', as widely discussed in athletic experience (Csikszentmihalyi, 1990 and 1975), is understood in self-determination theory as representing the heightened awareness and the feeling of wellbeing associated with intrinsic motivation. Frederick-Recascino (2002) noted that intrinsic motivation, the experience of "choicefulness", and challenge are important factors for positive experiences. One of the key concepts in self-determination theory, as well as flow, is 'optimal challenge'.

Deci and Ryan (1985) proposed that within an optimally challenging activity, the level of intrinsic motivation underlies the perceived competency. More particularly, feedback that reinforces one's perceived competency will increase the level of intrinsic motivation, in which perceived competency plays a pivotal part. Motivation is specific to each demand and the level of motivation, whether higher or lower, depends on what is of interest and importance to individuals and what they determine is achievable (Vieira, 2003). In order to maintain a healthy self-esteem (ego), individuals tend to accept tasks that they think they can successfully complete. Logically, when there is a perceived low level of probable success associated with a task there is a reduced motivation to engage in the activity or even to set a goal. The motivational process energises, maintains, and directs behaviour toward goals (Eccles & Wigfield, 2000). The perceived expectation of successful completion of a task, behaviour based on beliefs, and the importance ascribed to the task behaviour in pursuance of a goal based on values, determine if motivational activation or behaviour takes place. It also determines the intensity and persistence of the task behaviour (Grantham & Vieira, 2008). It is evident that perceived competency, optimal challenge, and intrinsic motivation are at the heart of both self-determination theory and flow theory.

The descriptions above imply that persons who experience flow achieve it while performing an activity of their own choice (self-determination), motivated by intrinsic factors (self-reward), which produce a desirable (positive/enjoyable) mental state (optimal experience) and outcome (goal achievement) that serve as motivation (reward/reinforcement) to re-engage the activity repeatedly. However, in terms of flow theory, once the above process has completed successfully and the flow experienced, the challenge has to be increased and skill improved, through learning and/or training, before flow can be re-experienced. This implies that flow is intrinsically linked to continuous performance improvement.

2.4. FLOW AND PERFORMANCE

Flow and performance are intertwined. This relationship is discussed below.

2.4.1. Manifestations of flow in performance

For decades, sport psychology has ascertained that mental states can lead to improved performance, but several other areas of human performance, such as music and problem-solving, have also shown optimal psychological states for participants (Kraus, 2003; Lindsay, Maynard & Thomas, 2005). High levels of both mental and physical performance usually depend on goal-directed attention produced by specific challenges and clear feedback (Locke, Shaw, Saari & Latham, 1981), therefore it is not surprising that a host of studies have found a strong positive relationship between flow and performance.

Flow experiences were reported in a variety settings, such as schooling (Carli, et al., 1988; Clarke & Haworth, 1994; Moneta & Csikszentmihalyi, 1996); computing (Trevino & Webster, 1992; Webster, et al., 1993; Chen, et al., 1999); family interaction (Csikszentmihalyi & Rathunde, 1993); leisure (Graef, et al., 1983; Csikszentmihalyi & LeFevre, 1989); occupational therapy (Jacobs, 1994; Emerson, 1998) and competitive and recreational sports (Jackson, 1992; Jackson & Roberts, 1992; Stein, et al., 1995; Catley & Duda, 1997; Kowal & Fortier, 1999) and video gaming (Cowley, et al, 2008).

Flow is also correlated with a heightened sense of playfulness (Webster & Martocchio,1992); self-control (Ghani & Deshpande,1994); increased learning (Canter, Rivers & Storrs, 1985) and increased positive subjective experiences (Csikszentmihalyi, 1997). Eisenberger et al. (2005), who examined the relationships of employees' perceived skill and challenge at work and need for achievement, found that among achievement-oriented employees only, high skill and challenge were associated with greater positive mood, task interest, and performance than other skill/challenge combinations. They also found that positive mood mediated the interactive relationship of skill/challenge and need for achievement with performance. Flow was found to be positively correlated with personality characteristics such as autonomy and internal locus of control (Taylor, et al., 2006), as well as autotelic personality and extroversion (Csikszentmihalyi, 2002; Asakawa, 2004).

Flow is reported by teenagers who like studying, by workers who are satisfied with their jobs, and by drivers who enjoy driving. Activities such as reading a good book, completing a crossword, or finishing a writing assignment can induce high levels of absorption associated with flow (Csikszentmihalyi, 1997).

The description of flow is similar to the one of a player immersed in a video game, during which he or she loses track of time and forgets external pressures. It is evident that gamers value video games based on whether or not they can provide flow experiences (Holt, 2000). Numerous authors have applied flow to human-computer interactions (Webster et al., 1993; Sharafi, Hedman & Montgomery, 2006) and to internet usage (Hoffman & Novak, 1996; Chen et al., 1999; Pace, 2004; Wan & Chiou, 2006; Chen, 2007). Hoffman and Novak (1996) and Chen (2007) have argued that qualities of the Internet and World Wide Web, such as control, ease of use, immediate feedback, interactivity, and access to entertainment, would inherently make them open to flow experiences.

Chen (2007) found that most web users experience positive moods while online, while Wan and Chiou (2006) have argued that the interactive and engaging properties of online games offer users the opportunity for optimal (flow) experiences. Chen et al. (1999) found that some of the most flow-inducing activities were information retrieval, reading and writing e-mails, creating web pages, playing online games, and chatting online. Using the components of flow, Chen (2007) encourages designers of computer and video games to provide an enjoyable interactive experience for the widest variety and number of users, by mixing and matching the components of flow; keeping the user's experience within the user's 'flow zone'; offering adaptive choices to allow different users to enjoy the flow experience in their own way; and embedding choices inside the core activities to ensure the flow experience is not interrupted.

Sherry (2004) asserts: "Some might comment that Csikszentmihalyi seemed to have video games in mind when he developed the concept of flow'' (p. 339), noting that ''[video] games possess ideal characteristics to create and maintain flow experiences in that the flow experience of video games is brought on when the skills of the player match the difficulty of the game'' (p. 340). These conditions are similar to those found in media experiences labelled as 'entertainment'.

Research suggests that the psychological experience of gaming is consistent with the dimensions of the flow experience as outlined by Csikszentmihalyi. Thus, the concept of flow forms the basis of the psychological presence of gamers within the game and provides a useful framework for game design (Bryce & Rutter, 2001). Hoffman and Novak (1996) proposed that creating a commercially compelling website depends on facilitating a state of flow.

Flow experiences occur especially while playing computer and video games, as they "… possess ideal characteristics to create and maintain flow experiences in that the flow experience of video games is brought on when the skills of the player match the difficulty of the game" (Sherry, 2004, p. 328). Voiskounsky, Mitina & Avetisova (2004), as well as Rheinberg and Vollmeyer (2003), demonstrated experimentally that players of so-called MUDs (Multi-User Dungeons, or Multi-User Dimensions) experience flow.

From the above literature it is evident that enjoyment and 'skill-challenge balance' are important factors related to the flow experience.

2.4.2. The flow - performance relationship

The term 'the zone' is frequently used in the literature of sport psychology, outlining a state of high intensity, strong focus, superior performance (Young, 2000), and peak experience (Murphy & White, 1995), which is indicated by heightened awareness and intrinsic motivation (Frederick-Recascino & Morris, 2004). Tolson (2000, p. 38) described playing in the zone as "when the body is brought to peak condition and the mind is completely focused, even unaware of what it's doing, an individual can achieve the extraordinary".

A sport journalist reported that elite athletes talk about 'being in the zone', a supposedly magical place in which mind and body work in synchronisation and movements seem to flow without conscious effort (Park, 2006). According to Park, major-league pitchers, National Basketball Association (NBA) stars, professional golfers and Olympic hopefuls dedicate their careers to the search for this elusive feeling, devoting hours of training to 'listening to their body' and 'reading their muscles', trying to construct a bridge between mind and body sturdy enough to lead them straight to 'athletic nirvana'. Loehr (1995) wrote in an article on tennis that top tennis players, after achieving "ideal performance [mental] states" during peak performances, would say they "zoned" or "flowed" or "tranced". They talked about time standing still, profound inner stillness and puzzling feelings of joy, power and control.

The relationship between flow and performance appears to be reciprocal, in which flow influences performance and vice versa, however, at this point the research results are too vague to invite conclusions on whether there is a one-directional connection between them, either way. More research is needed to untangle the relationship and to further examine directional or reciprocal links. Even though there is no strong evidence on the directional effects, aiming to increase both would be preferable, so that one or both variables will enhance the other. Even if flow does not have a direct effect on performance it would be worthwhile to enhance flow, because of the benefits for intrinsic motivation and enjoyment, and hence continued effort and persistence.

Privette and Bundrick (1987, 1997) proposed an experience model, consisting of two dimensions that were termed ‘feeling’ and ‘performance’. As shown in Figure 2.3, both dimensions consist of seven different states, which gradually increase from lowest (total failure) to highest (personal best) performance, and from lowest to highest feeling states, with neutrality as the centre point. According to Privette and Bundrick (1997), feeling states below neutrality are specified as boredom, worry, depression / misery, and are called ‘negative feeling states’. States above neutrality are labelled as enjoyment, joy, ecstasy / highest happiness, and are called ‘positive feeling states’. According to the experience model, feelings of worry and boredom are counterproductive to superior performances. Both experiences are related to performances that are below average. Enjoyment, on the other hand, which is a key aspect of flow, would signify performances that are above standard.

Testing the experience model, Privette and Bundrick (1997) examined 123 adults on their perceptions in various activities, such as sports, arts, and social services, to compare their feeling states in failure, average, and peak performance. The results showed that peak performances were characterised by factors of fulfilment, focus, play, and self in progress. In contrast, average performance revealed a lack of fulfilment, focus, and significance, whereas factors of play and sociability were reported as more important. Failing performances demonstrate most strongly an absence of fulfilment, focus, sociability, and self in progress.

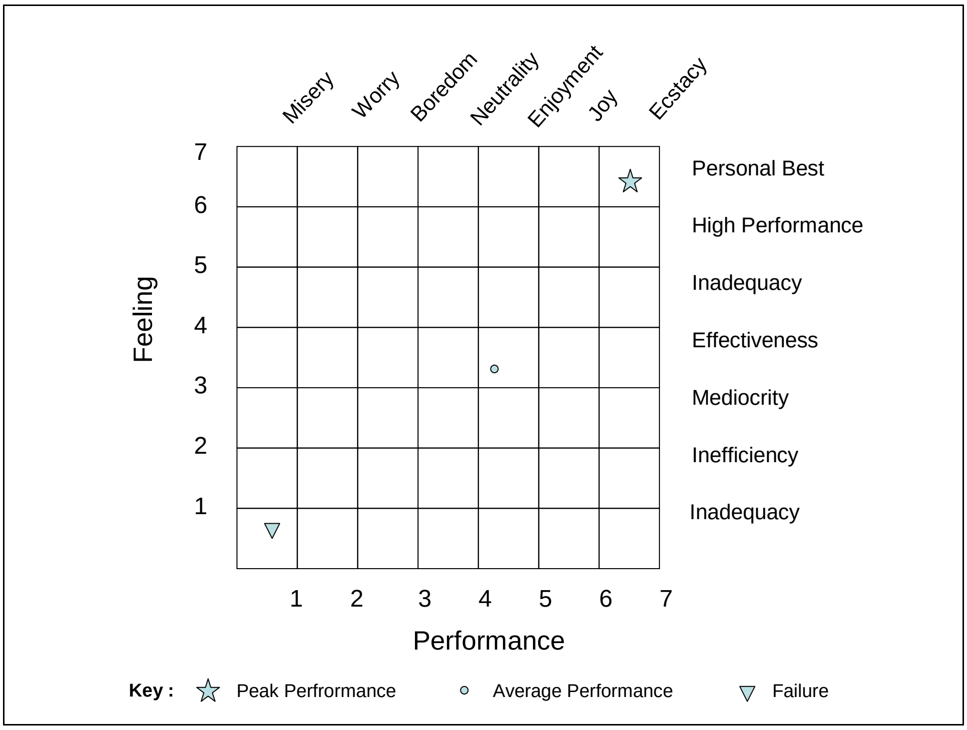


Figure 3. Experience model of feeling and performance (Privette & Bundrick, 1997)

The results, as indicated in Figure 3 above, showed distinct differences in athletes' experience that were related to the various performance levels, indicating that the stronger the performance the more positive the experience. Privette (1983) proposed several factors, such as absorption, joy, involvement, spontaneity, awareness, loss of time, and temporality, to be reflections of communal aspects of peak performance and flow. According to Privette, experiences of flow and peak performance are characterised by active processes, indicating interactivity and responsiveness between athletes and their environments. Similar to Csikszentmihalyi's (1975) flow experience, Privette (1983) proposed that peak performance manifests in a holistic experience, as indicated by a clear focus and strong awareness of one's action and self.

Young and Pain (1999) researched the notion of a universal zone in sport by contrasting the flow experiences of professional tennis players with Jackson's (1996) elite athletes. Using qualitative analyses on narratives of flow, they found support for flow theory's posited structure consisting of eight flow dimensions. Also, no significant differences were found between tennis players and elite athletes on the Privette's Experience Questionnaire (Privette, 1984), concluding that the analyses suggest that the zone or flow state is a universal phenomenon across sports, although intra-sport and inter-athlete differences are evident.

Jackson and Roberts (1992) found a positive relationship between ratings of flow and perceptions of peak performance. Jackson, Thomas, Marsh & Smethurst (2001), in a study researching the relationships between flow, self-concept, psychological skills, and performance among athletes, found that four dimensions of flow stood out as most predictive across performance measures, namely challenge-skill balance; clear goals; autotelic (intrinsic reward) experience; and action-awareness merging (absorption). The first two were also strongly correlated to self-concept and psychological skills (activation, emotional control, relaxation, and elimination of negative thoughts), while the latter two demonstrated the link between enjoyment of the experience, becoming absorbed in the activity, and quality of performance.

According to Kimiecik and Stein (1992), peak (optimal) experience and flow are distinctly subjective states experienced internally within the individual during a contest, whereas peak performance pertains more to the objective outcome of that contest. Privette (1981, 1983) discriminates between peak experiences and flow, arguing that there are differences with regard to individuals' involvement (for example, active or passive), level of intensity, motivation, and goal characteristics. Privette proposed that peak experiences do not necessarily arise as a result of participation in a specific activity. Individuals could be in a passive mode, characterised by receptive and perceptual experiences, such as reading a book, whilst peak experiences could be triggered spontaneously, occurring in inactive or non-motivated states in everyday life, for instance, by listening to radio or music, watching television, reading a book, dream scenarios, or forms of intoxication. In contrast, flow is highlighted by a strong active physical or mental involvement in a planned and structured activity, in which challenges match individuals' skills, including experiences of joy and enjoyment.

Several definitions have been proposed for peak performance, for instance by Privette, as "behaviour which exceeds one's average performance" (1982, p. 242), or as "superior functioning" (1983, p. 1361); and by Jackson and Roberts (1992, p. 156) as a "prototype of superior use of human potential", including physical as well as mental involvement. On a conceptual level, Jackson and Wrigley (2004, p. 426) define it as referring to:

> … an outcome or achievement of superior functioning rather than to an internal experience of optimal feelings and perceptions. Optimal experience (flow) describes an inner psychological state while engaged in an effortful and challenging activity, whereas peak performance refers to the outcome or accomplishment as a consequence of that person's effort and sustained concentration. Simply put, peak performance refers to an outcome rather than an experience.

Based on Jackson and Wrigley's contention of the relationship between flow and peak performance, flow has a strong subjective component that cannot be directly evaluated by others, whereas the result of a peak performance may be objectively quantifiable by observations and comparing previous performances.

In a similar vein, Kimiecik and Stein (1992) argued that peak experience and flow are rather subjective in nature, whereas peak performance is about objective results. Even though there are conceptual differences, Csikszentmihalyi (1993) reported that flow is tangentially related to peak performance, indicating that both states can occur at the same time.

2.4.3. Measurement of flow

Commonly, the flow state is measured by means of post-hoc questionnaires that measure performance or experience. In order to measure people's flow experiences, Csikszentmihalyi and LeFevre (1989) developed a technique they called the 'experience sampling method' (ESM) to capture behaviours, thoughts, and feelings as they occur in real time. This involved the random (electronic) sampling of participants during their daily lives. Questionnaires, such as their 'experience sampling form' (ESF), are then used to structure and record their experiences in real time. The ESF usually contains items asking participants to rate their levels of concentration, involvement, enjoyment, skill, and the challenge of the activity. Building on one of Delle-Fave and Massimini's (1988) findings, Csikszentmihalyi and LeFevre (1989) found that flow type situations occurred three times more often during work than in leisure.

Jackson and Marsh designed the ‘Flow State Scale’ in 1996, to assess flow on a scale of nine factors using a total of 36 items, derived from the work of Csikszentmihalyi (1990) and comprising: challenge-skill balance, action awareness merging, clear goals, unambiguous feedback, concentration on the task at hand, sense of control, loss of self-consciousness, transformation of time, and autotelic experience. Other studies have employed similar questionnaires or measures of flow based on subjective self-assessment (Jackson & Eklund, 2002).

Another adaptation of Csikszentmihalyi’s concept of flow relates to specific experiences of computer users. Rheinberg, Vollmeyer, and Engeser developed a Flow Short Scale in 2003 (Engeser & Rheinberg, 2008) which measures all components of the flow experience with ten items using a 7-point scale. The scale also contains three additional items to measure the perceived importance of the activity. The experienced difficulty of the task, perceived skill and perceived balance are measured on a 9-point scale. Using a factor analytical approach, it was found that the flow construct contains two dimensions namely, smooth and automatic running and absorption. The first factor refers to the feeling of utmost concentration and focusing, control over the activity, clarity of the operations, and smooth and automatic cogitations. The second factor refers to the feeling of full involvement, a distorted sense of time, optimal challenge, and absent-mindedness.

Building on the findings of Delle-Fave and Massimini's (1988) and Csikszentmihalyi and LeFevre (1989), Bakker (2008) developed a 13 item work-flow questionnaire, the WOrk-reLated Flow inventory (WOLF), to measure employees’ experience of flow in the workplace. Bakker found that when flow is applied to the work situation it can be defined as a short-term peak experience at work which is characterised by three factors, i.e., absorption, work enjoyment and intrinsic work motivation (Bakker, 2005). Absorption refers to a state of total concentration (totally immersed in work); work enjoyment refers to positive judgments (happiness) about work; and intrinsic motivation refers to performing a certain work-related activity with the aim of experiencing the inherent pleasure and satisfaction in the activity (Bakker, 2008).

2.4.4 Measurement of performance

Flow and performance are measured by different instruments and in different units of measurement, the former a subjective state measured by reflective instruments such as questionnaires, reports and interviews, the latter associated with objective measurements, expressed in standardised units of measurement and often expressed in relation to a performance standard. According to the *Collins Essential English Dictionary* (2nd Edition, 2006), performance can be described as, *inter alia*, “the manner or quality of functioning”, which implies that an action is measured and compared to a standard of excellence or rate-of-error.

Performance is also closely related to learning or practice and follows an identifiable curve, known as ‘learning curve’ or ‘experience curve’. The learning curve effect and closely related experience (or performance) curve effect express the relationship between experience (performance) and efficiency. As individuals and/or organisations become more experienced in a task they usually become more efficient at it.

The experience curve effect is broader in scope than the learning curve effect, reflecting efficiencies such as cost, production and effort. It assumes that the more often a task is performed the lower will be the cost (effort) of doing it.

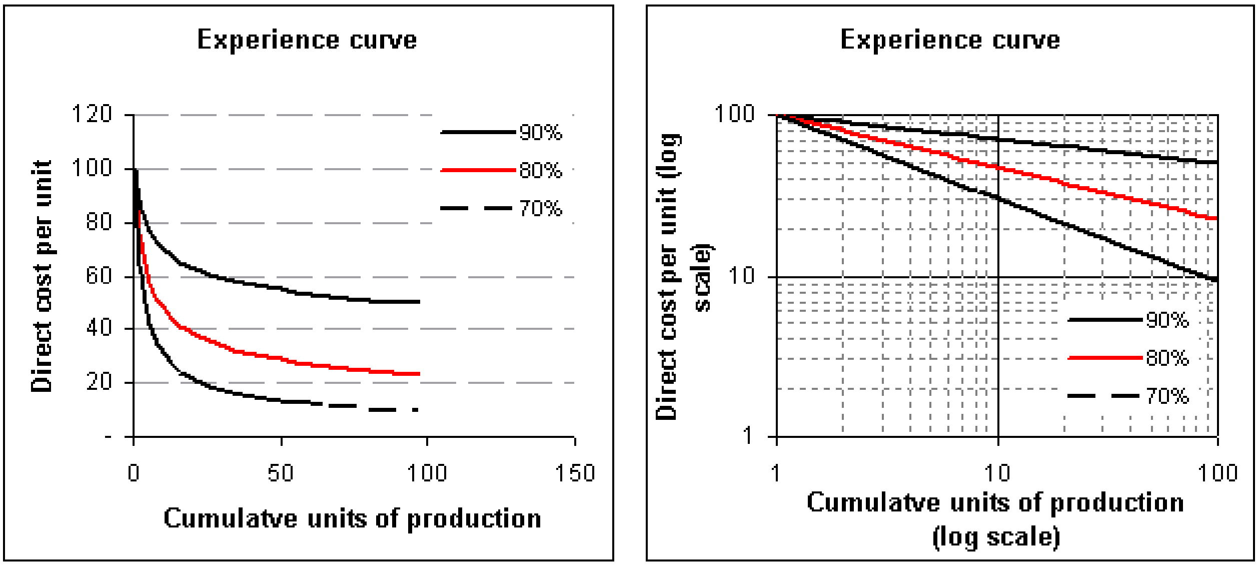


Figure 4. Experience curve **(**http://en.wikipedia.org)

Figure 4 (above) shows the learning or experience effect for a simple task plotted both on linear and log-log coordinates. The pattern is a rapid improvement followed by ever lesser improvements with further practice. Such negatively accelerated learning curves are typically described well by power functions, thus, learning is often said to follow the "power law of practice" (http://en.wikipedia.org).

Learning, progress, and performance also display a decrease in variance, as the behaviour reaches an apparent plateau on a linear plot. This plateau masks continuous small improvements with extensive practice that may only be visible on a log-log plot, on which months or years of practice can be seen. The longest measurements suggest that for some tasks improvement continues for over 100,000 trials (Rabbit & Banerji, 1989).

The power law of practice is ubiquitous. From short perceptual tasks to team-based longer term tasks, such as building ships, the rate that people improve with practice appears to follow a similar pattern. It has been seen in pressing buttons, reading inverted text, rolling cigars, generating geometry proofs and manufacturing machine tools (Newell & Rosenbloom, 1981), performing mental arithmetic on both large and small tasks (Delaney, Reder, Staszewski & Ritter, 1998), performing a scheduling task (Nerb, Ritter & Krems, 1999), and performance errors (Ohlsson, 1996).

The learning curve is visible with enough aggregation of dissimilar tasks or across similar tasks down to the level of individual subject's strategies. Fitts and Posner (1967) suggested that the learning process is sequential and that one moves through specific phases or stages as one learns:

(1) **Cognitive phase** - Identification and development of the component parts of the skill involving the formation of a mental picture of the skill. The learner tries to define the goal and general methods for achievement. He or she knows when the movement is not the desired one but does not know how to correct it. Frequent errors make the performance quite variable. The learner discovers dimensions of time, space, force and flow.

(2) **Associative phase** - Linking the component parts into a smooth action. It involves practicing the skill and using feedback to perfect the skill. The learner comprehends how parts of the movement relate to one another, and becomes more bio-mechanically efficient. Errors are less numerous. Quality practice produces refinement of the skill and the learner begins to recognise inappropriate performances.

(3) **Autonomous phase** - Developing the learned skill so that it becomes automatic. It involves little or no conscious thought or attention whilst performing the skill. The learner has acquired the ability to focus attention on other details of the environment, including the ability to self-correct and make minute adjustments. Not all performers reach this stage.

Fitts and Posner (1967) found gradual improvement with practice in most motor skills, and that learning follows an S-shaped learning curve, evident when someone learns a highly complex task. The initial part (cognitive phase) of the curve rises slowly as a person becomes familiar with basic components of a skill. The steep ascending phase (associative phase) occurs when there is enough experience with rudiments or simple components to start "putting it all together." Rapid progress follows until the skill "hits a ceiling" (autonomous phase) or stabilises at a high level. The S – curve is illustrated below.

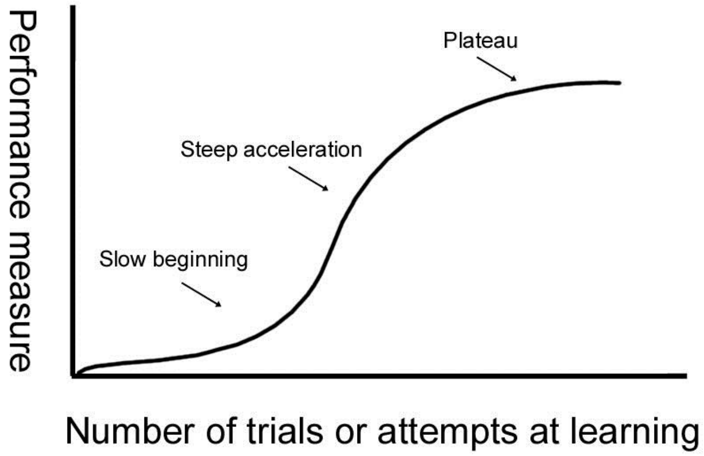


Figure 5. The S-shaped "learning curve" typical of complex learning (Fitts & Posner, 1967)

Gentile (2000) suggests that the first stage of learning involves explicit processes in which the learner matches the body's morphology to the environment's regulatory conditions and learns to manipulate parameters that scale the movement to different task demands. Later, during stages in which learning is less conscious, the learner improves in intrinsic processes, such as regulating inter-segmental or motion-dependent forces. Eventually, the skill is executed by implicit and unconscious processes.

Acquiring the skill of typing is a good example to illustrate the above phases of learning (skill acquisition). During the first, cognitive phase, attention is mostly consumed by concentration and thought regarding keyboard layout, finger movement and coordination, processing and transformation of visual input into motor output and correcting errors. During the second, associative phase, with repetition (practice), the keyboard layout becomes learned knowledge and less attention is spent on finger placement, therefore attention starts shifting away from the fingers and onto the text that has to be typed, together with feedback on accuracy (lack of error correction). Typing speed increases progressively as errors decrease. During the final, autonomous phase, attention is focussed mainly on the text that has to be typed and almost no attention is given to finger placement on the keyboard (motor skill). When no errors are made and typing speed is at the optimum, typing efficiency (performance) has become a function of errorless functioning, thus the longer the period of continuous errorless typing the higher the efficiency and better the performance.

Understanding the process of skill acquisition has been a major challenge in sports performance for decades. Once the process behind motor behaviour is understood, intervention programmes may be clarified to optimise skill acquisition. To examine differences in skill levels, beginners and experts are often compared on a specific task. According to Wrisberg (2001), the novice state is characterised by stimulus identification which involves mostly perceptual processes to find the relevant internal and external information for the motor task, whereas experts can already filter information and focus on decision and strategy processes. This processing of different information involves the handling of external and internal information as well as attentional resources which are fundamental in this process (Abernathy 2001). These processes take place at the brain level, on which measuring during a motor task is difficult.

From the above literature it is inferred that flow is likely to occur when skill reaches a certain level of competency and is most probable when the autonomous phase is reached, characterised by continuous errorless and seemingly effortless performance.

2.5. DISCUSSION

Flow, although anchored in social, development and positive psychology, is depicted as a state of mind and thus also grounded in theories of consciousness, often referred to as an altered or heightened state of consciousness. Situating flow as a level of consciousness enters the debate surrounding the entity of consciousness. Consciousness theories are all but unified in understanding and place in nature, researched from various angles by different schools of thought, but none producing all the answers.

Wilber (1997) provides a useful summary of the various theories on consciousness research. *Cognitive Science* views consciousness as anchored in functional schemas of the brain/mind, either in simple representational fashion or as hierarchically integrated networks. *Introspectionism* maintains that consciousness is best understood in terms of intentionality, anchored in first-person accounts, i.e., inspection and interpretation of immediate awareness and lived experience. *Neuropsychology* views consciousness as anchored in neural systems, neurotransmitters, and organic brain mechanisms. *Individual psychotherapy* views consciousness as primarily anchored in an individual organism's adaptive capacities. *Social psychology* views consciousness as embedded in networks of cultural meaning or as a byproduct of the social system. *Clinical psychiatry* views consciousness in strictly neurophysiological and biological terms. *Developmental psychology* views consciousness as a developmentally unfolding process with a substantially different architecture at each of its stages of growth. *Psychosomatic medicine* views consciousness as strongly and intrinsically inter-active with organic bodily processes. *Non-ordinary states of consciousness,* from dreams to psychedelics. *Eastern and contemplative traditions* maintain that ordinary consciousness is but a narrow and restricted version of deeper or higher modes of awareness, and that specific injunctions (yoga, meditation) are necessary to evoke these higher and exceptional potentials). *Quantum consciousness* views consciousness as being intrinsically capable of interacting with, and altering, the physical world. *Subtle energies* are the subtler types of bio-energies beyond the four recognised forces of physics (strong and weak nuclear, electromagnetic, gravitational).

Wilber (1997) made an in-depth study of all the above schools of thought and subsequently produced a `four quadrants' of existence consciousness model that draws on the strengths of each. The four quadrants model (FQM) integrates creature- and state-consciousness, built on the premise that holons (from the holonic nature of the Kosmos) evolve along four dimensions or facets (the four quadrants), i.e., intentional, behavioural, cultural and social, to increasing levels of development. Each quadrant has a different architecture and thus a different type of validity claim through which the three strands of knowledge operate, i.e., propositional truth (Upper Right), subjective truthfulness (Upper Left), cultural meaning (Lower Left), and functional fit (Lower Right). All four validity claims follow the three strands of valid knowledge acquisition: injunction, apprehension, confirmation/rejection (or exemplar, evidence, falsifiability). These three strands operate in the generation of all valid knowledge, on any level, in any quadrant. There are at least ten major levels of development in each of the quadrants, ranging from the eye of flesh to the eye of mind to the eye of contemplation, and thus the knowledge quest takes on different forms as movement goes through the various levels in each quadrant. The three strands and four claims are still fully operating in each case, but the specific contours vary.

Figure 6 is a schematic illustration, without the levels of evolution in each quadrant, of the FQM.

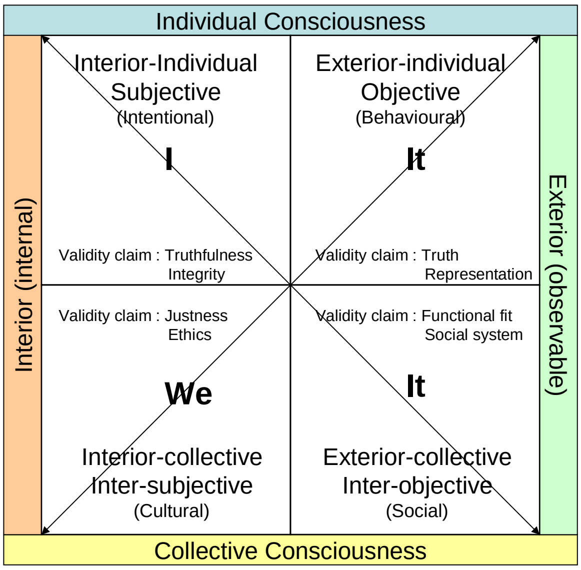


Figure 6. Four quadrant model of existence (Adapted from Wilber, 1997)

According to Wilber’s model, each quadrant represents a hierarchy consisting of holons, whole units that are simultaneously part of some other whole, for instance a whole atom is part of a whole molecule. The upper right quadrant consists of a hierarchy of holons of increasing complexity, each of which `transcends but includes' its predecessor in an irreversible fashion. However, individual holons always exist in communities of similar holons. These communities, collectives, or societies are summarised in the lower right quadrant. The two right hand quadrants both represent holons that all possess simple location, i.e., they can all be seen (observed), they are all empirical phenomena and exist in the sensori-motor world space. They are, in other words, objective and inter-objective realities, and are what individual and communal holons look like from the outside, in an exterior and objectifying fashion. However, every exterior has an interior. These are summarised in the upper left and lower left quadrants. The upper left quadrant represents the interior of individual holons, such as prehension to irritability to sensation to perception to impulse to image to symbol to concept to rule. The lower left quadrant represents the collective forms of individual consciousness, i.e., the various cultural or communal forms of consciousness.

Each of the quadrants is described in a different type of language. The upper left is described in `I' language; the lower left in `we' language; and the two right hand quadrants, since they are both objective, are described in `it' language. Each has a different `type of truth' or validity claim, that is, different types of knowledge with different types of evidence and validation procedures. Thus, propositions in the upper right are said to be true if they match a specific fact or objective state of affairs, so-called objective truth (representational truth). In the upper left quadrant, a statement is valid not if it represents an objective state of affairs but if it authentically expresses a subjective reality. The validity criterion here is not just truth but truthfulness or sincerity (integrity of information). In the lower right quadrant of inter-objective realities the validity claim is concerned with how individual *holons* fit together into interlocking systems. Truth in this quadrant concerns the elucidating of the networks of mutually reciprocal systems within systems of complex interaction. The validity claim, in other words, is grounded in inter-objective fit, or simply functional fit. In the lower left quadrant the concern is not simply with how objects fit together in physical space but how subjects fit together in cultural space. The validity claim here concerns the way that individual subjective consciousness fits with collective subjective consciousness, and how people together decide upon cultural practices that allow them to inhabit the same cultural space. The validity claim, in other words, concerns the appropriateness or justness of statements and actions (ethics in the broadest sense).

The figure below is a schematic illustration (with the levels of evolution in each quadrant) of the FQM.

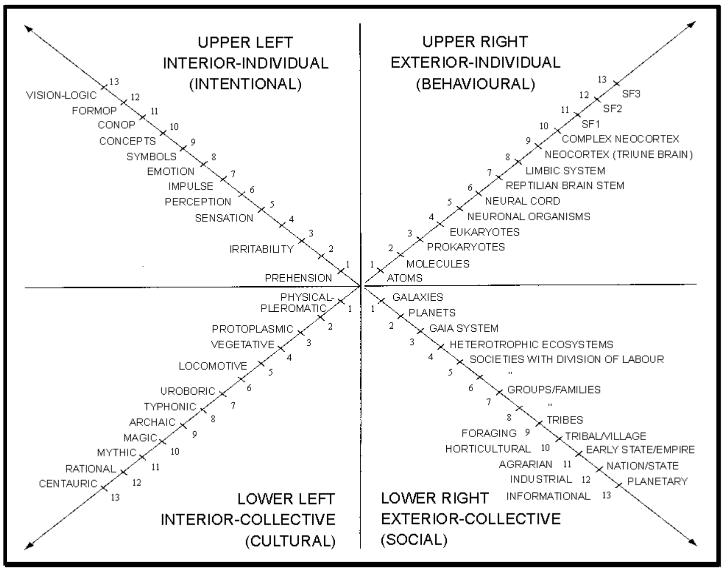


Figure 7. Four quadrant model of existence (Wilber, 1997)

Integrating the model, each quadrant has correlates in all the others, that is, since every holon has these four facets (intentional, behavioural, cultural, and social), each of these has a very specific correlation with all the others. These can readily be seen in Figure 7. For example, where one finds a holon with a limbic system one finds that it has an interior capacity for impulse/emotion, it lives in the collective of a group, herd, or family, and it shares an emotional-sexual worldview. Each quadrant causes, and is caused by, the others, in a circular and non-reducible fashion, which is why all four types of truth (and all four validity claims) are necessary to access the various dimensions of any holon.

According to Wilber (1997), the two right hand validity claims, objective truth and functional fit, are grounded in empirical observation, and some sort of correspondence theory of truth, whereas the two left hand validity claims, subjective truthfulness and inter-subjective meaning, require extensive interpretation or hermeneutics and some sort of coherence theory of truth. He argues that perhaps this is why the human knowledge quest has been divided into these two broad camps, empirical vs. hermeneutic, positivistic vs.

interpretive, scientific vs. intuitive, analytic vs. transcendental, Anglo-Saxon and continental, right hand and left hand. He postulates that the correct stance is that both are indispensable and that the one should not be reduced to the other.

Wilber (1997) argues that the first step toward a genuine theory of consciousness is the realisation that consciousness is not located in the organism, rather it is a four-quadrant affair distributed across all and anchored equally in each. Consciousness is not located merely in the physical brain, in the physical organism, in the ecological system, or in the cultural context, nor does it emerge from any one of those domains. Rather, it is anchored in, and distributed across, all of those domains with all of their available levels. The upper left quadrant is simply the functional locus of a distributed phenomenon. All holons therefore have four fundamental and irreducible aspects, so that every ‘information state’ actually and simultaneously has an intentional, behavioural, cultural, and social aspect; with each of those having at least ten basic levels.

Chalmers (1995) points out that all of the physicalist and reductionist approaches to consciousness only solve ‘the easy problems’, such as objective integration in brain processes, leaving the central mystery of consciousness untouched. Chalmers (1995, p 81) writes that “the hard problem [is] the question of how physical processes in the brain give rise to subjective experience”, that is, how physical and mental interact. According to Chalmers (1995) there is an explanatory gap between matter and sensation that has not yet been satisfactorily bridged, not by neuroscience, cognitive science, neuropsychology, phenomenology, or systems theory.

Wilber (1997) concludes that the attempt to solve this dilemma of an explanatory gap by any sort of reductionism, i.e., attempting to reduce left to right or right to left, or any quadrant to any other, or any level to any other, is doomed to failure, because the four quadrants are apparently very real aspects of the human holon, aspects that aggressively resist being erased or reduced. From a flow point of view, the learning point from Wilber’s line of argument is that the flow phenomenon or state of consciousness should be researched covering all four facets (intentional, behavioural, cultural, and social), using all four validity claims and following the three strands of valid knowledge acquisition:

injunction, apprehension, confirmation/rejection (or exemplar, evidence, falsifiability) relevant to each facet.

Flow theory, as reported by Csikszentmihalyi and associated researchers, mainly focus on left hand (subjective, individual and collective) intentional and cultural dimensions of flow. Csikszentmihalyi (1990) formulated a flow model (exemplar) through research using qualitative and quantitative techniques to gather and interpret peoples subjective experiences regarding a mental state in which there is order in consciousness, a match between challenge and skill, concentration on the task at hand, action-awareness merging, sense of control, loss of self-consciousness, transformation of time and autotelic experience, during which they experienced happiness, engagement and self-reward.

As far as right hand (objective, individual and collective) research regarding the flow state is concerned, many questions are still unanswered. What are the neural processes, pathways, structures and systems, associated with flow that accompanies the intentions and behaviours described in flow theory? Is there an identifiable neurological pattern that is representative of the flow state and which can be used as objective evidence of being in flow? Do individuals performing the same task and experiencing flow present with the same neurological pattern? From literature reviews it seems that in terms of flow theory the right hand dimensions (objective-behavioural and -social) are still much under-researched.

2.6 CONCLUSION

From the literature reviewed above, it is evident that flow and peak performance are interlinked and are even seen to be co-existing. Peak performance is only achievable once skill acquisition has reached the autonomous stage. During this stage a person will experience balance between ability or skill level and the challenge of the moment, that is, the activity, task or event. Additionally, a clear goal (performance standard) for achievement is set; attention is focussed on the task (challenge) and not the skill; direct and immediate feedback (error tracking) is continuous; a sense of personal control and therefore confidence, is experienced (being in control of the situation), and a feeling of automaticy (effortlessness); action awareness merging and loss of self-consciousness is experienced, creating an altered sense of time passing.

However, the questions persist, given the above descriptions, how do we know if a person is in flow or not? Are we always going to rely on post hoc self-reports? As pointed out by Weber (2009):

> Undoubtedly, much of the confusion associated with observations of flow results from challenges associated with using self-report techniques to measure experience governed by activity in implicit systems that is inaccessible to conscious awareness. All of this has led to an amalgamation of models and operational procedures used to study flow in which the sequence of antecedents and consequences is often difficult to untangle. What is considered a precursor in one study is regarded as the flow state itself in another.

Explaining flow in terms of the so-called right hand dimensions, especially the right upper quadrant, the schools of thought involving cognitive psychology, neurophysiology and neuropsychology are better suited than that of introspectionism and developmental psychology. As a matter of logic, one needs some bridging between concepts of the left upper-and the right upper quadrants, i.e., connecting propositions about flow with propositions of consciousness under conditions associated with flow, such as peak performance (Kim, 1998).

From a neurophysiological and neuropsychological perspective, peak performance has been widely investigated by, amongst other techniques, studying electro-cortical changes or neurological patterns in various areas of the brain during task execution. Since flow is associated with peak performance it leads that neurological patterns in the brain recorded during peak performances can be linked to behavioural patterns associated with flow and then explained in neuropsychological terms. The neuropsychological properties of flow and performance are pursued in the next chapter.

CHAPTER 3

THE NEUROPSYCHOLOGY OF FLOW AND PERFORMANCE

3.1 INTRODUCTION

Flow theory in its current state as mainly a motivational theory and its overlapping with other motivational theories was discussed above. However, flow as a so-called heightened state of consciousness and the neurological processes and systems underlying such a state have been largely ignored and left unanswered.

Neural theories of consciousness, or neural correlates of consciousness, attempt to explain why or how relevant correlations between various areas in the brain exist, thereby explaining the state of consciousness (Metzinger, 2000). Such theories are diverse not only in the neural processes or properties to which they appeal but also in the aspects of consciousness they take as their respective explanations.

Recent observations with brain imaging and the long standing evidence on oscillatory brain activity from Electroencephalography (EEG) and Functional Magnetic Resonance Imaging (fMRI), supports viewing the brain as a dynamic system of unprecedented complexity. Werner (2012) maintained that studying neural activity in terms of state space representations has proven of great heuristic value to account for the spatial and temporal dynamics of neural systems at micro-, meso- and macroscopic granularity. Its merit lies in making conceptual tools of statistical mechanics available for neural data interpretation. Notable examples of applications of this principle are Wackermann’s (1999) assessment of EEG field changes as state space trajectories; Hobson, Pace-Schott & Stickhold’s (2000) view of different stages of wakefulness and sleep in terms of state space dynamics; the demonstration of global brain state transitions occurring simultaneously across multiple forebrain areas (Gervasoni et al., 2004); Fell et al. (2004) mappings between brain states and phenomenal experience, and Churchland’s (1989, 2006) longstanding explorations with comparing human phenomenological with neural-network activation spaces.

In state space a system’s dynamics can encounter singularities along its path, which trigger sudden phase transitions to new macroscopic configurations with distinctly novel properties. Phase transitions consist of a change in the correlation function among the system’s elements, which characterises how the value at one point in the state space correlates with the value at another point (Werner, 2012).

In line with the above methodology, research has indicated that the EEG correlates of expert sportsmen during peak performance exhibit distinct patterns of cortical activity, which will be discussed below. Since flow is associated with peak performance it follows that the manifestation of flow, as a heightened state of consciousness, in terms of state space dynamics, can be regarded as a critical point in state transition in which the system undergoes a profound reconfiguration (distinct neural pattern) that, among other features, is expressed by changes in the correlation function between various system elements (cortical areas). Crick and Koch (1990) describe this process as neuronal binding through neuronal oscillations.

The change in correlations among the microscopic features at state transition can also be viewed as change to a coarser state space topology, with new neighbourhood relations among features and thus associated with novel physical or behavioural manifestations. The abrupt reconfiguration of neural state space may be the manifestation of global brain state transitions, that is, a qualitatively novel expression of functional brain organisation (Werner, 2008). Weber (2009) suggest that cognitive binding and network synchronisation are key to a better understanding of holistic, higher-order experiences that cannot be well explained by isolated traits of those experiences.

Despite the rich descriptions of flow in the psychological literature, very little is known about the neurological mechanisms that give rise to the flow state. Following the state-space argument, the suggestion is that flow, as a state, will be observable as a unique pattern of neural connectivity (neural network or state space topology), when various brain areas are recruited into synchronised activity (regions in state space become correlated) in order to achieve the objective underpinning the flow state. Flow can, therefore, be investigated as a neurological pattern that evolves as a result of changes in correlation between system elements of neural state space at the functional level.

In this chapter the anatomy of the brain will briefly be revisited, followed by consciousness and cognition as explored from a neuropsychological perspective. A plausible model for explaining the flow state during peak performance is then suggested.

3.2. BRIEF EXPOSITION OF BRAIN FUNCTIONING

Discussed below are some aspects of brain functioning that is relevant to the study.

3.2.1. Orientation

In order to describe the location of brain structures a variety of terms are used for different directions and planes of section in the nervous system. Since humans have an upright posture the nervous system makes a bend of nearly 90° somewhere between the forebrain and the spinal cord. By definition, this bend is said to occur in the region of the *midbrain-diencephalic junction*, therefore, for structures above the *midbrain* the orientation of the nervous system is the same with respect to the ground, as in reptiles. At the *midbrain* and below, however, there is a rotation of 90°, since in the standing position the *spinal cord* is approximately perpendicular to the ground in humans. A set of terms that is often used for orientation in the nervous system that remains constant with respect to the environment both above and below the *midbrain*, are *anterior*, *posterior*, *superior*, and *inferior*. Figure 8 (below) depicts the terms as they apply to humans (Blumenfeld, 2002).

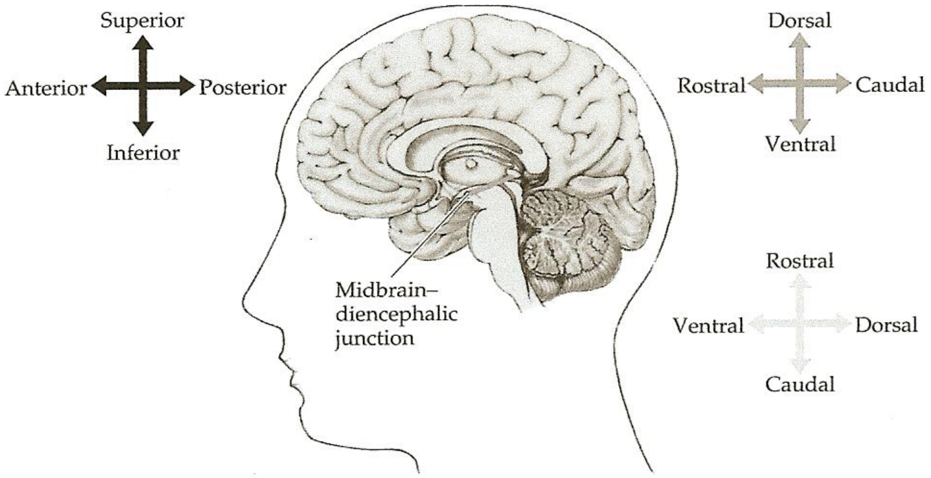


Figure 8. Directions and planes of sections (Blumenfeld, 2002)

The terms are the following:

(1) *posterior* - toward the rear of the head

(2) *anterior* - toward the front of the head

(3) *vertex* - central position on top of the head

(4) *dorsal* - toward the top of the head

(5) *ventral* - toward the bottom of the head

(6) *medial* - midline of brain (as seen from above)

(7) *lateral* - to the left or the right of the *midline*

(8) *superior* - closer to the top (*dorsal*)

(9) *inferior* - closer to the bottom (*ventral*).

3.2.2. The brain

The brain is the command centre of the body and controls it through the nervous system, the basic unit of which is the neuron, with billions of *neuronal* cells forming an intricate network of connections throughout. The nervous system has two parts: the *central nervous system* (CNS) and the *peripheral nervous system* (PNS). Information travels within and among these two divisions via *neural tissue*, transmission being dependent on electro-chemical activity within the nervous system. The CNS includes the brain and the spinal cord, whilst the PNS picks up much of its information from the spinal cord and makes connections with the rest of the body.

3.2.3. Brain lateralisation

The most prominent part of the brain is the *cerebrum*, divided into *left* and *right hemispheres* for which many differences have been observed. Brain function lateralisation is evident in the phenomena of right- or left-handedness and of right or left ear preference, but a person's preferred hand is not a clear indication of the location of brain function. Although 95% of right-handed people have left-hemisphere dominance for language function, only 18.8% of left-handed people have right-hemisphere dominance for language function. Additionally, 19.8% of the left-handed have bilateral language functions (Taylor & Taylor, 1990).

Research conducted at the Australian National University (ANU) seems to back up earlier studies showing that left- or right-handedness is determined in the womb and that many left-handers process language using both hemispheres of the brain, as opposed to right-handers, who seem to use primarily the left hemisphere for this purpose. The research adds to the slowly growing body of work supporting the hypothesis that people who favour their left hand for writing probably have brains that are more conducive to simultaneous, bi-hemispherical processing of information. From ANU tests designed specifically to measure the speed of information flow between the two sides of the brain, the left-handed subjects were found to be faster overall at this task (Cherbuin &

Brinkman, 2006).

According to Demos (2005), the left hemisphere is the dominant hemisphere for most people, being responsible for logic, mathematics, and analytical reasoning. Verbal expression and understanding are linked to Broca's area and Wernicke's area of the left hemisphere, and are crucial for finding details whilst disseminating information and governing grammatical principles and spelling. Verbal memories are stored in the left hemisphere.

The right hemisphere is usually the non-dominant one, responsible for activities on the left side of the body and governing emotions and music comprehension better than does the left hemisphere. The ‘sweet’ tones of singing and the ‘bitter’ sounds of swearwords all emanate from the right hemisphere, which knows why a joke is funny. Right hemisphere functions include creativity and perception, visual-spatial processing, orientation and recognising familiar places. Logic may be on the left, but intuition and insight are on the right. Perhaps one of the most important features of the right hemisphere is its relationship with human qualities such as facial recognition, empathy, and early self-concept (Demos, 2005).

Women and men differ in left-right hemisphere differences, as a women's brain has a thicker *corpus callosum* (the major connection between the two hemispheres) than a man's, and up to 30 percent more connections between left and right (Pease & Pease, 2000). This means women have higher quality and stronger connections between the emotional right hemisphere and the logical left hemisphere. This difference may contribute to a woman's ability to express and understand interpersonal emotions better than men. Carter (1998, p. 71) noted other functional differences between the sexes, including a greater tendency for women to involve both sides of the brain when completing complex mental tasks. Men often use only the side more obviously suited to do it, a pattern of activity that suggests women in some ways take a broader view of life, bringing into play more aspects of the situation when making decisions, for example. Men, on the other hand, are more focused.

Men use more of their brain, on both sides, than women when it comes to spatial abilities.

They are better at left-right recognition, determining which way is north, reading maps, and playing three-dimensional games or solving puzzles. Although there is much controversy about lateralisation of function and gender differences that may be due to, or exaggerated by, social roles, most engineers, pilots, and air traffic controllers are men. Contrary to popular opinion, male and female occupational differences may, however, not simply be a case of stereotyping or bias.

The research on lateralisation of brain functioning is continuous and its implications tightly delineated. However, the pseudoscientific applications of lateralisation are often exaggerated and applied to a wide range of situations. In terms of brain lateralisation, handedness and gender are possible moderator variables to be considered in the neuropsychological research regarding flow and performance during a continuous visuomotor task.

3.2.4. Lobe specialisation and functions

The outer layer of the *cerebrum*, the *cerebral cortex*, is responsible for higher mental functions. It has numerous crevices (*sulci*), and ridges (*gyri*), is about three millimetres thick and divided into four corresponding lobes in each hemisphere. The surface of the deep groove that divides the left and right hemispheres is known as the *cingulate gyrus*, which is considered to be the cortical portion of the *limbic system*. Fissures are the long deep grooves in the *cerebral cortex* that follow the boundaries between lobes. The central fissure creates a dividing line between the *somatosensory cortex* and *motor cortex* that extends from the *left lateral sulcus* to the *right lateral sulcus*. As indicated in Figure 9 (below), each lobe is named in conjunction with the *cranial* bones above it and is associated with specialised tasks.

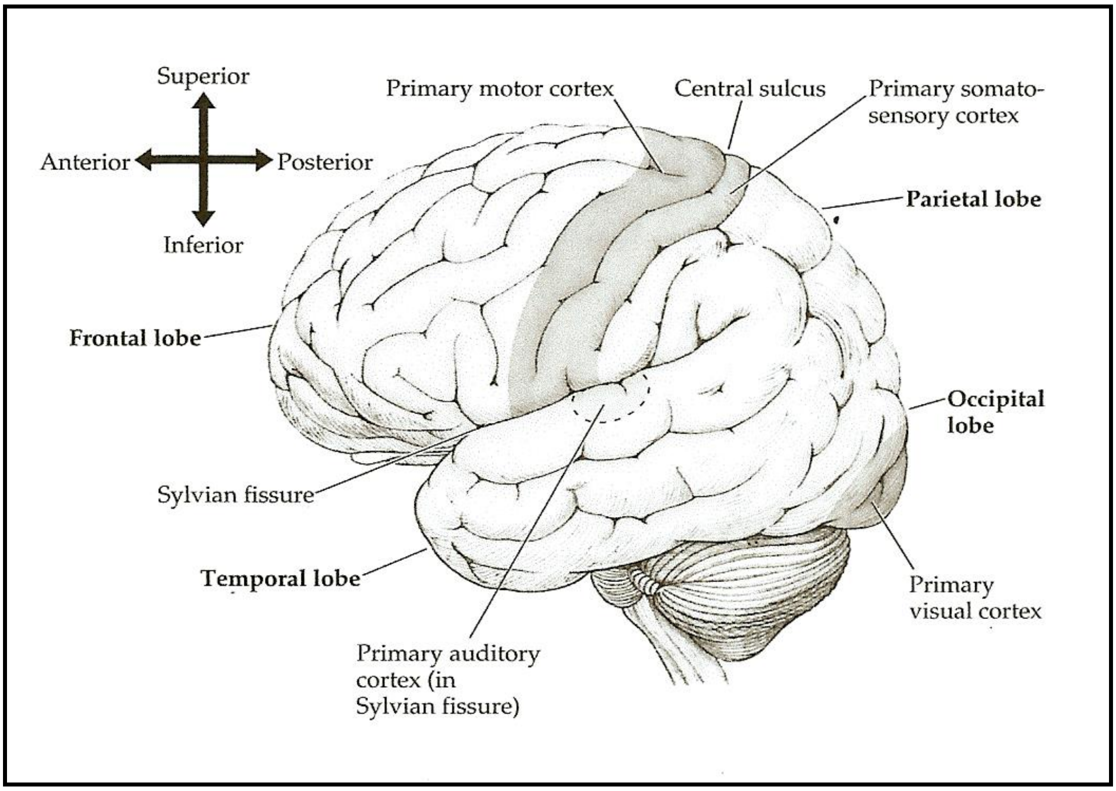


Figure 9. Primary sensory and motor cortical areas (Blumenfeld, 2002)

Much of the understanding of lobe functions comes from brain imaging and from observations made by neurologists when a local brain lesion occurs. Neurologists have observed that lesions occurring in specific regions of the brain produce specific symptoms. Conversely, specific symptoms relate to specific regions in the brain. There follows a discussion of brain regions.

3.2.4.1 Frontal lobes

Frontal lobes are responsible for immediate and sustained attention, social skills, emotions, empathy, time management, working memory, moral fibre or character, executive planning, and initiative (Demos, 2005). They are typically sub-divided into three regions, each with two-way connections to different thalamic nuclei and other cortical and sub-cortical structures. The *dorsolateral prefrontal cortex* has a generic function of real-time processing of information or working memory in the service of a wide range of cognitive functions, integrating attention, memory, motor, and affective dimensions of behaviour. The *medial* regions (*cingulate* or *limbic cortex*) are involved in moderating emotional and social behaviour, as well as drive and motivation. The *orbital* (*basal*, *ventral*) *frontal cortex* plays a key role in impulse control and in regulation and maintenance of set and continuous behaviour (Lezak, Howieson & Loring, 2004): "The frontal cortex, that is responsible for the brain's most complex processing, has the heaviest projections to the amygdala, and the two work together as part of the network that is the social brain" (Ratey, 2001, p. 312.).

3.2.4.2 Parietal lobes

The *parietal lobes* are associated with mathematical reasoning, naming objects, complex grammar, and spatial awareness. They solve problems that have been conceptualised by the *frontal lobes* and together with these are the main components of the *association cortex*. Complex grammar, the naming of objects, sentence construction, and mathematical processing are traceable to the left parietal lobe. Map orientation, knowing the difference between right and left, and spatial recognition are all functions of the right parietal lobe. However, specialisation has its limits, with, for example, PET scans having shown that the naming of objects involves several brain regions, including the *posterior frontal cortex*, the *inferior parietal cortex*, and the *superior temporal cortex* (Demos, 2005).

Sense of direction also encompasses more than one region: the *inferior pre-frontal cortex*, the *posterior parietal cortex*, and the *inferior temporal cortex* (Pinel & Edwards, 1998). Damage to the *posterior parietal cortex* can cause a classic deficit, known as Balint's syndrome, in which patients are unable to attend to multiple objects simultaneously, or figuratively, they ‘cannot see the forest for the trees’. The damage limits their ability to shift attention from one location to another and perhaps from one sensory modality to another (Ratey, 2001). People with *parietal lobe* problems may have more car accidents because they are not able to attend to both sides of the visual field. They might have trouble playing computer games such as solitaire, which require scanning from left to right. If they draw pictures and the left half of the picture seems incomplete this indicates a deficit in the right parietal lobe.

The *parietal lobe* is the ‘where’ area of sensory perception. Studies in lesions in the *right parietal lobe* indicate that it is involved in attention, music, body image, body scheme, face recognition, and the physical act of dressing (Ratey, 2001).

3.2.4.3 Temporal lobes

The *temporal lobes* are associated with verbal memories, verbal-analytic and language functions such as word recognition, reading, language, as well as emotion in the left hemisphere, while the temporal lobes in the right hemisphere are associated with music, facial recognition, social cues, object recognition, and visuo-spatial and integrative processing (Springer & Deutsch, 1998). The temporal lobes have proximity to the *amygdala* (emotion) and the *hippocampus* (memory).

Luria (1973) indicated that lesions to the *left mid-temporal zone* interfere with verbal memory making. Damage to this zone prevents the storage of longer passages of information, although short phrases may be retained. Consequently, it becomes difficult to keep up with a conversation because information is being lost. Lesions to the *right temporal lobe* often result in the inability to recognise intricate rhythmic melodies.

The *temporal lobe* houses the *auditory cortex* in close proximity to the *hippocampus*, and consequently is critical to the memory-making process, especially verbal memories. Springer and Deutsch's (1998) review of literature comparing cerebral blood flow and memory, explained that memory can be placed into three different categories: short-term, working, and long-term. Each activity tends to activate different parts of the brain, as shown in PET scans. Short-term memory, which includes recalling a seven-digit number such as a telephone number, activates Broca's area and the *left inferior parietal cortex*. If a short-term-memory task is visual or spatial in nature the right hemisphere is activated, including the right *occipital*, *parietal*, and *prefrontal cortices*. If a short-term-memory task is phonetic, the *left posterior/inferior parietal lobe* is activated. Phonological memory takes in the correct order and transmission of speech sounds, the phonetic pattern of a language.

Long-term memory can be divided into two branches: semantic and episodic. The former includes the recall of objects and word understanding, especially in language, and is associated with left temporal lobe (Wernicke's area) problems. the latter involves functional tasks such as remembering to pay bills, filling the car’s tank, how to play baseball, and where glasses and keys are placed. Deep lesions to the mid-temporal extending into the hippocampal lobes result in a dysfunctional episodic memory. *Left prefrontal cortical regions* are more involved in retrieval of information from semantic memory and in simultaneously encoding novel aspects of the retrieved information into episodic memory. The *right prefrontal cortical regions*, on the other hand, are involved in episodic memory retrieval (Springer & Deutsch, 1998, p. 215-216).

Working memory is an example of short-term plus long-term memory joined in problem-solving tasks associated with mathematics or reading. Studies show an activation of the *frontal lobes* in the case of verbal or mental tasks (Springer & Deutsch, 1998, p. 206), but for memory problems it is not possible to isolate them to the *temporal lobes*.

The *anterior left temporal lobe*, due to its proximity to the *amygdala*, may also be implicated in depression. Davidson, Abercrombie, Nitschke & Putnam (1999, p. 230) reported that investigators found that blood flow in the left *dorsolateral prefrontal cortex* and the *left anterior temporal cortex* is negatively correlated with severity of negative symptoms, suggesting that these cortical zones play a role in generating positive affect, motivation and goal-setting, and that their inactivity leads to negative symptoms.

3.2.4.4 Occipital lobes

The *occipital lobes* are associated with the visual field that helps to locate objects in the environment, see colours, recognise drawings, and correctly identify objects. Reading, writing, and spelling depend upon an accurate visual field. They are closely associated with the visual cortex and border the *parietal* and *temporal lobes*. There are two well-identified visual systems with separate pathways, one running dorsally from the *occipital* to the *parietal lobe* and being involved with spatial analysis, providing ‘where’ information. The *temporo-occipital pathway*, which takes a ventral route, conveys information about shape and patterns, the ‘what’ of visual perception behaviour (Lezak, et al., 2004).

3.2.4.5 Sensory and motor (sensori-motor) cortex

The *sensory cortex* and *motor cortex* run parallel to each other and are divided by the *central sulcus*, with the two cortices combined being known as the *sensori-motor corte*x. A key function of the *primary motor cortex* is conscious control of all skeletal muscle movements. Key functions of the *primary somatosensory cortex* are spatial discrimination and the ability to identify where bodily sensations originate.

The *sensori-motor cortex* marks the division between the *parietal lobes* and the *frontal lobes*. The *primary motor cortex* is *anterior* and within the *frontal lobes*. The *primary somatosensory cortex* is *posterior* and within the *parietal lobes*. Together the *sensory* and *motor cortices* reach downward to both the *left* and *right temporal lobes* to the *lateral sulcus*. The close proximity of these two adjacent structures lends support to the notion that they not only divide the *anterior* from the *posterior* but they also serve as a junction that coordinates movement that is partly guided by sensation. Much of what people do and who they are translates into moving legs, hands, torso, or neck into action. From the Greek root *soma*, for body, the *somatosensory system* is responsible for both the external senses of touch, temperature, pain, and the internal senses of joint position, visceral state, and pain (Damasio, 1994, p. 65).

The functions of the *primary motor cortex* have been associated with skilful movements and smooth repetitive operations such as typing, playing musical instruments, handwriting, the operation of complex machinery and fluid speaking. It is the hub and switching station between voluntary muscles of the body and the brain. Research into the *sensori-motor cortex* indicates discreet locations that correspond to actual movements in the hands, legs, mouth and jaw.

Sterman, Mann, Kaiser & Suyenobu (1994) relate the generation of EEG field potentials at scalp level to the influence on the *thalamus* of three integrative activities of the brain, which they call vigilance, sensori-motor integration and cognitive integration. The *vigilance system* involves diffuse networks and specific centres in the *brainstem* and their ascending influence on *thalamic, sub-cortical* and *cortical centres*. The *sensori-motor system* involves the ascending touch and *proprioceptive pathways* and their projections to the *thalamus* and on to the *sensori-motor cortex* and the *efferents* from this cortical area. This system generates the sensori-motor rhythm (SMR), the 12 - 14 Hz rhythm (also called the *lobeta frequency range*) over the *sensori-motor strip*. Cognitive integration involves a range of centres that process and integrate sensory inputs and motor responses.

Sterman et al. (1994) relate the generation of SMR, *alpha* and *theta rhythms* to the presence or absence of input from these systems on the *thalamic oscillatory generators*. Specifically, the different oscillatory modes in the *thalamus* appear when influence of combinations from the three modalities is withdrawn from it. As noted above, the prototypic example involves initiation of *alpha rhythms* by the withdrawal of *brainstem cholinergic* activity from the *thalamus*. If sensori-motor inputs are withdrawn, the SMR rhythm appears. If cognitive processing is withdrawn (as in relaxed states without cognitive activity), *alpha* appears. If vigilance is withdrawn (as in states of inattentive drowsiness), *theta* appears. Thus the presence of these rhythms on the EEG indicates the underlying brain states of vigilance, cognitive processing, and sensori-motor integration.

Ratey (2001, p.14) explains that the *motor cortex* helps the *cerebral cortex* to encode both physical and cognitive tasks, asserting that the brain circuits employed to order, sequence and time a mental act are the same ones used to order, sequence, and time a physical act. This means that the *somatosensory cortex* shares in orchestrating both physical and mental processes. It governs more than just sensory and motor functions.

3.2.4.6 Cingulate gyrus

The *anterior cingulate gyrus* contributes to mental flexibility, cooperation, and attention. It helps the brain to “shift gears”, the young child to make transitions, the mind to let go of problems and concerns, and the body to stop ritualistic movements and tics. It contributes to the brain circuitry that oversees attention, the social self, and personality, and is closely aligned with the *amygdala*. The *posterior cingulate gyrus* , meanwhile, is closely aligned with *para-hippocampal cortices* and shares in the memory-making process. It provides orientation in space, as well as eye and sensory monitoring services (Voght, Finch & Olson, 1992).

The entire *cingulate gyrus* (both *anterior* and *posterior*) divides the two hemispheres. The *anterior cingulate cortex* (ACC) is closely associated with the *anterior ventral medial site* that is central to the *prefrontal cortex*. The *anterior cingulate* is in the *frontal lobes* and the *posterior cingulate* (PCC) is in the *parietal lobes*. The *cingulate gyrus* intersects the *central sulcus* at the *vertex*. The *cingulate* is referred to as the *cortical portion* of the *amygdala*. Damasio (1994, p. 71) summed up the operations of the *cingulate* by stating

> I would like to propose that there is a particular region in the human brain where the systems concerned with emotion/feeling, attention, and working memory interact so intimately that they constitute the source for the energy of both external action (movement) and internal action (thought animation reasoning). This 'fountain-head' region is the anterior cingulate cortex, another piece of the limbic puzzle.

The *anterior cingulate cortex* is known to monitor and control attention and impulse control, keeping one motivated and on task. It is in the home of the *primary* and *secondary motor cortices* that control movement and activity (Demos 2005).

3.2.5. Deeper brain structures

Beneath the lobes of the *cerebral cortex* is a complex network of connections and structures.

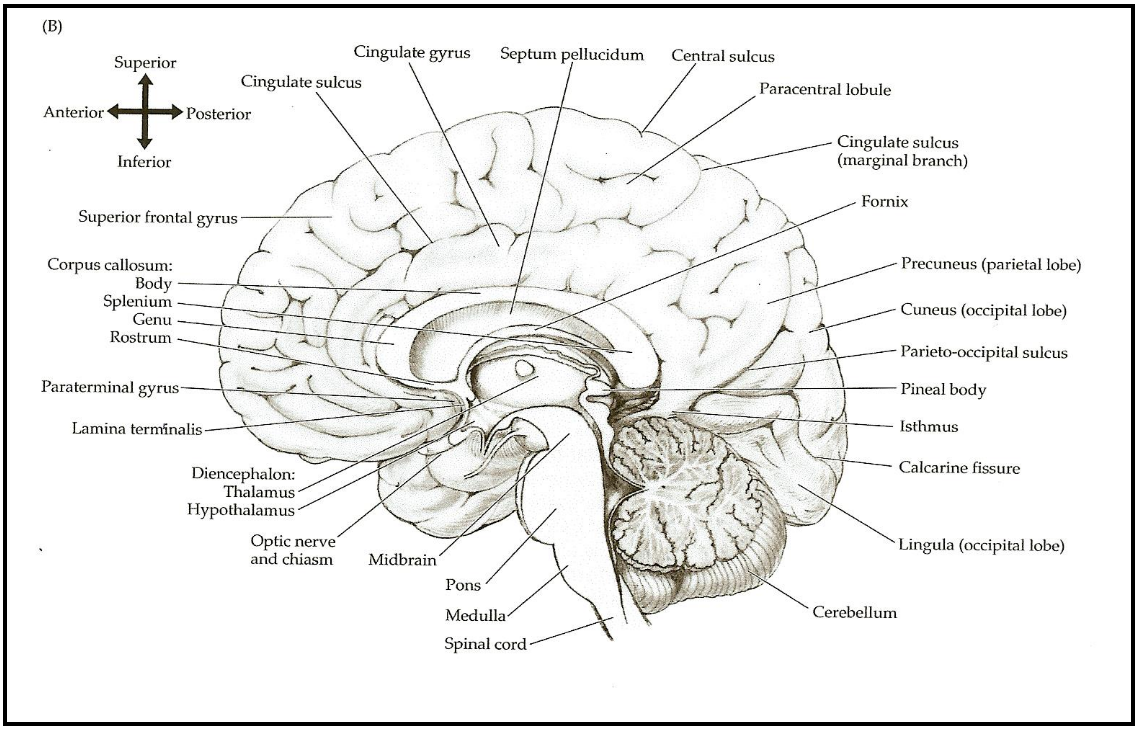


Figure 10. Medial view of right hemisphere (Blumenfeld, 2002)

Beneath the layers of the cerebral cortex lie key supporting structures, a brief description of a few of which follows.

3.2.5.1 The limbic system

The *limbic system* is thought to be the seat of emotion, even though the right cerebral hemisphere also is involved in processing emotions and feelings. Within it we find the *hippocampus*, *amygdala*, *olfactory button*, *septum*, a portion of the *thalamus*, and the *fornix*. The hypothalamus is included as part of the *limbic system* by some but not all researchers (Blumenfeld, 2002).

The *hippocampus* stores conscious memories and orchestrates the process of making a memory permanent. Information that is combined with emotion may be stored faster because the *hippocampus* is contained within the *limbic system*, in proximity to the *temporal lobes*. The *left temporal lobe* seems to work closely with the *hippocampus* in the memory-making process. The connections between the *prefrontal cortex* and the *hippocampus* serve to enlist the representation as a contextual cue that forms part of an episodic ensemble of information (Thierry, Gioanni, Degenetais & Glowinski, 2000). The more salient the context the more important it becomes for enhancing the retrieval or recognition of episodic memories. Thus, the *hippocampus* also serves to help bind the activation of objects, words, faces, scenes, procedures and other information stored in posterior cortices and basal structures to representation-based contextual information, such as themes or plans. Furthermore, the *hippocampus* may be involved in the linkage of sequentially occurring events. The ability to explicitly predict a subsequent event requires conscious recollection of forthcoming events and should require the participation of a normally functioning *hippocampus*.

The *amygdala* stores unconscious memories, which like the *hippocampus* has reciprocal connections with the *prefrontal cortex*. The former, in particular, has extensive connections with the *ventromedial prefrontal cortex* (Price, 1999; Zalla et aI., 2000). Its signals may provide a somatic marker or cue to the stored information ensemble in the *ventromedial prefrontal cortex* representing social attitudes, rules, and knowledge. The more salient the input provided by the somatic cue the more important the somatic marker becomes for biasing the activation of social knowledge and actions. Early childhood trauma may still govern adult behaviour. Sharp negative reactions may follow a simple trigger in the environment, such as a particular smell, facial expression, hair colour, or style of clothing. The reaction does not necessarily follow a clear memory of details, rather, it is inward-knowing, a memory that has been driven in by fear (Van der Kolk, McFarlane & Weisaeth, 1996, p. 230). The aggression of temporal lobe epilepsy may be in part driven by its proximity to the *amygdala* in the brain. There are many cerebral cortex connections to the *amygdala*, including the *anterior ventral medial cortex*, the *visual cortex* and the *temporal lobes*. The emotion of the *amygdala* is not always dark, but is also involved in positive feelings and emotions.

The *thalamus* is an editor for sorting and directing sensory information and emotions, and moderates between sensory information and the *cerebral cortex*. Its influence over the *cerebral cortex* and the EEG were reported by Marieb (1995, pp. 393-395). In addition to sensory inputs, most inputs ascending to the *cerebral cortex* are funnelled through the *thalamic nuclei*, thus the *thalamus* plays a key role in meditating sensation, motor activities, cortical arousal, and memory. It is the gateway to the *cerebral cortex*.

The *hypothalamus* is just below the *thalamus*. A key player in the control of the endocrine system and the autonomic nervous system (ANS), it influences eating, body temperature, sleep, and emotional responses. It has the job of activating the fight-or-flight response, arouses the sympathetic nervous system and the endocrine system, and prepares the body to take action. It is also part of the chain of command that calms things down by activating the *parasympathetic nervous system*.

3.2.5.2 Reticular formation

The *reticular formation* sends a continuous flow of impulses toward the cerebral cortex, and keeps the brain alert, awake and ready to receive more information: "The outstanding feature of the reticular neurons is their far-flung axonal connections. Such wide spread connections make reticular neurons ideal for governing the arousal of the brain as a whole" (Marieb, 1995, p. 402). The *reticular activating system* (RAS) is an "arm of the reticular formation", and filters out sensory data. For example, it can shut out sensory data in noisy and crowded environments to prevent sensory overload. The *hypothalamus* and other neuronal circuitry shut it down when it is time for sleep (Marieb, 1995).

3.2.5.3 Cerebellum

The word *cerebellum* literally means "little brain." It is beneath the occipital lobes and it protrudes beyond them, keeping the body erect and governing posture. The lobes of the *cerebellum* work in conjunction with the *cerebral cortex* to carry out voluntary muscle movements. It processes information coming from *proprioceptors* throughout the body then it becomes possible to direct and coordinate muscle movements smoothly and efficiently.

3.2.5.4 Basal ganglia

Together with the *cerebellum* the *basal ganglia* act by modulating the output of the *cortico-spinal* and other descending *motor systems*. They receive direct connections from different regions of the *prefrontal cortex* and some of these connections may carry cognitive 'commands'. The *basal ganglia*, in turn, send back to the *prefrontal cortex*, via the *thalamus*, signals that reflect their own processing. Even if the *basal ganglia* work in concert with the *prefrontal cortex*, their exact role in cognitive processing is still debatable. It appears to play a role in the storage of visuomotor sequences (Pascual-Leone, Grafman, Clark, Stewart, Massaquoi, Lou & Hallett, 1993; Pascual-Leone, Grafman & Hallett, 1995), in reward related behaviour (Zalla, Koechlin, Pietrini, Basso, Aquino, Sirigu & Grafman, 2000), and in automatic cognitive processing, such as over-learned word retrieval. It is likely that the representations in the *prefrontal cortex* bind with the visuomotor representations stored in the *basal ganglia* to produce an integrated set of cognitive and visuomotor actions (Koechlin, Corrado, Pietrini & Grafman, 2000; Koechlin, Danek, Burnod & Grafman, 2001; Pascual-Leone, Wassermann, Grafman & Hallett, 1996).

3.3. THE NEUROPSYCHOLOGY OF FLOW AND MOTOR PERFORMANCE

The words “conscious” and “consciousness” are umbrella terms applied to both whole organisms (creature consciousness) and to particular mental states and processes (state consciousness) (Rosenthal, 1986; Carruthers 2000; Gennaro 2004). Following the state consciousness paradigm in cognitive and neuropsychology, consciousness is defined by integrative neural structures and processes, as discussed in the previous section, underlying various attributes of neurocognitive functioning, such as attention, awareness, arousal, pattern recognition, memory, perception, knowledge and reasoning. Flow, purported to be a heightened state of consciousness, will thus be defined by the same neural structures and processes, although organised in an altered, unique pattern under conditions of peak performance. This peculiar pattern of cognitive functioning will be explored below.

3.3.1 Cognitive functioning

In cognitive psychology, cognitive functioning is traditionally described from either an information processing point of view or from a connectionist approach. The latter emphasises cognition as a neuronally based, parallel-processing cognitive system that works as a unit and cannot be broken into parts. The information processing approach to cognition emphasises an abstract, serial analysis of cognitive processes, which implies that cognitive functioning is hierarchically ordered with a modular organisation, into identifiable sub-systems. In the next section, features of both approaches will be used, firstly to conceptualise a model for consciousness and cognitive functioning, and secondly, based on the first, to propose a model for flow as an optimal state of cognitive functioning.

A probable hierarchy for consciousness and cognitive functioning, as illustrated below, is then discussed.

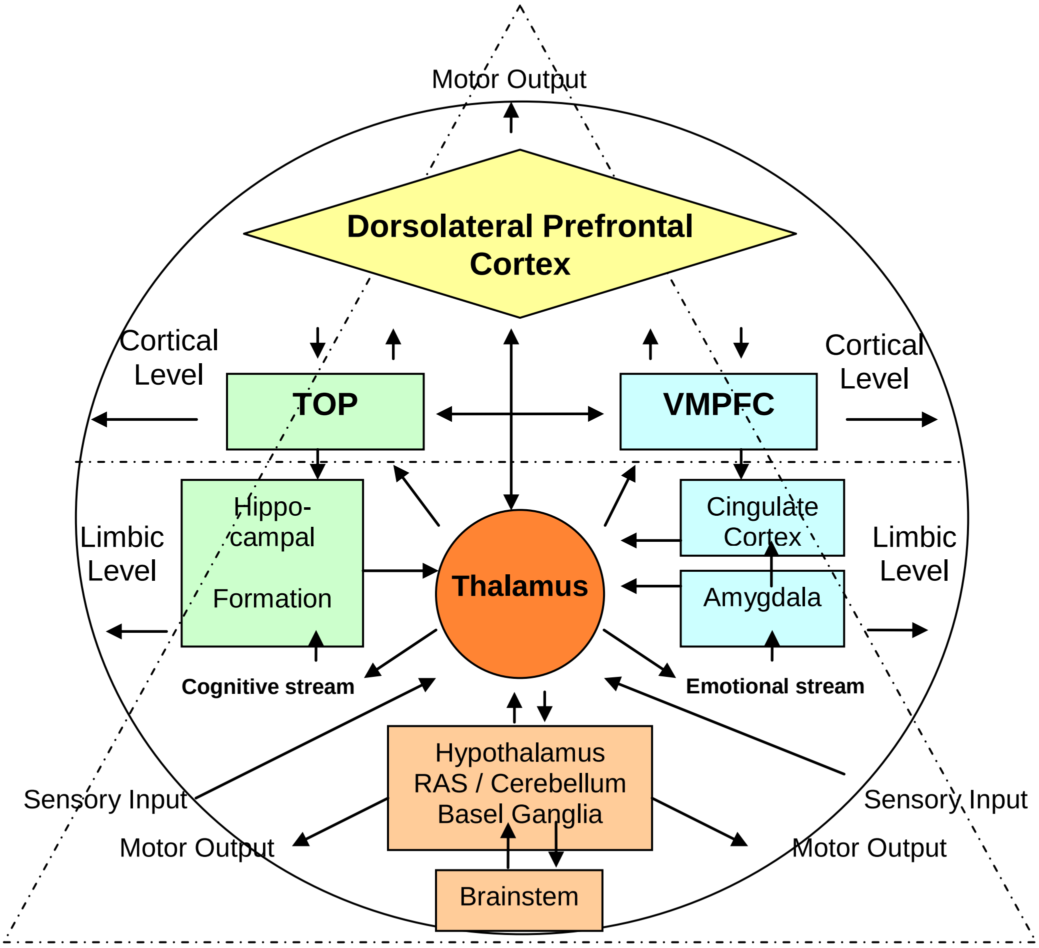


Figure 11. Hierarchy of consciousness (adapted from Dietrich, 2003).

The model illustrates the hierarchical organisational structure of consciousness, with the *dorsolateral prefrontal cortex* (DLPFC) as the higher order seat and the *thalamus* as the lower order seat of consciousness. It further illustrates that cognitive and emotional information processing follows different neural pathways that splits at the *thalamic* structures, and culminate in the DLPFC. The *cognitive stream* includes the *hippocampal formation* and the *temporal*, *occipital* and *parietal* areas (TOP), while the emotional stream includes the *amygdale*, *cingulated cortex*, and the *ventromedial prefrontal cortex* (VMPFC).

Dietrich (2003) describes consciousness as hierarchically ordered cognitive functioning, in which no single neural structure is necessary and sufficient to constitute consciousness. The *cerebral cortex,* in particular the *prefrontal cortex*, is at the top of the hierarchy, representing the neural basis of higher cognitive functions (Frith & Dolan, 1996; Fuster, 2000). The *limbic structures* provide the lower order or primary neural circuitry for consciousness.

According to Ulric Neisser (1967), cognition begins with sensory input. The senses bring energy, loaded with information, from the physical world outside the body into the neural and cognitive systems. Information processing is central to cognitive functioning and is the “data management system” of the brain.

3.3.2 Information processing: attention, cognition and emotion

The cornerstone of conscious information processing is ‘attention’, which refers to both the preparedness for and selection of certain aspects of the physical environment, for example, objects, or some ideas in the mind that are stored in memory. Posner proposed and provided strong empirical evidence for a three-network view of attention involving alerting, orienting, and executive processes (Posner, Inhoff, Friedrich & Cohen, 1987).

‘Alerting’, also known as ‘sustained attention’, ‘vigilance’, and ‘alertness’, is the ability to strengthen and maintain response readiness in preparation for an impending stimulus (Raz & Buhle, 2006). ‘Orienting’, or ‘scanning/selection’, is the ability to choose between incoming sensory information (Lang, 2000; Lynn, 1966). ‘Executive attention’ is also described as ‘selective attention’, ‘conflict resolution’ and ‘focussed attention’. These computations involve planning or decision-making, error-detection, new or not well-learned responses, conditions judged to be difficult or dangerous, regulation of thoughts and feelings, and the overcoming of habitual actions. Some consider any instance of top-down control as executive attention, whereas others construe it as the monitoring and resolution of conflict between computations in different neural areas (Raz & Buhle, 2006).

The next component in the information processing system is the sensory system, which generates a code to the incoming information before it is passed on to the memory. According to cognitive psychology, there are two types of memory, i.e., permanent memory and working memory. Permanent memory can be considered a vast depository of both declarative knowledge (storing facts) and procedural knowledge (skills and motor programmes). Working memory may be likened to the “scratch pad” of the brain, a kind of workbench for cognitive codes and the site in which goals are established (Best, 1999).

When solving problems, a “central processor” allocates attention to the cognitive processes involved in code modification (matching and altering possible solutions and operations) and monitoring (tracking). It is also the centre from where the response system is controlled (Best, 1999). The concept of a central processor can be associated with the concept of “global workspace” propagated by Baars (1997). According to Global Workspace Theory (GWT), sensory information integrates in a “central space” on a conscious and unconscious level, whether cognitive or emotional, and serves as an exchange platform for input and output processes in order to assign limited attentional resources to selective stimuli. The “global workspace” can thus be seen as an “executive controller” of information flow in the brain and therefore requires a neural architecture to execute such functioning.

Figure 12 (below) illustrates the working of the information processing system.

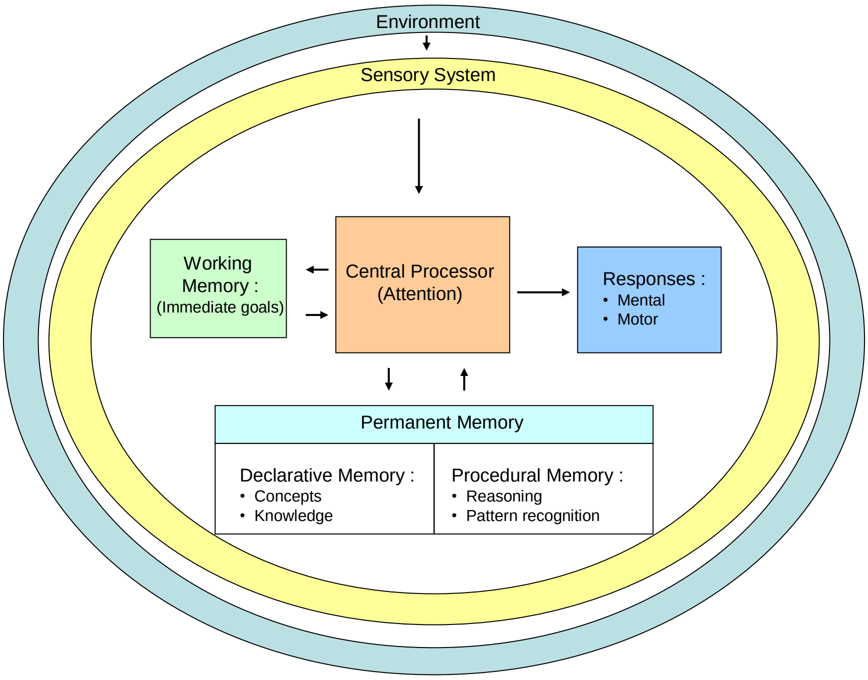


Figure 12. The human information processing system (adapted from Best, 1999).

As described above, the *thalamus* is regarded as an ‘editor’ for sorting and directing of sensory information, including emotion. It plays a key role in mediating sensation, motor activities, cortical arousal, and memory, and is considered the gateway to the *cerebral cortex*. With reference to the “central processor” or “executive controller”, the *thalamus* can probably be seen as the lower order seat of central processing or “global workspace”.

According to LeDoux (1996), two distinct tracks of information processing start to diverge at the level of the thalamus. With the first track, initial processing of emotional content (see Figure 9 above) occurs in various *limbic system* structures such as the *amygdala*. The computational product of is used by the next levels of affective processing represented by the *anterior cingulate cortex* (ACC) and the *ventromedial prefrontal cortex* (VMPFC) (Damasio, 1994).

LeDoux (1996) postulated that the emotional brain is designed to attach a value tag to the incoming information that allows the organism to evaluate the biological significance of a given event. On the other hand, a separate and parallel line of information processing that is devoid of any salient information is designed to perform detailed feature analysis. This perceptual evaluation of the environment is used to construct sophisticated representations that function as the basis for cognitive processing. Each line of information processing contains a functional hierarchy in which increasingly higher-order structures perform progressively more sophisticated computations. These two functional systems can be dissociated not only anatomically but also in the way they process information.

Unlike the computational mode of the cognitive system, the emotional system appears to compute information in a non-algorithmic, skilled-based manner (Churchland, 2002). Each system keeps a record of its activity so that emotional memory is part of the emotional circuitry and perceptual and conceptual memory is part of the cognitive circuitry (LeDoux, 1996).

Emotional control, which is associated with self-discipline and achievement, self- esteem and confidence, and closedness to new ideas, is linked to the *middle frontal* and *superior frontal gyri* extending medially to the ACC, and the *inferior parietal cortex*. Several studies investigating different aspects of emotional processing have also observed activation in similar regions of the prefrontal and parietal lobes (Cunningham, Johnson, Gatenby, Gore & Banaji, 2003; Heinzel et al., 2005; Paul et al., 2005). For example, it has been suggested that the *medial prefrontal cortex* has a general role in emotional processing, and the ACC in emotional recall and imagery (Phan, Wage, Taylor & Liberzon, 2002). These regions may provide the critical resources in the top-down control processes necessary for conscious emotional control, in response to incoming emotional information (Williams et al., 2006).

According to LeDoux, (1996), the second tract is the cognitive system (see figure 3.4), which is represented by another set of *limbic structures*, primarily the *hippocampal formation* and the *temporal*, *occipital*, and *parietal cortices*, which will be collectively referred to as TOP, with TOP neurons devoted primarily to perception and long-term memory (Dietrich, 2003). The *primary sensory cortices* of all sense modalities are located in TOP and its *association cortex* further assembles and assimilates sensory information decoded initially in the *primary cortex*. The required level of selective attention to process the information is also supplied by these structures (Taylor, 2001). It is generally agreed that TOP is the site of long-term memory storage (Gilbert, 2001). Although there are multiple connections at various levels between the two information processing systems, full reintegration of emotional and cognitive information does not appear to happen until both types of computations converge back on the *dorsolateral prefrontal cortex* (DLPFC) (Fuster, 2000).

In studies on monkeys it was found that the DLPFC has preferential connections with many motor system structures, and may be the primary regions by which the *prefrontal cortex* exerts control over behaviour. The DLPFC is interconnected with motor areas in the *medial frontal lobe*, such as the *supplementary motor area* (SMA), pre-SMA, and the *rostral cingulate*, with the *premotor cortex* on the *lateral frontal lobe*, and with the *cerebellum* and *superior colliculus* (Goldman & Nauta, 1976; Bates & Goldman-Rakic, 1993; Lu, Preston & Strick, 1994; Schmahmann & Pandya, 1997). The DLPFC also sends projections to the frontal eye fields, a region important for voluntary shifts of gaze. As with the *sensory cortex* there are no direct connections between the *prefrontal cortex* and *primary motor cortex*. Rather, it is connected with premotor areas that, in turn, send projections to the *primary motor cortex* and the *spinal cord*. Also important are the dense interconnections between the *prefrontal cortex* and *basal ganglia*, a structure that is likely to be crucial for automating behaviour. The *basal ganglia* receive inputs from much of the *cerebral cortex*, but its major output, via the *thalamus*, is to the *frontal cortex*.

By contrast, in humans, the DLPFC does not receive direct sensory input, is not involved in emotional computations, and does not store long-term memory. It is involved in executive function, that is, it further integrates already highly processed information, supplied by the TOP regions and VMPFC, to enable still higher cognitive functions such as self-construct, self-reflective consciousness, abstract thinking, cognitive flexibility, planning, willed action, and theory of mind (Dietrich, 2003). It formulates plans and strategies for appropriate behaviour in a given situation and instructs the adjacent motor cortices to execute its computational product. At all levels of the functional hierarchy, neural structures have direct access to activating the motor system, but behaviour that is based on prefrontal activation is more complex.

Three other cognitive functions of the DLPFC, working memory (Goldman-Rakic, 1992; Baddeley, 1996; Fuster, 2000), temporal integration (e.g., Fuster, 1995; Knight & Grabowecky, 1999), and sustained and directed attention (e.g., Posner, 1994; Sarter, Givens & Bruno, 2001) provide the infrastructure to compute these complex cognitive functions by actively attending to information, providing a buffer to hold that information in mind, and ordering it in space-time (Dehaene & Naccache, 2001; Duncan & Owen, 2000). With reference to its role as "central processor" or "executive controller", the DLPFC can probably be seen as the higher order seat of central processing.

In line with the two-tract theory, Rowe et al. (2007) found that social cognitive function is underpinned by distinct structures and neural function, and often represents more automatic and unintentional processing, in contrast to effortful and intentional cognitive processing involved in general cognition. Core domains of general cognitive ability include information processing speed, memory (verbal and working), attention, sensory-motor, verbal (such as fluency) and executive planning functions. Social cognitive functions, on the other hand, include aspects of emotional intelligence, such as emotional regulation and control and the capacity for effective interpersonal interaction, and emotion processing biases, such as the "negativity bias" towards expecting and perceiving negative events.

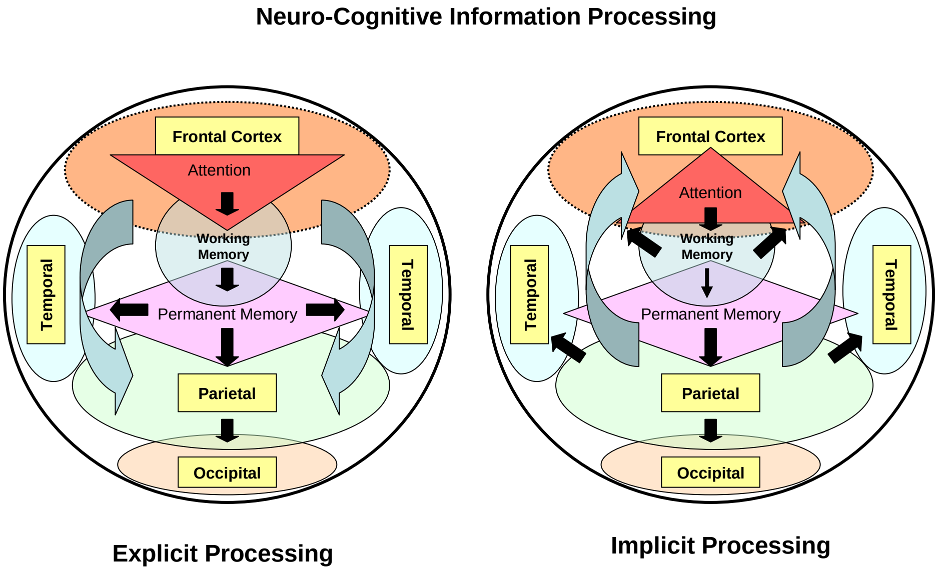
With regards to working memory, the view emerging from the cognitive and neuro-scientific literature is that it contains the content of consciousness (Baddeley, 1996; Courtney, Petit, Haxby & Ungerleider, 1998). In other words, immediate conscious experience of the here and now is made possible by the sustained buffering of information in working memory. It is this ability to superimpose already highly complex mental constructs that dramatically increases cognitive flexibility.

Bottom–up processes are complemented by top–down processes, as the DLPFC appears to exert inhibitory control over inappropriate or maladaptive emotional and cognitive behaviours. Francois Lhermitte documented this tendency by showing that frontal lobe patients are overly dependent on immediate cues. They tend to act on what they see without taking into account the wider context (Lhermitte, Pillon & Serdaru, 1986).

Imaging studies have shown that the *prefrontal cortex* is activated during object and spatial tasks (Courtney, Petit, Maisog, Ungerleider & Haxby, 1998; Prabhakaran, Narayanan, Zhao & Gabrieli, 1999), one finding not only that overlapping regions of it were activated by 'what' and 'where' input, but also that the it was more activated when subjects needed to integrate these attributes in working memory than when they could remember each separately. This suggests that the *prefrontal cortex* is particularly engaged in tasks that require integration, thus, the *frontal lobe* provides for cognitive flexibility and freedom, and it releases one from subjection to direct environmental triggers or the memory stored in the TOP regions (Dietrich, 2003).

3.3.3 Explicit and implicit systems

According to Dietrich (2004), in addition to the type of information or knowledge, whether emotional or cognitive, the weight of evidence suggests that the brain also operates two distinct information processing systems to acquire, memorise, and represent knowledge. Once information has entered the sensory system and is coded with a cognitive and/or emotive tag it is further processed by either an explicit or implicit information processing system. The two systems are illustrated in Figure 13 (below) then discussed in more detail.


Neuro-Cognitive Information Processing

Explicit Processing

Implicit Processing

Figure 13. Explicit vs implicit information processing

The explicit system is characterised by conscious processing that requires broad-based attention with high demand on *frontal lobe* structures and working memory. The implicit system is characterised by unconscious “automatic” processing that requires low demand for attention and working memory and is largely driven by *posterior* and *limbic* structures.

With reference to Figure 3.6 (above), the explicit system is rule-based, its content expressible by verbal communication and tied to conscious awareness. In contrast, the implicit system is skill- or experience-based, its content not capable of being verbalised, only conveyable through task performance, and inaccessible to conscious awareness (Ashby & Casale, 2002; Dienes &| Perner, 1999). Similar distinctions, such as between conscious and unconscious, declarative and non-declarative, voluntary and automatic, or deliberate and spontaneous, have been made in other domains. Although probably uncommon, information can be acquired exclusively by either system. Implicit learning ‘‘takes place largely independently of conscious attempts to learn and largely in the absence of explicit knowledge about what was acquired’’ (Reber, 1993, p. 5). A prototypical example is language acquisition in children.

In contrast, explicit learning proceeds through the conscious application of rules. In this process, the explicit system forms a mental representation that includes not only the actual information but also knowledge, about what is acquired and the fact that it was acquired. A prototypical example might be learning a second language in adulthood.

Most often, learning engages both systems simultaneously. Studies on neurological patient populations and health subjects suggest that a typical learning situation results in the formation of two distinct mental representations, one explicit and one implicit (Schacter, 1987; Dienes & Perner, 2002). Because each system sub-serves different functions it is unlikely that either representation alone is a complete characterisation of the learned task. While some information may be represented in both systems, other information may reside in one but not the other.

Learning to drive a car, for example, requires a variety of tasks that are exclusively explicit, such as the sequence of events and rules of driving, while a variety of other tasks, such as changing gears and turning, are largely implicit. The degree to which either system has a complete representation depends on the amount of practice and the nature of the task. Considering, for instance, language, a person’s native language is entirely learned and largely represented in the implicit system, but with considerable study the explicit system can develop its own representation of the phonology, semantics, and grammar, which will enable a person to teach the language to others. On the other hand, a second language that is learned in adulthood is acquired painstakingly by the explicit system with no feeling or intuitive understanding for it. However, with extensive practice the knowledge can also become represented in the implicit system.

Thus, knowledge can be explicit and/or implicit, but is mostly represented in varying, partially overlapping degrees of each. The nature of the task appears to determine the initial degree of explicitness and implicitness. Implicit knowledge can be thought of as task-specific, that is, it is inaccessible to other parts of the system and thus less versatile (Karmiloff-Smith, 1992). Explicit knowledge on the other hand can dramatically increase behavioural flexibility, because it can be broadcast to a so-called “global workspace” (Baars, 1997), which allows one to test conflicting hypotheses and to integrate seemingly counter-intuitive notions about the world.

According to Toates (2006), with extensive repetition of flexible behaviour, a behavioural system can change its parameters to acquire some features of a reflex (Dickinson, 1985) or modal action pattern (Barlow, 1977). Behaviour becomes automatic, stereotyped, and under stimulus control. The adjustment points to the adaptive value of exploiting the benefits of speed and simplicity, as reflected by the term ‘automaticity’ (Baars, 1988; Schneider & Shiffrin, 1977).

Neumann (1984, p. 258) notes that the course of an automatic process is determined by relatively permanent structural connections, either wired-in or acquired through practice. According to Wilhelm Wundt (in Neumann, 1984, p. 280), without automaticity, a sensory event and a motor action have to be linked by a conscious act. Automatisation occurs during practice if there is an invariant relationship between the sensory event and the subsequent motor action. This results in the establishment of direct neural connections between them, so that the sensory event can lead to the proper action without any conscious mediation.

The above ties in with the abovementioned theory of Fitts and Posner (1967), which posits that the learning process is sequential and that we move through specific phases or stages as we learn. There are three stages to learning a new skill, firstly, the *cognitive*, during which the learner discovers dimensions of time, space, force and flow (sequence) through the identification and development of the component parts of the skill. The second stage is *associative*, during which the component parts are linked into a smooth action and the skill is practised using feedback and error correction. The final stage is *autonomous*, during which the learned skill becomes automatic. It involves little or no conscious thought or attention and the learner acquires the ability to focus attention on other important details in the environment whilst performing the skill.

Fitts and Posner (1967) also found that learning follows an S-shaped learning curve, which is most evident when someone learns a highly complex task. In the initial cognitive phase the curve rises slowly as a person becomes familiar with basic components of a skill. The steep ascending associative phase occurs when there is enough experience with rudiments or simple components to start putting it all together. Rapid progress follows until the autonomous phase, when the skill stabilises at a high level.

Integrating the implicit/explicit theory, the Fitts and Posner learning process, and the automaticity principle of Wundt, together with the S – curve, the process of skill acquisition and optimisation, are illustrated as below.

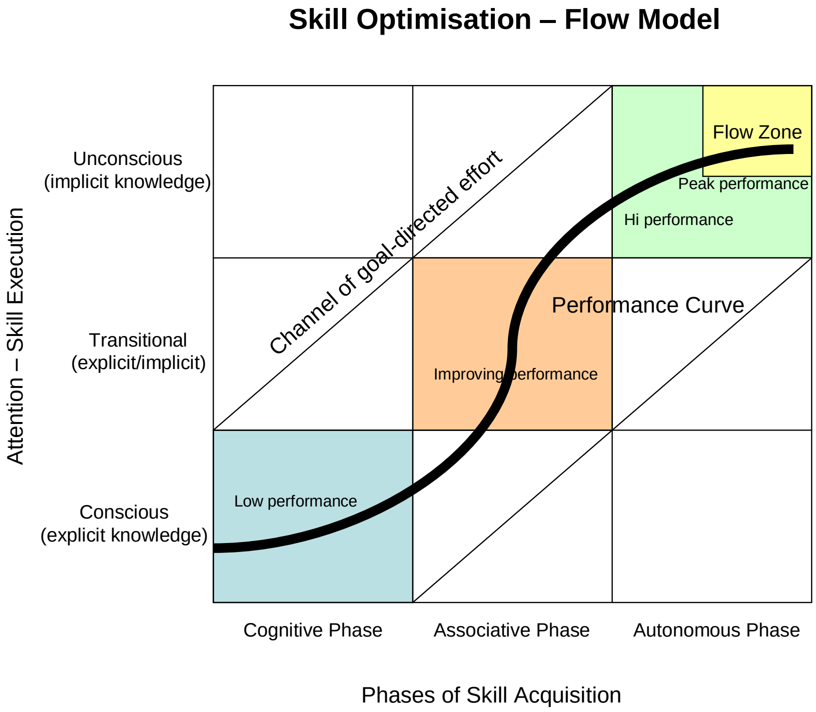


Figure 14. Skill acquisition and optimisation

Figure 14 (above) indicates that the process of skill acquisition starts with a conscious process during which attention is focussed on the goal of acquiring explicit knowledge regarding the composition and execution of the skill. During this phase, performance is low and conscious effort is put into learning, hence the term cognitive phase. As learning progresses through repetition, explicit knowledge becomes entrenched and transforms into implicit knowledge, performance improves because fewer errors are made, and attention is freed up for other use. Once explicit knowledge has transformed into implicit knowledge, unconscious, effortless execution of the skill is achieved, which is characterised by a perception of automaticity. During this phase, performance is delivered at peak output and attention is mostly applied to focussing on essential environmental cues aligned with goal achievement behaviour. Automaticity implies that skill and challenge are balanced, attention is directed towards goal accomplishment, and flow is likely to occur.

Toates (2006) argues that, considering conscious control to be a type of higher-order control, the link with unconscious processes does not become entirely functionally severed following a move to automaticity. The probability of engaging automatic processes appears to be modulated by conscious intentions, pointing to joint responsibility and thereby integration between controls. Although the sequence of events is not mediated via conscious processing it usually only occurs if an appropriate conscious intention is present. The above executive process can be deductively linked to the executive control of the executive controller within the context of global workspace.

In line with the above concepts of implicit and explicit information processing, global workspace theory, and the concept of automaticity, Luu et al. (2009) describe information processing in terms of a slow circuit and a fast circuit. Accordingly, the outcome of successful learning reflects the integrated function of self-regulatory processes, such as regulation of motives, action monitoring, memory encoding and retrieval, controlled by specific *corticolimbic* networks. According to Luu et al. (2009), the *prefrontal lobes* and *anterior cingulate* have been observed to be strongly engaged early in the learning cycle when stimulus-response mappings are actively being established (Toni, Krams, Turner & Passingham, 1998; Chein & Schneider, 2005; Luu et al., 2007). In later stages of learning, however, once contingency mappings have become consolidated, these *frontal* structures exhibit a reduction in activity. In contrast, *posterior* regions demonstrate increased activity during these later stages (Toni & Passingham, 1999; Chein & Schneider, 2005; Luu et al, 2007). The reduction of activity observed in *frontal* structures in later stages of learning appear to represent reduced reliance on top-down control systems once learning has been established, while the increased activity observed in *posterior* structures may represent the establishment and automatisation of the learned action patterns as well as continued monitoring of performance (Toni & Passingham, 1999; Chein & Schneider, 2005). During a visuomotor learning task it was found that *posterior cortical regions*, including *parietal*, *posterior cingulated cortex*, and *para-hippocampal cortices*, as indexed by the P3 scalp position, became progressively engaged as participants discovered and learned stimulus–response mappings (Luu et al., 2007).

According to Luu et al. (2009), the evidence from neurophysiological activity in feedback processing indicates *fronto-limbic* response to feedback, indexing the functions of the fast learning system. This is strongest during early learning and declines as subjects consolidated the stimulus–response mappings during learning. Similarly, the index of activity in the slow learning system (P3 – *parietal lobe*) supports the notion that the slow learning system decreases its activity in response to correct.

As actions become more automated, contextual representation appears to transfer to posterior networks such as the *posterior cingulated cortex* (PCC) (Gabriel, Burhans, Talk & Scalf, 2002). Therefore, in a fully automated stage of learning and action control (as described above, representing the top end of the S-curve), it would be expected that activity in the *dorsal anterior cingulated cortex* (ACC) decreases, unless an error is committed, in which case there will be a strong ACC response. In an fMRI study, Toni et al. (1998) found that learning a sequence of motor responses is associated with an initial rise in dorsal ACC activation, followed by sustained activity and then an eventual decline. By emphasising the ACC's role in representing the context for action, the theoretical links between the context representation supported by other dorsal cortical networks, including the PCC and *hippocampus*, are recognised.

The role of frontal and temporal regions in visuomotor learning has been attributed to memory operations, in which targets take on associative meaning (Toni, Ramnani, Josephs, Ashburner & Passingham, 2001; Bunge, Kahn, Wallis, Miller & Wagner, 2003; Brovelli, Laksiri, Nazarian, Meunier & Boussaoud, 2007). Results from memory studies suggest that the *ventrolateral prefrontal cortex* is involved in memory retrieval through its interaction with temporal lobe structures, including the *hippocampus* (Simons & Spiers, 2003; Badre et al., 2005).

Passingham, Toni & Rushworth (2000) noted that the *ventral* aspects of the *prefrontal lobe*, including the *inferior frontal gyrus*, have been shown to be involved in the representation of the stimulus, the responses made to the stimulus, and the feedback (i.e., outcome) of the action. These representations are central to acquiring visuomotor associations.

Luu et al., (2009) concluded that as participants learn a task, representations of the task parameters (for example, stimulus–response mappings, feedback contingencies) that can be understood as forming rule-related expectancies, gradually develop within the slow learning system (Keng & Gabriel, 1998) and violations of the context (i.e. post-learned errors) require template or contextual updating mechanisms (Donchin & Coles, 1988; Gonzalvez et al., 1999), perhaps supported by additional control processes, as reflected in the involvement of the *medial prefrontal cortex*.

An alternative explanation for the observed increase of the P3 amplitude for error feedback after learning is that errors are rare and error feedback is more salient. This results in attention being allocated preferentially to error feedback, which would produce a large P3 response.

The above research infers that the explicit learning pathway of Dietrich and the fast learning system proposed by Luu, present with many commonalities and can be seen as a pre-dominantly PFC driven neural pathway, to deal with the cognitive/executive part of skill acquisition and mastery, while the implicit, slow learning systems, are responsible for skill automation, driven mainly by the so-called TOP and *limbic* structures.

3.3.4 Flexibility versus efficiency

As reviewed above, multi-dimensional tasks are more likely to be embedded implicitly, due to the capacity limit of working memory (Cowan, 2001). Controlled studies, in which subjects are prevented from rehearsing, or chunking, support a capacity limit of 4 ± 1 items that can be held in working memory at a time (Cowan, 2001). Alternatively, it has been suggested that ‘‘working memory limitations are best defined in terms of complexity of relations that can be processed in parallel’’ (Halford, Wilson & Phillips, 1998, p. 723). Halford et al. (1998) have argued that the number of dimensions one can manipulate concurrently is one quaternary relation. Information of greater complexity overloads the capacity limit and invokes executive processes that collapse dimensions into fewer chunks and/or process chunks in a serial manner. This course of action, however, makes some information temporarily inaccessible. Thus, it is evident that explicit learning cannot occur if the rules governing the task reach a complexity that exceeds the capacity limit.

In contrast, the implicit system does not seem to be capacity-limited, for instance, a motor task such as a serve in tennis and what it would take to write a computer programme that specifies each muscle twitch, in the correct order and intensity, to make a world-class tennis serve. The computational difficulty of complex motion is great and the amount of information that must be held concurrently in the focus of attention, and thus working memory, far surpasses the capacity limit.

A complex motion, such as the tennis serve, is either learned by observation or, if learned through explicit instruction, by breaking it up into smaller components, each of which cannot contain more than four independent pieces of information. Once these are morphed into a single chunk, larger chunks can be combined to acquire intricate motion. To illustrate, using the example of learning to drive a car with the explicit instructions of the person in the passenger seat, the explicit system in the prefrontal cortex forms a mental representation of the task requirements and recruits the *pre-motor cortex* and *primary motor cortex* to execute it (Jenkins et al., 1994). This effortful process takes time because the capacity limit restricts the number of items that can be amalgamated at a time to smooth out motion.

As a result of this working memory cap, the *frontal attentional network* is fully engaged, making it impossible to attend to anything else, such as sightseeing or daydreaming. Neuroimaging studies have shown that skill acquisition activates the *prefrontal cortex*, the *pre-motor cortex*, the *parietal cortex* as well as the *cerebellum* (Jenkins et al., 1994). Synchronised oscillations have been found to be a neural correlate of integration processes during conscious perception (Engel & Singer, 2001), attention (Niebur, 2002), working memory (Sarnthein, Petsche, Rappelsberger, Shaw & von Stein, 1998) and recollection of episodic information (Klimesch et al., 2001).

Naghavi and Nyberg (2005) also found significant and consistent overlapping *fronto-parietal* patterns in studies of attention, working memory, episodic retrieval, and conscious perception. Figure 15 (below) illustrates the peaks of activation in *fronto-parietal* areas associated with the above processes. The overlap was most pronounced in the *bilateral parietal cortex* and the *dorsolateral prefrontal cortex*.

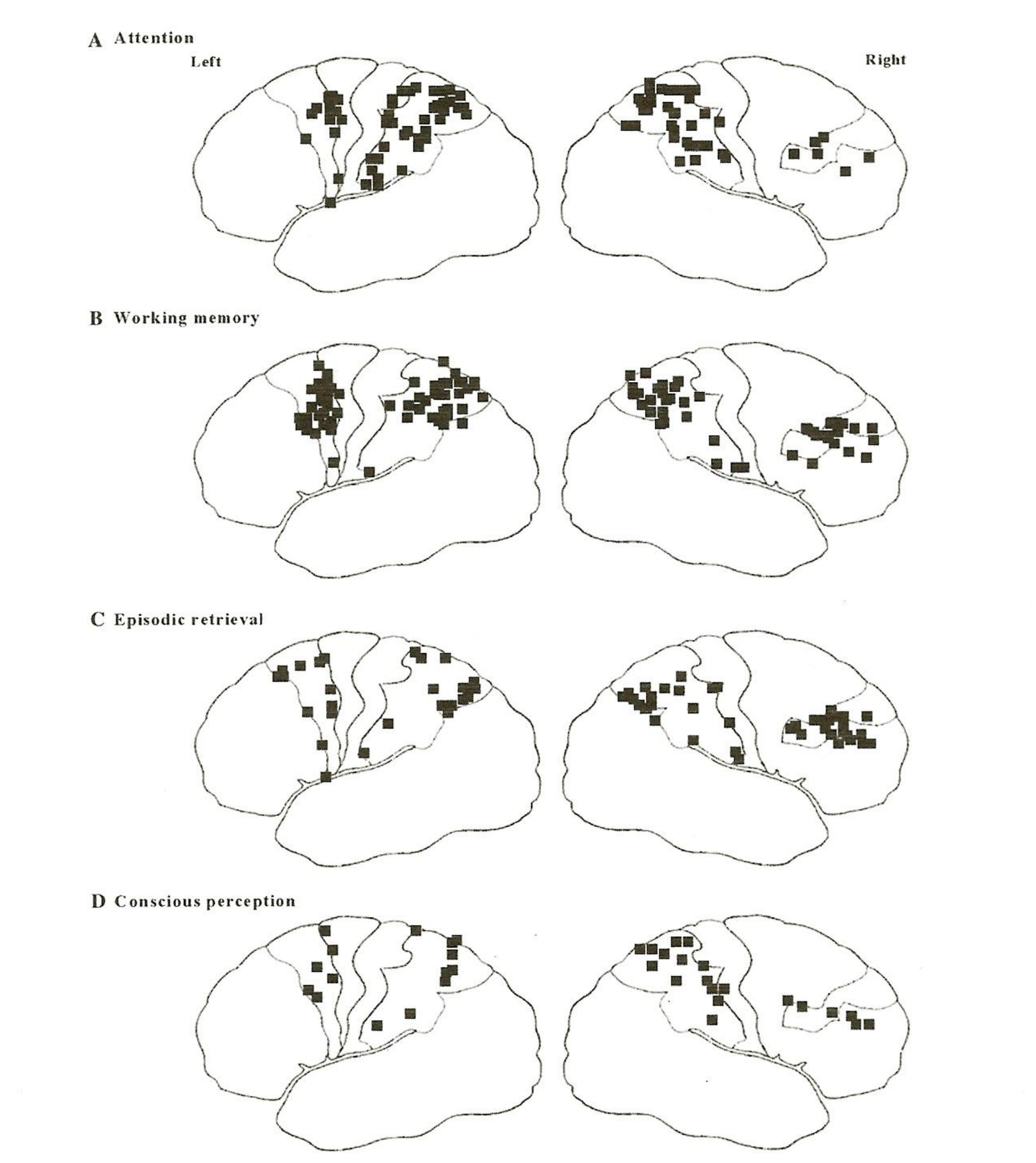


Figure 15. Peaks of activation in *fronto-parietal* areas associated with the indicated processes (Naghavi & Nyberg, 2005).

Although the above presentation clearly illustrates the high degree of anatomical overlap among activation patterns associated with the four mentioned functions, it does not confirm or suggest synchronous functioning, but merely simultaneous or parallel functioning. Studies have also shown that shifts in neural control occur as a function of practice so that the details of a motor task become gradually controlled by the *basal ganglia* (Mishkin, Malamut & Bachevalier, 1984) in a circuit that also includes the *supplementary motor cortex*, the *motor thalamus*, and the *hippocampus* (Jenkins et al., 1994). The implicit system thus builds its own mental representation, which is the equivalent of what is commonly, and misleadingly, known as ‘‘muscle memory.’’ An internalised, or skilled, motor pattern is controlled entirely by this *basal ganglia circuit* and little prefrontal activity is required during its routine execution. As the *basal ganglia* and *supplementary motor cortex* drives the car, aided by perceptual input from the *parietal cortex,* working memory is no longer tied up, allowing executive attention to fill its premium computational space with other content such as negotiating the traffic, listening to the radio, or daydreaming. This bypassing of consciousness by performance of implicit skill confirms on a neural level what has been known on a psychological level for some time, namely that to do two things at a time one has to be automatic, or implicit (Broadbent, 1958).

Processes that involve dissociations between cognitive processes, and disconnections between brain regions, together with selective inhibition and enhancement of abilities and processes, are similar to those appearing during hypnosis (Gruzelier, 2000). In a study regarding frontal functions, connectivity and neural efficiency underpinning hypnosis and hypnotic susceptibility, Gruzelier (2006) found that during hypnosis there was no commensurate increase in blood oxygenation in the left frontal cortex (LFC), in the subjects most susceptible to being hypnotised, as had occurred in the *anterior cingulated cortex* (ACC). This result represents an uncoupling or dissociation between the ACC and LFC with hypnosis. This interpretation was borne out by EEG recordings during the same task (Stroop – conflict monitoring) in a separate session (Gruzelier, 2000). EEG coherence measures indicate that following instructions of hypnosis, reduction in connectivity between the *anterior cingulated* and the *left dorsolateral prefrontal cortex* (F3 scalp position), as reflected in the gamma rhythm coherence, was characteristic of highly susceptible subjects. There was none with the converse effect in those with low susceptibility. This evidence assists in clarifying the nature of the alteration in frontal functions with hypnosis. The *left inferior frontal locus* that was activated has been implicated in contention scheduling and contextual control processes, including associating external cues with appropriate actions (Passingham, et al., 2000). This underscores the disruption of executive functions with hypnosis through dis-connectivity.

3.3.5 Interaction between explicit and implicit motor control

Anatomically, the *medial prefrontal cortex* is bilaterally interconnected to the *cingulate* and *supplementary motor areas* (Roullier, Liang, Babalian, Moret & Wiesendanger, 1994), which have strong bilateral connections to motor effectors (Penfield & Welch, 1949; Brinkman, 1984; Lim et al., 1994; Kazennikov et al., 1998) and to *basal ganglia nuclei* (Wiesendanger, Roullier, Kazennikov & Perrig, 1996). The putative specific role of these areas in the control of coordinated motor movement can be derived from recent neurophysiological evidence, indicating that medial prefrontal and anterior cingulate areas represent explicit processes (subject's intention, awareness) associated with bilateral motor sequences, having an inhibitory effect on automatic or implicit processes (Destrebecqz & Cleeremans, 2001; Destrebecqz et al., 2005), whereas *cingulate* and *supplementary motor areas* may represent the automatic or implicit processes, subserving temporal and ordinal representation of the motor sequence (Deiber et al., 1991; Ashe, Lungu, Basford & Lu, 2006).

In terms of information processing, such as during the learning of a skill, if information is part of the explicit and implicit knowledge base (driving a car or making a golf putt) the neural control of its execution is transferred from one system to the other. However, a skilled behaviour that is largely acquired implicitly, such as a golf swing, would have to be explicated first. This must proceed through induction processes (Dienes & Perner, 2002). Naturally, a skill is performed by a conscious person and is thus accompanied by conscious experience. This allows the explicit system to buffer the event and engage in hypothesis testing that will eventually lead to the extraction of the skill's critical elements. In similar fashion, a golfer has to use explicit knowledge to make a decision on club selection, taking into account implicit knowledge regarding what type of shot required.

It is notable that fully implicit knowledge cannot cause explicit knowledge through a bottom–up process. The implicit system cannot label the information itself as knowledge and thus cannot broadcast it to the system, preventing its use by other parts within that system. Only through the circuitous route involving actual behaviour can the explicit system come to embody an implicitly learned skill. This is exemplified when trying to retrieve a telephone number that is temporarily inaccessible. People typically solve that problem by dialling the number on an imaginary dial, using the execution of implicit knowledge to trigger explicit representation. That the implicit system cannot tell the explicit system directly what it does and why it does it, leading to the curious situation that one often cannot explain why one does what one does and leaving little choice but to explain that the behaviour was guided by intuition. This is a particularly common experience when trying to explain a motor skill to others.

Two studies further illustrate the way the explicit and implicit systems interact in skill performance. In an experiment by Bridgeman and colleagues (1991) and Bridgeman, Peery and Anand (1997), the motion of a rectangular frame across a computer screen created the apparent motion of a stationary dot placed inside the frame moving in the opposite direction. Subjects were briefly exposed to the visual illusion and then asked either to indicate verbally which of five marked spots best described the last location of the dot, or to point to that location using their hands. The verbal condition would engage the explicit system while the implicit system would control the steering of the finger. The results show that all verbal subjects were highly susceptible to the illusion, whereas half the subjects in the pointing condition could accurately specify the location of the dot. These results indicate that procedural knowledge is not only fast and efficient but also more accurate in real time sensory-motor integration.

The second piece of evidence is from an experiment by Castiello, Paulignan, and Jeannerod (1991). Subjects were seated in front of three candle-sized rods and were asked to grasp one as soon as it was illuminated. On some trials a rod was illuminated but after the subject had already started a visually guided movement to that target, the target was changed by illuminating a different rod. Not surprisingly, this resulted in a smooth and very rapid correction of the hand’s trajectory. The subjects were also asked to give a vocal indication as soon as they were aware of the switch. The experiment produced numerous instances in which a subject had already grasped the new target before they were aware of it. Such smooth feedback-driven sensory-motor integration can produce complex movement patterns that can serve an overall and/or higher goal, yet require no more than the reaction to immediately preceding input.

Because these are fluid situations occurring in real time they require, primarily, efficiency. A system is most efficient if it represents knowledge in a fully implicit manner; that is, it codes the application of the knowledge within the procedure and refrains from buffering any other property (for example, predication, pre-supposition, or time) of the information in a higher-order representation. On the other hand, this setup is the reason motor behaviour must progress stepwise from immediately preceding input. The lack of meta-representation precludes the system from calculating hypothetical future scenarios that would enable it to anticipate several steps in advance. Framed in computational terms, it becomes clear why such meta-representation is unattainable for movement.

Consequently, the explicit system is limited to representing tasks that can be solved outside real time and that can be broken up into chunks of complexity less than a quaternary (simultaneous, parallel processing of four pieces of information) relation. Since this is not the case for movement, the only viable solution is to increase the number of reflexive systems and/or the number of response patterns within a reflexive system. This does not change the system's modularity, rather it is still a reflexive system, as output remains guided by the immediately preceding input. However, it now has an increased number of specialised and independent response patterns.

Putting the above in perspective, an acquired skill such as playing tennis would require a limited number of reflexive systems, each responsible for a different basic stroke (for example, forehand, backhand, serve, volley) in addition to a number of specific and independent response loops within each system. A tennis match is a dynamic system with two moving targets. Although it might settle to one or more strange attractors, such as one player's weak backhand, moment-to-moment events are unpredictable. Given the above analysis that such situations must be managed by the implicit system, it is proposed that initial practice of a skill leads to the establishment of broad reflexive systems (for example, forehand, backhand), while extensive practice results in an increase in the number of specific and independent response patterns within each system. Moreover, it is proposed that with thousands of hours of highly dedicated practice and match experience these patterns become automated (the plateau of the S – Curve in motor learning), that is, the application becomes part of the stimulus-response procedure.

Once the implicit system becomes "automated" through skill competence, it provides the explicit system with workspace capacity to devise strategies for goal attainment and improved performance.

3.3.6 Towards a neuropsychological model of flow

In terms of flow theory, Csikszentmihalyi draws a strong relationship between cognitive and emotional aspects of performance, claiming that the positive emotions, such as joy and happiness, that accompany flow are by-products of the act of achieving control (order) over the content of consciousness by virtue of controlling thought (cognition) through selective attention (focussed concentration) with the intention (intrinsic motivation) to achieve a certain goal (outcome). In order to achieve flow during a task (motor performance) there should be a perceived balance between the challenge (required outcome) presented by the task and the skills required to match (achieve outcome) the challenge, implying that the skills required are already acquired, and the person is confident of achieving success.

Explaining flow in terms of neuropsychology, as a matter of logic, some bridging to connect propositions about flow behaviour with similar aspects in neuropsychology is necessary.

In terms of neuropsychology, consciousness is considered to be ordered hierarchically, with the *prefrontal cortex* at the top of the hierarchy, representing the neural basis of higher order cognitive functions, supported by the *temporal*, *occipital*, and *parietal cortices* and *limbic structures*, which together provide the lower order, or primary neural circuitry, for consciousness. It was also the *dorsolateral prefrontal cortex* (DLPFC), considered the higher order seat, and the *thalamus* as the lower order seat of central processing. In brief terms, sensory information is fed into the *thalamus* and distributed to other centres, including memory, for encoding before being sent to the DLPFC for higher order processing, which then returns the information to the *thalamus* for action response. The *thalamus* processes information, presumably in "bottom-up" fashion, through a two-track circuit, one for cognitive processing (via the *hippocampal formation* and the *temporal, occipital,* and *parietal cortices*, which are devoted primarily to perception and long-term memory) and one for emotional processing (via the *amygdala, anterior cingulate cortex* and the *ventromedial prefrontal cortex*, which compute information in a non-algorithmic, skilled-based manner associated with self-discipline, achievement, self-esteem and confidence). Each system retains a record of its activity so that emotional memory is part of the emotional circuitry and perceptual and conceptual memory is part of the cognitive circuitry. Although there are multiple connections at various levels between the two information processing systems, full reintegration of emotional and cognitive information does not appear to happen until both types of computations converge back on the DLPFC.

In addition to the type of information or knowledge, emotional or cognitive, the brain also operates two distinct information processing systems to acquire, memorise, and represent knowledge. Once information has entered the sensory system and is coded with a cognitive/emotive tag, it is further processed, presumably by the DLPFC in “top-down” fashion by either or both explicit or implicit information processing systems that contain both cognitive and emotional information. The explicit system is rule-based, its content can be expressed by verbal communication and it is tied to conscious awareness. In contrast, the implicit system is skill or experience-based. Its content cannot be verbalised, only conveyed through task performance, and it is inaccessible to conscious awareness.

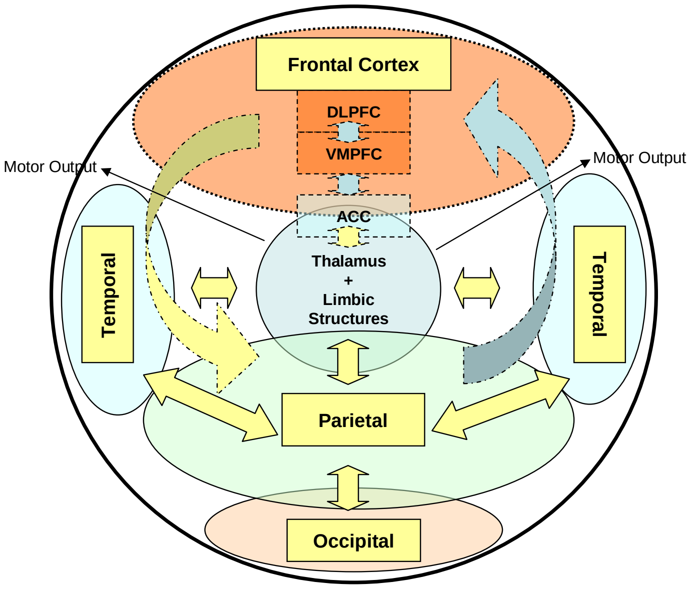
The process of skill acquisition starts with a conscious process during which attention is focussed on the goal of acquiring explicit knowledge regarding the composition and execution of the skill. The *prefrontal lobes* and ACC have been observed to be strongly engaged early in the learning cycle when stimulus-response mappings are actively being established. During this phase performance is low and conscious effort is put into learning. As learning progresses through repetition, explicit knowledge becomes entrenched (transforms into implicit knowledge), and performance improves because fewer errors are made. Attention is, therefore, freed up for other use. In later stages of learning, once contingency mappings have become consolidated, the frontal structures (PFC and dorsal ACC) exhibit a reduction, while the *posterior* regions (*basal ganglia circuit* including *parietal, posterior cingulated cortex,* and *parahippocampal cortices*, as indexed by the P3 scalp position) demonstrate an increase in activity. An internalised (skilled) motor pattern is eventually controlled entirely by this *basal ganglia* circuit and little prefrontal activity is required. Unconscious, effortless execution of the skill is achieved, which is characterised by a perception of "automaticity".

According to flow theory, characteristics of flow are dimensions of concentration on the task at hand (focussed attention), action-awareness merging (absorption or immersion), sense of (being able to take) control, loss of self-consciousness, transformation of time, and autotelic (self-rewarding) experience. Csikszentmihalyi (1975) labelled action-awareness merging as one of the clearest indications that someone is experiencing flow, when all actions appear to be happening spontaneously, effortlessly, and automatically, and the individual being led as if by an autopilot. This implies that peak performance, and thus flow, is likely to occur once explicit skill knowledge has transformed into implicit knowledge so that unconscious, effortless execution of the skill is possible and when achieved will be characterised by a perception of "automaticity".

It was argued above that, considering conscious control (explicit information processing) to be a type of higher-order control, the link (with unconscious or implicit processes) does not become entirely functionally severed following a progression to automaticity. Therefore, automatic processes appear to be modulated by conscious intentions, such as goals, objectives or strategies, pointing to joint responsibility and thereby integration between implicit and explicit controls.

These arguments imply that during flow, skill execution is implicitly and unconsciously controlled by posterior structures, through the application of repertoires of automated reflexes, skilfully tweaked by input from explicit conscious adjustments by the *fronto-limbic* structures, made in response to dynamic external changes in the task environment. This joint implicit/explicit control is supported or maintained by unambiguous dynamic feedback from the sensory system. When task efficiency is achieved by little or no correction from the explicit system, a perception of being controlled by unconscious effortless automaticity of the implicit system is experienced. Since attention is fully and consciously invested, by the PFC, in the task environment, loss of self-consciousness is experienced. Also, since the implicit system contains both cognitive and emotional information processing, the achievement of flow will include not only logical, time and spatial motor responses, but also emotional responses associated with motivational and task behaviour.

It follows logically that during flow it is to be expected that the brain will function in a similar state, as during the autonomous phase of skill execution, perhaps with some added frontal lobe peculiarity, allowing for error correction. Figure 16 (below) illustrates the probable pattern of neural information processing during the flow state.



Neuropsychological Model of Flow

Figure 16. A neuropsychological model of flow

The model illustrates the reduced flow of information from the *fronto-limbic* structures to the *posterior-temporal* structures and the almost autonomous functioning of the latter structures during peak performance and flow.

A neuropsychological model for flow proposes that flow is a product of neural (information processing) productivity during which the brain attempts to optimise processing efficiency (speed versus energy consumption) by using the least quantity of resources necessary to achieve maximum task performance. Probably the most critical resource in dynamic cognitive functioning is attention and its interaction with working memory. It not only plays a pivotal role in executive and frontal lobe functioning but is also a resource with limited capacity, and a key area for optimising during neurocognitive functioning.

It is hypothesised that during the early phases of the learning cycle (skill acquisition), the frontal attentional network is fully engaged because of working memory capacity constraints. This makes it impossible to attend to anything else. During this period, the *fronto-limbic* networks and *posterior cortico-limbic* networks are strongly engaged in establishing stimulus-response mappings that will form a neural template (algorithm) for skill competence. Ventral aspects of the prefrontal lobe in association with temporal lobe structures, including the *hippocampus*, have been shown to be involved in the representation of the stimulus, the responses made to the stimulus and the feedback on the action.

During these early phases, attentional resources are thus consumed by association processes, converting explicit information into implicit knowledge. As a result, representations are being gradually captured in permanent memory where they become implicitly entrenched for future use. Representations of task parameters thus gradually develop within the slow learning, or implicit knowledge system and violations of the context (i.e. post-learned errors) undergo template or contextual updating. The latter modifications require both frontal and posterior involvement.

In later stages of learning, once contingency mappings have become consolidated, these frontal structures exhibit a reduction in activity. In contrast, posterior regions demonstrate increased activity during the later stages. Shifts in neural control occur as a function of practice so that the details of a motor task become gradually controlled by the *basal ganglia* in a circuit that also includes the *supplementary motor cortex*, the *motor thalamus*, and the *hippocampus*. Once internalised, a motor pattern is controlled entirely by the *basal ganglia circuit* and little prefrontal activity is required during its routine execution, freeing up working memory and allowing executive attention to fill its premium computational space with other environmentally relevant content that requires higher order processing.

Once task representations have transformed into implicit knowledge, unconscious, effortless execution of the skill is achieved, which is characterised by a perception of automaticity. During this phase, performance is delivered at peak output and attention is almost entirely applied in focussing on essential environmental cues aligned with goal achievement behaviour. The latter condition (automaticity) implies that skill and challenge are balanced, attention is directed towards goal accomplishment, and flow is likely to occur.

The above argument supports Dietrich's (2004) proposal that optimal performance or peak performance, involving a real-time sensori-motor integration task is associated with maximal implicitness of the task's execution. Given that the explicit system is sub-served by prefrontal regions, it follows that a flow experience must occur during a state of transient hypofrontality that can bring about the inhibition of the explicit system.

3.4 CONCLUSION

In the following chapter research studies involving EEG technology and visuomotor response tasks are investigated to establish possible links to the above theoretical frameworks and its correlates to flow and performance. Considering the above theories, the research question is whether there is evidence of a neurological pattern suggesting a shift between the implicit and explicit systems, or a shift from the frontal networks to the posterior networks during peak performance.

CHAPTER 4

EEG RESEARCH FINDINGS ON FLOW AND PERFORMANCE DURING VISUOMOTOR TASKS

4.1. INTRODUCTION

This chapter is divided into three main parts. Firstly, it provides a brief overview of EEG terminology and its applications to brain functioning and the measurement of electro-cortical changes in the brain. Secondly, it covers recent research studies which investigate the neurological changes in the brain during tasks related to visuomotor performance. Thirdly, the expected EEG observations based on the model built in the previous chapter are provided. Assumptions are formulated regarding the expected neural changes that will take place in the brain during periods of peak performance, and therefore flow, during the execution of a visuomotor task and how these changes are reflected in EEG.

4.2 BRAIN ACTIVITY AND ELECTROENCEPHALOGRAPH

Three types of neurons, *sensory*, *motor*, and *association*, form the basic units of nervous system communication and are responsible for all of the connections in the brain. Sensory neurons carry information from the skin or other organs upward toward the CNS. The impulse is received by the *sensory cortex*, the *anterior* portion of the *parietal lobes*. The *motor neurons* send information downward and away from the CNS to various muscles. The origin of the signal comes from the *motor cortex*, the *posterior* portion of the *frontal lobes*. The *axons* of most *sensory* and *motor neurons* travel inside the spinal column.

Association neurons, or *inter-neurons*, help make the connection between *sensory* and *motor neurons*, as the most numerous kind of neurons in the CNS. Neuronal transmission is an electro-chemical event. A nerve impulse, also called an action potential, is an electrical charge that travels from the cell body toward the terminal buttons at the ends of the *axons*. A stimulated cell body sends a signal toward the terminal buttons. The impulse travels along the *axon* in “domino” fashion, each membrane having the job of stimulating the next membrane down the line. The whole process resembles a chain reaction and is known as ‘de-polarisation’. At this point the terminal buttons release *neurotransmitters* into the *synapse*. *Dendrites* from adjacent neurons pick up the message and further transmit it from neuron to neuron, until the purpose for the initial impulse is accomplished.

Brainwaves are formed by a dual action, a ‘push-pull’ process. A cycle begins when a *neurotransmitter* is released to excite an adjacent neuron and ends when the process reverses due to an inhibitory response. Two terms define the process of making brainwaves, i.e., *excitatory post-synaptic potential* (EPSP) and *inhibitory post-synaptic potential* (lPSP). Each *dendrite* of the adjacent *neuron* can be excited or depolarised by the release of an *excitation neurotransmitter*. The inhibitory process is invoked by the release of an *inhibitory neurotransmitter* (Blumenfeld, 2002).

As a result of neural signals that move upward toward the *cerebral cortex*, then back downward to the *thalamus*, repeatedly, EEG rhythmic activity is created. The total rhythm caused by millions of communicating neurons can be recorded at the cortical level in microvolts (amplitude) and cycles per second (frequency). The electroencephalograph (EEG) is a graphical representation of the neuronal activities in the *cerebrum*, a uniquely powerful and revealing indicator of brain function, and one of the best methods available for assessing and monitoring neural activity in real time. It owes much of its value to its sensitivity to neuronal synchrony. The primary mechanism that produces measurable scalp EEG is the summation, through volume conduction, of *post-synaptic potentials* that occur in pyramidal cells within the *cerebral cortex*. When cells polarise, or depolarise, in unison the resulting potentials are added in the conducting media, leading to external fields that can be measured. This phenomenon is so pronounced that a mere 1% of cortical cells in a 1 cm^2 area of cortex, when acting in synchrony, are sufficient to account for more than 96% of the EEG signal (Shaw, 2003). In other words, the very existence of an EEG potential implies some degree of local synchrony within a population of cells lying beneath the affected sensor. By an extension of this logic, if a mere 1% of cortical cells are coordinated in some way with 1% of the cells in some other location, then 96% of the connectivity might be accounted for in the EEG (Collura, 2008).

Connectivity metrics are intended to detect these connections and their function, as well as short-term and long-term changes in the dynamics of the interconnections. When neighbouring locations act in a synchronised manner, local amplitudes are increased, and manifest as the presence of a measurable EEG wave. The observed brainwave frequencies are *epiphenomena*, that is, by-products of normal brain function and not a brain signal in itself. EEG is a secondary measure, such as the temperature of an electronic circuit. EEG waves, for example alpha waves, are produced as a result of certain types of brain activity, recognisable by associated EEG waves or wave patterns.

Brain states or states of mind are recognisable by EEG in the domains of time and space, notably mood, arousal, sleep, drowsiness, alertness, and relaxation. They also include flow. In EEG terms, time refers to frequency, and space indicates localisation of EEG activity in the brain. States of mind are recognisable in the range of 1 Hz to about 40 Hz. Sleep accompanies delta activity (1-3 Hz); drowsiness and seizure activity accompany theta activity (4-7 Hz); deep relaxation and meditative states accompany the alpha rhythm (8-12 Hz); sleep initiation and calm focus accompany SMR rhythms (13-15 HZ); and focused attention and alertness accompany the beta rhythm (15-18 Hz). High levels of concentration accompany the higher end of the beta spectrum (20-32 Hz). Information processing occurs at a higher frequency, approximately 40 Hz (gamma).

Each bandwidth is associated with both positive and negative behavioural characteristics, described in greater detail, as follows.

4.2.1 Delta (1 - 4 or 1 - 3.5 Hz)

Delta oscillations are intrinsic neuronal rhythms with *thalamocortical* origins (Olejniczak, 2006). Delta is associated with sleep and thus predominant in infants. High-amplitude rhythmic delta in adults is an indication of traumatic brain injury and other disorders, whereas arrhythmic delta has been observed in college students during problem-solving tasks (Lubar, Angelakis, Frederick & Stathopoulou, 2001). Vogel, Broverman, and Klaiber (1968) addressed this discrepancy by postulating two kinds of behavioural inhibition: (a) Class I inhibition, which refers to a gross inactivation of an entire excitatory process that results in a relaxed, less active state, such as sleep, and (b) Class II inhibition, which refers to the selective suppression of inappropriate, or non-relevant, neural activity during mental task performance. An example of the latter type is found in the research by Harmony et al. (2009), which found that increased delta power and synchronisation in the *frontal*- and *occipital* areas related to inhibition of non-relevant stimuli during go/no-go tasks. Attention to internal processing during difficult tasks, such as calculation and memorisation, increases delta power (Harmony et al., 1996), while increases in synchronised delta power are associated with the moment of creative insight (Whitton, Modolfsky & Lue, 1978). Class I delta are associated with synaptic reorganisation, plasticity, and waking-state information consolidation (Hobson & Pace-Schott, 2002).

4.2.2 Theta (4 - 7, 4 - 7.5, or 4 - 8 Hz)

Theta is associated with creativity and spontaneity, also with distractibility and inattention, daydreaming, depression, and anxiety. Theta that is excessive, or laterally asymmetrical, may reflect depression, anxiety, and other emotional disorders. Children have higher theta amplitudes than older adults (Blume & Kaibara, 1995). Numerous studies have indicated that theta is associated with attention in cognitive (Smith, McEvoy & Gevins, 1999), visuomotor (Slobounov, Fukada, Simon, Rearick & Ray, 2000; Grunwald et al., 2001) and sensori-motor tasks (Baumeister, Reinecke, Liesen & Weiss, 2008). Theta increases have also been linked to working memory (Gevins, Smith, McEvoy & Yu, 1997; Krause et al., 2000; Onton, Delorme & Makeig, 2005). More specifically, increases in frontal theta power have been associated with working memory load in the maintenance interval (Gevins et al., 1997; Jensen & Tesche, 2002; Onton et al., 2005).

Frontal theta is a prominent feature in EEG reported to increase in tasks that require attention or working memory (Gevins et al., 1997; Slobounov et al., 2000; Grunwald et al., 2001; Baumeister et al., 2008). Both decreased and increased frontal theta activity have been linked to increased cognitive demands. Increased frontal theta is reported in a wide variety of tasks, such as mental arithmetic (Yoshii, 1972; Mizuki, Tanaka, Isozaki, Nishijima & Inanaga, 1980; Inouye et al., 1994; Sasaki, Tsujimoto, Nishikawa, Nishitani & Ishihara, 1996; Inanaga, 1998; Lazarev, 1998; Smith et al., 1999), error detection (Luu et al., 2003; Luu et al., 2004), language comprehension (Bastiaansen, Posthuma, Groot & de Geus, 2002; Hald, Bastiaansen & Hagoort, 2006) and working memory tasks (Gevins et al.,1997; Krause et al., 2000; Jensen & Tesche, 2002; Onton et al., 2005). Smith et al. (1999) reported increased frontal theta power associated with task complexity and focussed attention in a cognitive (3-back working memory task) and visuomotor task (video game ‘space fortress’). Fournier et al. (1999) found increased theta power in posterior brain areas with increased task complexity during a complex visuomotor task.

With regards to theta synchronisation, Horan (2009) reported that there are two different types: (a) type-1: related to an increase in power over a broad range of frequencies and exhibiting irregular oscillatory epochs. Such theta dominates in slow wave or non-rapid eye movement sleep (non-REM); (b) type-2: a selective activation of working memory and related to an increase in power within a narrow frequency band of the peak theta frequency (Klimesche, 1996).

Horan (2009) postulated that theta is correlated with scanning for visceral pleasure, enhanced artistic creativity, responses to novel situations and various forms of training. He argued that since theta activity reflects encoding of new information into memory, learning, and responding to task difficulty. It forms part of hypnogogic reverie, REM, and slow wave sleep; and seems to be related to emotional reward. It is assumed that the general function of theta (i.e., types 1 and 2) in relation to creativity is to effect neuropsychological closure (i.e., integration), both explicitly and implicitly, in response to new (or difficult to assimilate) information coupled with an affective orientation (i.e., transcendence) toward emotional satisfaction. Theta activity, whether selective or not, appears to reflect an innate intention to achieve greater levels of affective fulfilment, or joy, which may result from humans’ existential inclination to be free of informational limits (i.e., transcendence) as well as the ability to adapt to new environments (i.e., integration).

4.2.3 Alpha (8 -12 Hz)

Classic alpha looks like a rhythmic sinusoidal wave, normally ranging from 9 to 13 Hz during wakefulness and dropping to 7 to 8 Hz during drowsiness. Sometimes activity between 10 and 12 Hz is not true alpha activity when it resembles a series of interconnected arches, known as Rolandic mu or mu rhythm. Mu waves do not change when the eyes change from closed to open, whereas normal alpha show a sharp decrease when the eyes open (referred to as ‘alpha blocking’). Alpha is prominent in the *occipital*, *parietal*, and *posterior temporal lobes*. Mu rhythms are found mainly in the *sensori-motor cortex* or occasionally in the *parietal lobes* (Blume & Kaibara, 1995, p. 39).

The functional meaning of low- (alpha 1) and high-frequency alpha (alpha 2) rhythms is different. Alpha 1 rhythms sub-serve global attentive readiness. On the other hand, alpha 2 rhythms reflect the task-related oscillation of specific neural systems for the elaboration of sensori-motor or semantic information (Klimesch, 1996, 1999; Klimesch et al., 1998).

Globally, alpha activity reflects a relaxed wakefulness state, and decreases with concentration, stimulation or visual fixation (Stern & Engel, 2005). Rowe et al. (2007) postulated that the alpha rhythm is a measure of the strength and delay of signal transfer in *cortico-thalamocortical loops*. Increased alpha power, particularly in the eyes open state, suggests signals are being boosted through to specific areas of the cortex, while increased frequency suggests the propagation of neural activity through *cortico-thalamocortical loops* is faster. Collectively, this may increase the efficiency and accuracy of *thalamocortical* transfer. Consistent with this, alpha demonstrates positive correlations with information processing speed.

Alpha is also involved in anticipatory attention, which involves top-down interactions between higher-order and primary areas of the visual cortex. These, in turn, have been linked to synchronisation in the alpha (and theta) frequency band (von Stein et al., 2000) and to dynamic cross-frequency interactions between alpha and gamma oscillations for integration across neuronal processes (Palva & Palva, 2007; von Stein et al., 2000).

Alpha power increases have been linked to active inhibition of neuronal activity that could otherwise disturb the working memory (WM) process (Jokisch & Jensen, 2007; Klimesch et al., 2007). Differential alpha power effects can be seen in upper and lower sub-bands (Klimesch, 1999). Decreases in power in the lower alpha band have been linked to higher task demands and attentional processing, whereas decreases in power in the upper alpha band have been related to increased declarative memory performance. Klimesch et al. (1999) observed an increase during WM maintenance of character strings which suggest that this is related to inhibition of memory activities that could otherwise disturb the working memory process.

Various authors have linked *parietal* alpha-2 power to *somatosensory* information processing (Gevins et al., 1997; Slobounov et al., 2000; Grunwald et al., 2001; Baumeister et al., 2008). Smith et al. (1999) reported decreased *parietal* alpha-2 values with increased information processing in a cognitive (3-back working memory task) and visuomotor task (video game ‘space fortress’). According to Williams and Krane (1998), general increase in event-related alpha power in the temporal regions implies widespread reduction in cortical activity and seems consistent with the phenomenological reports of highly skilled athletes that their actions or performance become effortless. Babiloni et al. (2008) postulated that alpha rhythms might represent a major physiological mechanism at the basis of ‘neural efficiency’ during the judgment of observed actions.

Babiloni et al. (2008) reported that high baseline power of bilateral alpha rhythms in the sensori-motor area predicts good cognitive performance in both visual stimulus encoding and memory formation (Neubauer & Freudenthaler, 1995; Klimesch, 1999; Babiloni et al. 2006), but not in successful performance of fine motor acts. They argue that it is still a matter of debate whether enhanced alpha power represents a general pattern of cortical neural inhibition common to all skilled and target sports Palva & Palva, 2007). If this is the case, hemispheric differences in preparatory alpha power among sporting gestures might reflect specific inhibitory versus excitatory processes associated with exogenous versus endogenous direction of attention, and with verbal versus spatial processes (Wertheim, 1981; Klimesch, 1999).

4.2.4 Sensori-motor rhythm or lobeta (12 -15 or 12 -16 Hz)

Sensori-motor rhythm (SMR), also called low beta, or lobeta, may reflect a state of being internally oriented. True SMR predominates only in the *sensori-motor cortex* (sensori-motor strip), and increases when the brain's motor circuitry is idle. Consequently, SMR amplitude increases with stillness and decreases with movement (Othmer, Othmer & Kaiser, 1999, p. 267).

4.2.5 Beta (15 - 18 Hz)

Beta comprises fast wave activity, and has been associated with being focused, analytic, externally oriented, or in a state of relaxed thinking (Demos, 2005). Maximal beta amplitude is usually in the *fronto-central* regions, but it may be widespread. Increased beta activity has been related to the alertness level, and decreases during drowsiness (Eoh, Chung & Kim, 2005). Research by Gross et al. (2004) revealed that communication within the *fronto-parieto-temporal attentional network* proceeds via transient long-range phase synchronisation in the beta band. Changes in synchronisation reflect changes in the attentional demands of the task and are directly related to behavioural performance. The *fronto-parieto-temporal attentional network* is known to be involved in target detection, visual attention, and working memory, that is, processes that are required for the successful execution of any visually based task. They concluded that synchronisation and de-synchronisation appear to be candidate mechanisms for enhancing target processing while at the same time avoiding interference by suppressing the processing of non-targets, respectively. Such a mechanism may define an important aspect of what is commonly referred to as ‘‘attention.’’

Pfurtscheller, Woertz, Supp & Lopes da Silva, (2003) suggested that beta synchronisation or de-synchronisation plays an important role in motor control. Research indicated that beta-rhythm oscillations de-synchronise during automotoric movement and again become synchronised over a larger scale when attention to sensori-motor integration is required (Pfurtscheller & Andrew, 1999; Ivanitsky et al., 2001; Fingelkurts et al., 2005; Schnitzler & Gross, 2005). According to Logar et al. (2008), it seems that during the combined operation of multiple brain regions information transfer between the regions is the predominant contribution to the beta rhythms.

Van Wijk, Daffertshofer, Roach and Praamstra (2009) reported that the role of beta synchrony in biasing response competition is related not only to a biasing role of alpha activity in the selection of visual information (Worden et al. 2000; Kelly et al. 2006; Thut et al. 2006; Rihs et al. 2007), but also to the concept of ‘‘focal desynchronisation/surround synchronisation’’ (Pfurtscheller & Lopes da Silva 1999).

According to research on the functional and anatomical loops connecting *basal ganglia* and *cortex*, it has been proposed that tuning of neural activity to different frequency bands may reflect a means of marking and segregating continuous processes in different cortical-subcortical circuits (Fogelson et al., 2006). At the level of the striatum, task-related beta de-synchronisation occurs very focally amidst widespread beta oscillatory activity, giving rise to the proposal that beta oscillatory synchrony operates as a spatiotemporal filter to sharpen action-selection by *corticobasal ganglia* networks (Courtemanche et al., 2003).

4.2.6 High Beta (20-32 Hz)

High beta is associated with peak performance, cognitive processing, worry, anxiety, over-thinking, and ruminating. Excessive 20 - 32 Hz beta could be a marker for any one of a number of disorders, or it could imply that the brain is compensating for excessive theta activity (Demos, 2005).

4.2.7 Gamma (40 or 38 - 42 Hz)

Synchronous bursts of gamma band 40-Hz activity have been found during problem-solving tasks for adults and children. It is often lacking when learning disorders or mental deficits are present. Gamma is found throughout the scalp rather than at one discreet location. Appearing to help organise the brain, promote learning and allow for mental sharpness, it is activated when the brain needs to be active and idle and no specialised task is at hand (Hammond, 2000).

Gamma oscillations are observed in the *thalamus* and *auditory, visual, and motor cortices*. Gamma is prominent especially during high alertness and after sensory stimulation, likely contributing to the ‘‘binding” of diverse information into a single coherent percept. Gamma, high beta and beta waves seem to be associated with selective attention, transient binding of cognitive features, and conscious perception of visual objects (Hughes, 2008).

Increased gamma power has also been linked to working memory maintenance (Tallon-Baudry et al., 1998; Lutzenberger et al., 2002; Kaiser et al., 2003; Jokisch & Jensen, 2007).

4.3 CONNECTIVITY MEASURES

Insight into the neurobiology of motor performance can be attained by examination of the functional interconnectivity (or *cortico-cortical* communication) between specified topographical regions of the brain. In this manner, “networking” activity can be quantified by deriving coherence estimates between selected pairs of electrodes or recording sites (Busk & Galbraith, 1975).

4.3.1 Coherence

Oscillatory synchronisation is a prevalent property encountered among groups of neurons throughout the mammalian brain (Buzsáki & Draguhn, 2004; Kruse & Julicher, 2005). Despite its widespread occurrence only recent experimental evidence succeeded in showing that synchronised oscillatory activity (or coherence) among neuronal groups within and across cortical areas could be functionally relevant and support the dynamics of cognitive processes in a variety of tasks (Engel et al., 2001; Varela et al., 2001). The emerging view from these findings is that neuronal coherence sub-serves the selective and effective transmission of information among neuronal groups during the integration of sensory information to ultimately trigger adaptive motor performance (Salinas & Sejnowski, 2001; Laughlin & Sejnowski, 2003; Fries, 2005; Sejnowski & Paulsen, 2006).

Classical or “pure” coherence is a measure that is derived from the engineering field, and designed to reveal connectivity as reflected in a consistent phase relationship between two or more signals. It can be interpreted as a generalisation of the Pearson correlation coefficient to variables expressed in the complex frequency domain. It has widespread use in time-series analysis (Carter 1987). A coherence value between 0.6 and 0.8 is considered significant.

Coherence is a specific quantitative measure of functional relations between paired locations. It is a squared correlation coefficient that measures phase consistency recorded at paired locations, for each frequency component in the EEG. For example, if two regions exhibit an EEG coherence of 0.36 at some frequency, a large-scale dynamic correlation coefficient of 0.6 is implied between these regions at this frequency. Paired locations in dynamical systems may exhibit high coherence in some frequency bands and, at the same time, low coherence in other bands in the same set of data. Such correlated neocortical activity can result from direct connections between the two regions, common input from the *thalamus* and other neocortical regions, or both (Nunez, 2000).

4.3.2 Asymmetry

Asymmetry may also be regarded as a connectivity metric, in that it reflects relative activation between the sites of interest. Asymmetry can be measured in any manner that reveals differences in signal amplitudes. This metric has the benefit of being independent of the individual signal amplitudes.

EEG asymmetry is of particular value in working with inter-hemispheric EEG, in particular that of the frontal lobes. For example, it has been found to correlate with mood in general and depression in particular. The measurement and training of frontal EEG asymmetry has become an important avenue in clinical neuro-feedback when applied to depressed patients. It is also of potential value when used intra-hemispherically, particularly front-to-back, in which posterior amplitudes can be trained in relation to anterior amplitudes, to seek normal relationships (Collura, 2008).

Where coherence is primarily a measure of phase consistency over time, asymmetry is a measure of magnitude difference between waves. Both coherence and asymmetry are viewed as indicators of synchrony or functional integration between two scalp positions, in other words, indicating the amount of coordinated connectivity between two streams of neural activity in different locations of the brain. Significant similarity is an indication of binding or synchronised functioning (Tononi et al., 1992).

4.4 ELECTROENCEPHALOGRAPH TERMINOLOGY

Specific terms are employed to locate brain structures and other anatomical features. Neurologists often describe brain regions with anatomical directional terms. The International 10-20 system assigns letters and numbers to 19 primary sites on the scalp. The International 10-20 System of Electrode Placement is the most widely used method to describe the location of scalp electrodes. The 10-20 system is based on the relationship between the location of an electrode and the underlying area of cerebral cortex. Each site has a letter, to identify the lobe, and a number or another letter to identify the hemispherical location.

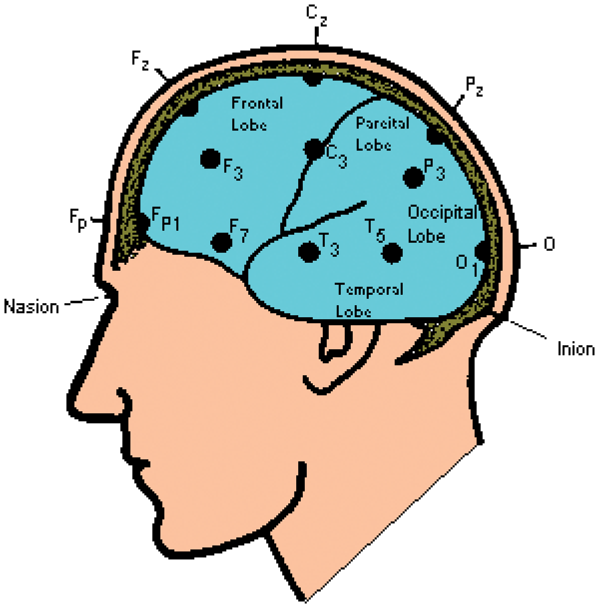
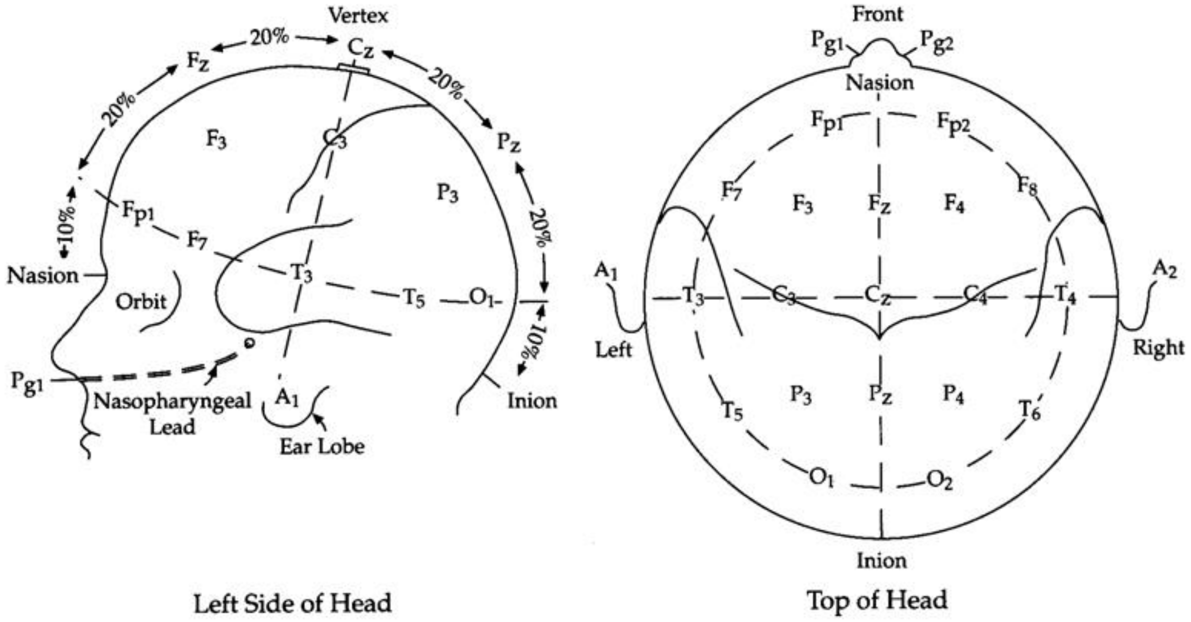


Figure 17. Lateral view of the brain indicating the location of scalp electrodes according to the 10-20 system

The letters used are: "F" - Frontal lobe, "T" - Temporal lobe, "C" - Central lobe, "P" - Parietal lobe, "O" - Occipital lobe. There is no central lobe in the cerebral cortex. "C" is used for identification purposes only. Even numbers (2, 4, 6, 8) refer to the right hemisphere and odd numbers (1, 3, 5, 7) refer to the left hemisphere. "Z" refers to an electrode placed on the mid line. The smaller the number the closer the position is to the mid line. "Fp" stands for Front polar. "Nasion" is the point between the forehead and nose. "Inion" is the bump at the back of the skull.

The "10" and "20" (10-20 system) refers to the 10% and 20% inter electrode distance. The figure below illustrates the systems outlay.



Left Side of Head

Top of Head

Figure 18. View of the brain indicating the location of scalp electrodes according to the 10-20 system.

When recording a more detailed EEG with more electrodes, extra electrodes are added, utilising the spaces between the existing 10-20 system.

Following the above overview of EEG technology and terminology, the following section will investigate EEG-related research regarding neurological changes in the brain during performance on visuomotor tasks and its possible relationships with the flow experience.

4.5 ELECTROENCEPHALOGRAPH STUDIES OF VISUOMOTOR PERFORMANCE TASKS

Flow is mostly related to a diverse range of motor tasks, such as writing, athletics, sports, surgery, playing musical instruments or computer games. It most often involves a visual component associated with intense concentration and coordinated motor function.

Several neurological studies, especially using EEG technology, have researched the neural changes taking place in the human brain during the execution of motor tasks, often related to differing levels of performance. Very few studies were found directly related to flow.

4.5.1 Studies

According to Csikszentmihalyi (1997), Jean Holcomb (changed from Hamilton) reported that in a set of experiments, students who did and who did not report frequent flow experiences were asked to pay attention to flashes of lights, or to tones, in a laboratory. While the subjects were involved in this attentional task, their cortical activation in response to the stimuli was measured by EEG evoked potentials and averaged separately for the visual and auditory conditions. Holcomb's findings showed that subjects who reported only rarely experiencing flow, behaved as expected, i.e., when responding to the flashing stimuli their activation increased significantly above their baseline level. The results from subjects who reported flow frequently were very surprising. Their activation decreased when they were concentrating. Instead of requiring more effort, investment of attention actually seemed to decrease mental effort. A separate behavioural measure of attention confirmed that this group was also more accurate in a sustained attentional task.

Kramer (2007) studied the predictive power of lateralised cortico-electrical patterns (measured by EEG) and arousal (measured by Galvanic Skin Conductance) on performance during a visuo-spatial motor-response task. The task was a video game specifically designed to induce flow based on the criteria for flow state established by Csikszentmihalyi (1997). A regression analysis of the data found that greater left temporal alpha activity, compared to that of the right temporal lobe, was a positive predictor of performance. No significant results were found regarding delta activity, however, skin conductance was found to positively correlate with performance. Theta activity (4-8Hz) and mid-beta activity (16-20Hz) were also found to have a main effect on performance. Kramer (2007) concluded that, during the trial, performance was aided by higher mid-range beta in the left hemisphere.

These two studies appear to be the only ones directly related to the flow experience. In the first study, flow was measured subjectively and performance-related neural activity was measured by evoked potentials. In the second study, no subjective measurement of flow was taken, and EEG was only recorded at two scalp positions (T3/T4). Both studies thus have very limited value in terms of the larger scope of neural changes happening in other parts of the brain. Since flow is closely associated with peak performance, studies involving EEG recordings during various levels of performance were investigated.

According to Janelle and Hatfield (2008), the findings of recent investigations robustly support a so called “neural efficiency” hypothesis, which postulates more efficient cortical functioning in high than low performers, a refinement in the activity of the cerebral cortex with improved performance. In essence, it appears that experts alter the neurocognitive processes in a dynamic fashion such that analytical processes, important at the early stage of preparation, become non-essential activity that then drops out. Such a dynamic process may well represent the neural underpinnings of focused attention and ability to regulate “noise” that may disrupt the critical attention and motor processes associated with successful performance.

Janelle and Hatfield (2008) argue that it may be that this basic pattern of cortical activation described above represents a broad principle such that superior performance in many psychomotor skills is dependent on refinement of neural activity to those essential responses to a given challenge. The details of brain activation may well differ depending on the nature of the task being performed, but the principle of regional economy within the cerebral cortex with expertise provides a testable model by which to compare experts and novices, to investigate the effects of practice over time, and, importantly, the impact of stress on the brain.

Overall, studies suggest that superior performance is marked by mental economy, particularly of analytical associative processes and that pruning of excessive cortico-cortical communication between such processes and motor regions underlies enhancement and consistency of psychomotor performance (Hatfield & Hillman, 2001). Support for this principle has been provided by a number of studies ranging from preparation for karate moves in elite competitors (Collins, Powell & Davies, 1990), during the quiet eye period of target shooting (Janelle, Hillman, Apparies & Hatfield, 2000; Janelle, Hillman, Apparies, Murray et al., 2000), and other self-paced motor tasks such as dart-throwing, golf, and archery (Salazar et al., 1990; Crews & Landers, 1993; Landers et al. 1991, 1994; Radlo et al., 2001).

Haufler et al. (2000, 2002) contrasted EEG activity (recorded from the *frontal*, *central*, *temporal*, *parietal*, and *occipital* regions) in novice and expert marksmen who were challenged with a target-shooting task as well as comparative verbal (i.e., word recognition) and spatial tasks (i.e., dot localisation). Lower activation in the *cerebral cortex* was observed in the experts during the aiming period. Comparative log-transformed gamma power (36–44 Hz), which is positively related to cortical activation, from the *frontal* and *temporal* regions. The entire EEG spectrum recorded at site T3 (averaged for both experts and novice groups) clearly showed that the experts exhibited higher levels of alpha power (8–12 Hz) at this site as well as lower levels of beta and gamma power. The group differences associated with the frontal region during the aiming period suggested that the experts were, indeed, less reliant on effortful executive processing (i.e., planning and coordinating processes) than were their novice counterparts, whereas the group differences in temporal activation during aiming imply a reduction in the reliance of verbal-analytic thinking with expertise.

Baumeister et al. (2008) researched the cortical activity of skilled performance in a complex sports-related motor task using EEG recordings to demonstrate cortical changes in the brain during a golf putting performance in an expert-novice paradigm. The success in putting (score) and performance-related cortical activity showed significantly better performance in the expert golfers, associated with higher fronto-midline theta power and higher parietal alpha-2 power values than the novices. The findings suggest that with increasing skill level, golfers have developed task solving strategies, including focussed attention and an economy in *parietal* sensory information processing which lead to more successful performance.

Pfurtscheller and Berghold (1989) reported that alpha 2 event related de-synchronisation (ERD) showed a characteristic pattern before and during self-paced finger movement in a shooting simulation. Just prior to movement, there was a significant ERD prominent at *sensori-motor* area electrodes (C3 and C4) contralateral to actual movement, while during movement, there was a bilateral ERD pattern. In terms of alpha synchrony, Andrew and Pfurtscheller (1999) reported high levels of interhemispheric coherence for alpha 1 data and low interhemispheric coherence for alpha 2 data in a similar experiment. They concluded that the higher frequency EEG data was representative of Rolandic mu (12 Hz) activity and that left and right hemisphere Rolandic mu coupling was not affected by movement. The alpha 1 activity was said to represent coherent ‘classic alpha’ activity. Similar effects were also reported by Florian et al. (1998). However, they additionally demonstrated that alpha 1 coherence (synchrony) increased during movement, whilst alpha 2 coherence showed no such effect.

Babiloni et al. (2008), researching alpha and beta rhythms during golf putts, reported that alpha 2 ERD over the *right primary sensori-motor cortex* was at maximum during successful putts, suggesting that fine cortical control of the left arm and hand movements is crucial for winning performance.

These results contribute to the debate on the functional significance and hemispheric distribution of alpha rhythms recorded during sporting performance. An inhibitory increase in broad alpha power (8–12 Hz) in the left hemisphere before the performance of skilled marksmen (Hatfield et al., 1984) and archers (Salazar et al. 1990; Landers et al. 1994; Shaw, 2003) has already been shown, which would favour visual–spatial processes in the right hemisphere. Furthermore, a correlation has been reported between the reduction in power of right parietal alpha (ERD) and skilled karate performance (Del Parcio et al., 2007b). In contrast, other studies have pointed to a bilateral increase in alpha power during skilled karate performance (Collins et al., 1990), and an inhibitory increase in alpha power over the right hemisphere during skilled golf performance (Crews & Landers, 1993).

According to Babiloni et al. (2008), relationships between the topography of baseline alpha power and subsequent cognitive-motor processes are quite complex, possibly depending on the specific tasks to be performed. Previous evidence showed that high baseline power of bilateral alpha rhythms predicts good cognitive performance in both visual stimulus encoding and memory formation (Neubauer & Freudenthaler, 1995; Klimesch, 1999; Babiloni et al., 2006), but not in successful performance of fine motor acts. It was suggested that successful golf putting performances are characterised by excitatory de-synchronisation of frontal alpha rhythms during action execution, in line with the traditional model of alpha power modulation (Pfurtscheller & Lopes da Silva, 1999; Palva & Palva, 2007).

Babiloni et al. (2008) also reported that successful golf putts were additionally characterised by alpha 2 ERD over the *medial prefrontal, cingulate and/or supplementary motor* areas. These *cortical* areas play a pivotal role in the planning, selection and regulation of learned complex sequences performed with both arms and both hands, thanks to their bilateral anatomical connectivity (Rosenbaum, Vaughan, Barnes & Jorgensen, 1992; Rosenbaum, Meulenbroek, Vaughan & Jansen, C. 2001; Ashe et al., 2006).

Andrew and Pfurtscheller (1999) and Pfurtscheller et al. (2003) proposed that voluntary finger movement causes beta rhythm de-synchronisation. As observed by Murthy and Fetz (1996), volitional movements of the hand cause phase lags between different cortical areas, however, according to the same authors, as well as Andrew and Pfurtscheller (1999), the beta-rhythm oscillations again become synchronised over a larger scale when the attention to sensori-motor integration is required (Pfurtscheller & Andrew, 1999; Ivanitsky et al., 2001; Fingelkurts et al., 2005; Schnitzler & Gross, 2005).

According to recent research it is inferred that synchronisation is probably how the brain achieves the large-scale integration (i.e., neural binding) of its many parallel processing activities, allowing coherent complex brain functioning, cognition and behaviour (Engel et al., 2001; Buzsáki & Draguhn, 2004). A study performed by Classen et al. (1998) showed increased coherence (synchronisation) during the performance of tasks that require visuomotoric integration, which means that two brain regions involved in a process, by means of the synchronisation and de-synchronisation of a certain frequency and a constant change of signal phase, exchange the information needed. In other words, the phase characteristics of the emitted signals together with their oscillatory activity represent a possible mechanism of information coding in the brain (Hopfield, 1995).

According to Logar et al. (2008), it seems that during the combined operation of multiple brain regions information transfer between the regions is the predominant contribution to the beta rhythms. Similar conclusions were made by Pfurtscheller et al. (2003), who also suggested that beta synchronisation and de-synchronisation play an important role in motor control.

Edin et al. (2007) trace recent functional magnetic resonance imaging studies that demonstrate that increased task-related neural activity in the *parietal* and *frontal cortex* during development and training is positively correlated with improved visuo-spatial working memory (vsWM) performance. An integrative experimental and computational analysis was performed to determine the effective balance between the *superior frontal sulcus* (SFS) and *intra-parietal sulcus* (IPS) and their putative role(s) in protecting the attentional networks against distracters. EEG recordings during a visuo-spatial working memory task, together with a biophysically based computational cortical network model, were used to analyse the effects of different neural changes in the underlying cortical networks on the directed transfer function (DTF) and spiking activity. Combining a DTF analysis of the EEG data with the DTF analysis of the computational model, a directed strong SFS → IPS network was revealed

It was found that the *fronto-parietal network* is more resistant to distraction than the *symmetric* or *parieto-frontal networks*. Thus, if the IPS were to be distracted, a low IPS → SFS connection strength protects the distraction of the SFS. Further, a strong SFS → IPS connection protects the IPS from being distracted in the first place. Conversely, if the IPS → SFS connections are the strongest, then the network is even less resistant to distraction than the *symmetric network*. Therefore, this shows that SFS–IPS asymmetry affects working memory performance and indicates a way to redistribute inter-regional connections in order to increase the resistance to distraction.

A further assumption in this study was that the vsWM maintenance network consisted of only the IPS and the SFS (Rowe et al., 2000; Todd & Marois, 2004). Based on this, the DTF connectivity analysis was performed on the electrode pairs F3 ↔ P3 and F4 ↔ P4. However, several regions of the brain are active during the vsWM delay period, and they could affect the results by acting as hidden nodes leading to spurious connections in the experimental analysis. Most importantly, *sub-cortical* structures such as the *medio-dorsal nucleus* of the *thalamus* cannot be excluded from constituting a major pathway of crosstalk between the IPS and SFS. Such structures are especially likely to affect the results of the DTF in the lower part of the frequency spectrum. Other methods are needed to probe the effective connectivity to *sub-cortical* structures.

Edin et al. (2007), remarked that in both the studies by Olesen et al. (2007) and Sakai et al. (2002), higher distracter resistance was associated with higher activity in the *dorsolateral prefrontal cortex*, which dynamically modulates interregional connection strength. It will be of great interest to understand the mechanisms whereby it exerts its influence on the SFS–IPS connection.

With reference to the above study, there are some references which connect the findings in frontal theta power and parietal alpha-2 power to the load of the working memory and in more detail to focused attention and information processing. In a cognitive task, Sauseng et al. (2005) demonstrated that frontal theta and parietal alpha-2 power act in a *fronto-parietal network* which represents functions in the concept of working memory.

Fournier et al. (1999) found increased theta power in posterior brain areas with increased task complexity during a complex visuomotor task. The authors suggest that parietal theta activity was higher with higher cognitive and behavioural demands. This is supported by Dolce and Waldeier (1974), who found higher parieto-occipital theta power in a reading task than an easy mental task. However, the data suggests that higher parietal theta power is associated with higher skill level during a complex sports performance such as the golf putt.

Deeny et al. (2003) assessed inter-electrode coherence (synchrony) between motor planning (Fz) and association areas of the brain during skilled marksmanship in two groups of participants. Although both groups were highly experienced, approximately 18 years of experience in each group, one consistently scored higher under the stress of competition and performed better under pressure. The investigators predicted a lower level of coherence or communication between the left temporal and central motor planning regions, thus simplifying the organisation of motor processes, resulting in more stable and consistent performance. As predicted, the superior competitors exhibited significantly lower values (coherence) between these regions (F3 - Fz), although no other differences were observed for either the left or right hemisphere. The results support the notion of refined networking in the *cerebral cortex* of those who consistently perform well in competition by reducing neuro-motor “noise” and interference with task-relevant motor functions. The reduction of such non-essential networking may stem from the control of emotional reactivity owing to limbic system processes (i.e. *amygdala*), resulting in a quiet cortex that, in turn, simplifies and stabilises motor processes.

More specifically, there is evidence in support of an inverted-U relationship between cortical activity and performance as opposed to a monotonic relationship such that “more relaxation is better”. Heightened EEG alpha power was observed in expert marksmen prior to the decision to abort a shot, relative to that observed prior to trigger pull, suggesting that excessive relaxation, or a failure to regulate central arousal in an appropriate manner, may lead to dis-regulation of attention and reduce the quality of psychomotor performance. Similarly, Landers et al. (1994) also observed that the poorest shots during archery performance were associated with the highest levels of temporal EEG alpha power.

Babiloni et al. (2008) reported that alpha rhythms might represent a major physiological mechanism at the basis of “neural efficiency” and that these rhythms reflect the functional modes of *thalamo-cortical* and *cortico-cortical* loops that facilitate/inhibit the transmission and retrieval of both sensori-motor and cognitive information into the brain (Steriade & Llinas 1988; Brunia 1999; Pfurtscheller & Lopes da Silva 1999). Compared to the brains of non-athletes, those of elite athletes require a quite selective engagement of *thalamo-cortical* and *cortico-cortical* loops spanning the *occipital* and *temporal cortex* of ventral and dorsal pathways for a successful judgment of observed sporting actions. It can be speculated that such modulation of alpha rhythms support both global attentional (low-frequency alpha rhythms) and task-specific (high-frequency alpha rhythms) processes (Klimesch, 1996, 1999; Klimesch et al., 1998). This might be the same mechanism at the basis of a well-known phenomenon observable in healthy subjects: the progressive reduction of event-related cortical activity along learning phases. In this vein, it has been shown that training induces a decrease of activity in motor cortex from pre- to post-training phase during motor tasks (Haufler et al., 2000; Koeneke et al, 2006). Furthermore, the trained motor tasks were performed with a suppression of cognitive processes (Kerick et al., 2001, 2004).

According to Janelle and Hatfield (2008), neurophysiologically, the stress response is mediated by the *limbic system* but the central components of this emotional circuit are the two *amygdalae*. Multiple sensory pathways converge in the *basal lateral nuclei* of the *amygdalae* so that threatening environmental events are immediately processed (Pare, Quirk & LeDoux, 2004). The higher association regions of the *cerebral cortex* also communicate with the *amygdalae* so that worry and rumination can further stimulate these important sub-cortical structures. According to Bear, Connors, and Paradiso (2001), the lateral nuclei communicate with the central nucleus in each *amygdala*, which, in turn, affects critical forebrain, brainstem, autonomic, and endocrine processes that mediate the expression of emotion. More specifically, there are interconnections from the central nuclei to the *hypothalamus*, which results in sympathetic arousal and stimulation of stress hormones via the *hypothalamic-pituitary-adrenocortical* (HPA) axis; to the *periaqueductal grey*, which mediates motor responses; and to the *cingulate cortex*, which could result in excessive cortico-cortical communication.

Interconnections to the *pontine nuclei* in the reticular formation result in an increase in overall arousal. Such an orchestrated response underlies the mind-body connection that may be highly regulated to match task demands under conditions of confidence or dis-regulated under conditions of fear, resulting in excessive and uncontrolled arousal. The efficiency of cerebral cortical activity would be compromised as part of this overall response, particularly affecting attention and fine motor control. Timing and coordination are then altered and likely reduced in quality while attentional resources intrude on the typical automatic programming of well-learned responses. In this manner, non-essential cognitive processing in the *cerebral cortex*, as fear-related activity, can directly influence the *limbic system* and initiate a cascade of events disruptive to superior performance.

In support of such an “over thinking” hypothesis, Chen and colleagues (2005) recently provided psychophysiological evidence of increased networking between the left temporal region and the motor planning regions of the brain under conditions of psychological stress. When compared to a practice-alone condition, EEG alpha coherence between T3 and the motor planning region (Fz) was elevated when participants were asked to perform a dart-throwing task under the pressure of social evaluation. The increased ‘traffic’ in the brain was also accompanied by heightened reports of state anxiety and reductions in self-reported confidence levels.

As expected, the accuracy of performance was also reduced. The activation of the *amygdalae* serves as a pivotal event in the response to stress and the control of such activity would exact a powerful influence on the mental and physical states. A critical component in the management of fear is the executive control over limbic function and sub-cortical emotional circuits, which is housed anatomically in the frontal regions of the forebrain. It is well established that the *prefrontal cortex* has extensive anatomical connections with *sub-cortical limbic structures*, particularly the *amygdalae*, although the communication is indirectly achieved via the *anterior cingulate region* (Davidson, 2002; 2004).

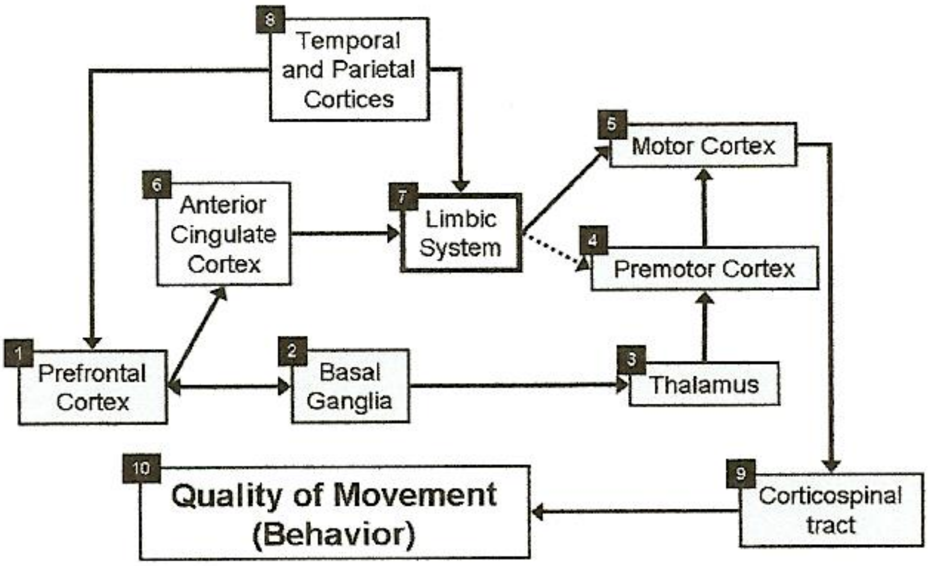


Figure 19. Stress induced cortical dynamics model (Janelle & Hatfield, 2008.

According to Janelle and Hatfield (2008), Figure 19 (above) illustrates the pivotal role of the prefrontal cortex in brain processes related to cognition, emotion, and, particularly, motor processes. According to this model, individuals under high stress will exhibit reductions in prefrontal asymmetry (box 1) compared to a low-stress condition, implying a lack of executive control over the *fronto-meso-limbic circuit*. Consequently, participants will experience heightened activation of the *limbic region* (*amygdala* in the limbic system; box 7). The resultant emotional reactivity, in turn, will lead to EEG alpha de-synchrony, particularly in the left temporal (T3) and parietal (P3) regions (box 8), along with increased cortico-cortical communication between these regions and the motor planning centres (box 4). Such deregulation of the *cerebral cortex* will be expressed as inconsistent input to the motor loop (boxes 2 – 5), resulting in inconsistent cortico-spinal output and shooting performance (motor unit activity, trigger pull, boxes 9 and 10).

Unmanaged or uncontrolled fear can significantly alter brain, muscle, and metabolic activity in such a way as to concretely alter the quality of performance. Importantly, the magnitude of change specified in the model would be significantly related to degradation in shooting performance (i.e., slower and less accurate). In this manner, management of the *limbic system* and refinement of cortical activation from executive control would most likely result in enhanced attention accompanied by smooth, fluid, graceful and efficient movement.

Calhoun et al. (2002) reported, after researching different activation dynamics in multiple neural systems during a simulated driving experience, that driving is a complex behaviour that recruits multiple cognitive elements. Signal in the *anterior cingulate cortex*, an area often associated with error monitoring and inhibition, decreases exponentially with a rate proportional to driving speed, whereas decreases in *fronto-parietal regions*, implicated in vigilance, correlate with speed. Increases in *cerebellar* and *occipital* areas, presumably related to complex visuomotor integration, are activated during driving but are not associated with driving speed.

Spiers and Maguire (2007), in a study to determine the neural substrates of driving behaviour, used an accurate interactive virtual simulation and a retrospective verbal report methodology. Different events that characterise the driving process on a second-by-second basis and the brain regions that underlie them, were identified. Prepared actions such as starting, turning, reversing and stopping were associated with a common network comprising *premotor*, *parietal* and *cerebellar* regions.

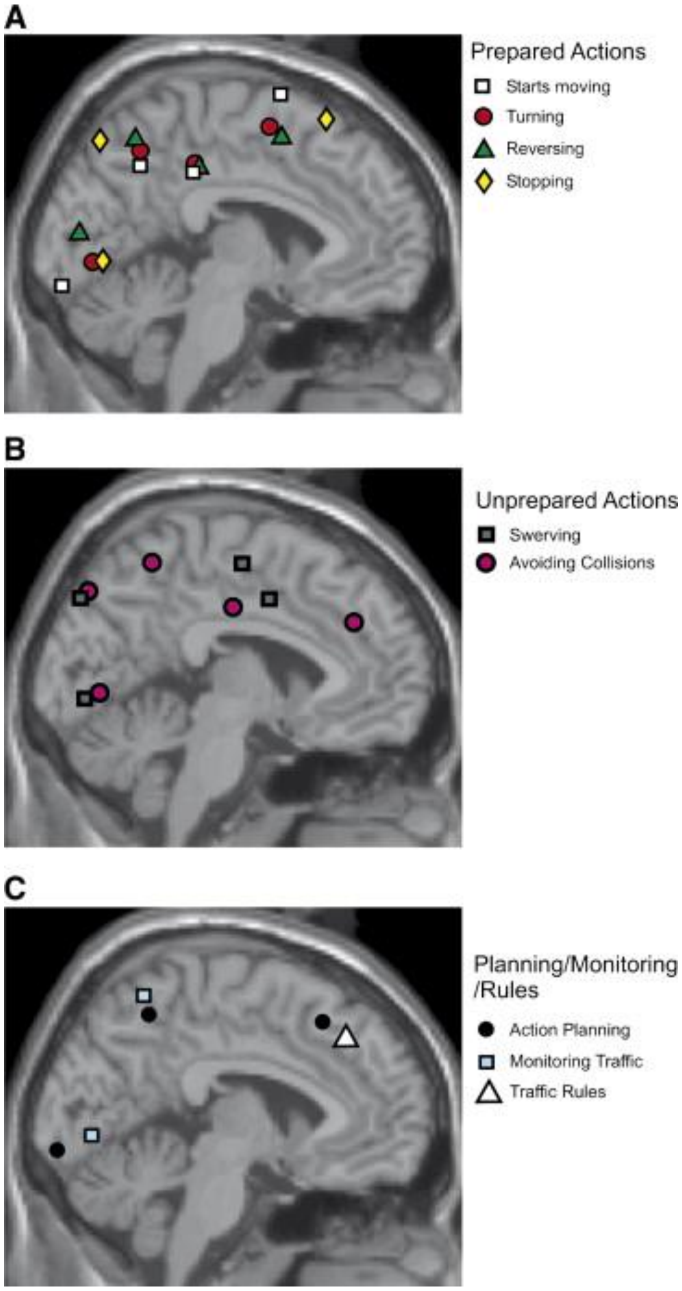


Figure 20. The various brain regions associated with aspects of driving (Spiers & Maguire, 2007)

Unexpected hazardous events, such as swerving and avoiding collisions, were found to be associated with activation of *lateral occipital* and *parietal regions*, the *insula*, as well as a more *posterior region* in the *medial pre-motor cortex* than is found with prepared actions. By contrast, planning future actions and monitoring other road users were associated with activity in *superior parietal, lateral occipital cortices* and the *cerebellum*. The *anterior pre-sensori-motor area* was also recruited during action planning. The *right lateral pre-frontal cortex* was specifically engaged during the processing of road traffic rules.

Jap et al. (2009) assessed four EEG activities, delta (δ) (±0 to 4 Hz), theta (θ) (4–8 Hz), alpha (α) (8–13 Hz), and beta (β) (13–20 Hz), during a monotonous simulated driving session in order to assess algorithms for detecting fatigue in drivers. Results showed stable delta (frontal) and theta (frontal, central, parietal) activities over time, a slight decrease of alpha (temporal) activity, and a significant decrease of temporal beta activity. All four algorithms showed an increase in the ratio of slow wave to fast wave EEG activities over time. This implies that alertness will increase with decreasing slow wave to fast wave ratios.

In summary, according to Janelle and Hatfield (2008), as a function of practice, the establishment of memory processes or an internal model to guide the performance as a function of practice would result in reduced activation in such regions. In addition, it seems likely that the novice would show increased frontal activation due to reliance on effortful executive processing such as explicit planning and response inhibition to distracting stimuli. Beyond such regional particular differences in activation one would also predict overall heightened cortical activation across a wide topographical distribution, relative to that observed in experts in light of the novelty of the task demands on the performer

4.5.2 The electroencephalograph correlates of the neuropsychological model of flow

From the above information, it is reasonable to assume flow is marked by mental economy under conditions of peak performance (Di Russo et al. 2005). This is achieved by the pruning of excessive cortico-cortical communication between attentional networks and motor regions, resulting in the enhancement and consistency of psychomotor performance (Hatfield & Hillman, 2001). It is also important to manage the stress response through the management of arousal level. Both improved performance and optimum arousal levels are influenced by training.

In the previous chapter it was hypothesised that during the early phases of skill acquisition the *fronto-limbic*, or *attentional networks* and the *posterior cortico-limbic networks* are strongly engaged in establishing stimulus - response mappings. Attentional resources are consumed by association processes converting explicit information into implicit knowledge. Representations of task parameters thus gradually develop within the slow learning or implicit knowledge system and violations of the context (i.e., post-learned errors) undergo template or contextual updating. The latter modifications require both *frontal* and *posterior* involvement.

It was hypothesised that in later stages of learning, once contingency mappings have become consolidated, these *frontal structures* exhibit a reduction in activity, while *posterior regions* demonstrate increased activity. Shifts in neural control occur as a function of practice so that the details of a motor task become gradually controlled by the *basal ganglia* in a circuit that also includes the *supplementary motor cortex,* the *motor thalamus,* and the *hippocampus*. Once internalised, little prefrontal activity is required during routine skill execution, freeing up working memory and allowing executive attention to fill its premium computational space with other environmentally relevant content that requires higher order processing.

Once task representations have transformed into implicit knowledge, unconscious, effortless execution of the skill is achieved, which is characterised by a perception of automaticity, and implies that flow is likely to occur.

Recent experimental evidence succeeded in showing that synchronised oscillatory activity, or EEG coherence, sub-serves the selective and effective transmission of information among neuronal groups during the integration of sensory information to ultimately trigger adaptive motor performance (Salinas & Sejnowski, 2001; Laughlin & Sejnowski, 2003; Fries, 2005; Sejnowski & Paulsen, 2006).

In line with the above hypotheses, neuroimaging studies have shown that skill acquisition activates the *prefrontal cortex, premotor cortex, parietal cortex* and *cerebellum*. Therefore, during the early stages of skill acquisition, the *prefrontal cortex* (indexed by F3/F4) is involved in the construction of mental representations of implicit and explicit task requirements through the engagement of *thalamo-cortical* and *cortico-cortical loops* spanning the *occipital* (indexed by O1/O2) *cortex, temporal cortex* (indexed by T3/T4) *pre-* and *primary motor cortex* (indexed by C3/C4), and *parietal cortex* (indexed by

P3/P4). Synchronised *fronto-parietal* (indexed by F3 - P3) oscillations have been found during conscious perception (Engel & Singer, 2001), attention (Niebur, 2002), working memory (Sarnthein et al., 1998), problem-solving tasks (Lubar, et al., 2001) and recollection of episodic information (Klimesch et al., 2001). It is therefore inferred that the early stages of skill acquisition are characterised by synchronised neural activity between the *prefrontal-*, *parietal-*, *temporal-*, *occipital-* and the *motor cortices*. Increased delta power and synchronisation in the *frontal* and *occipital areas* are involved in inhibition of non-relevant stimuli (Harmony et al., 2009). Increased frontal theta is reported in mental arithmetic (Sasaki et al., 1996; Smith et al., 1999); error detection (Luu et al., 2003; Luu et al., 2004); language comprehension (Bastiaansen et al., 2002; Hald et al., 2006); working memory tasks (Gevins et al.,1997; Jensen & Tesche, 2002; Krause et al., 2000; Onton et al., 2005); task complexity and focussed attention. Increased theta power in posterior brain areas are linked to increased task complexity during complex visuomotor tasks (Fournier et al., 1999). Alpha power increases have been linked to active inhibition of neuronal activity that could otherwise disturb the working memory process (Jokisch & Jensen, 2007; Klimesch et al., 2007).

Decreases in power in the lower alpha band have been linked to higher task demands and attentional processing, whereas decreases in power in the upper alpha band have been related to increased declarative memory performance. Beta synchronisation played an important role in motor control. Beta oscillations become synchronised over a larger scale when the attention to sensori-motor integration is required (Pfurtscheller & Andrew, 1999; Ivanitsky et al., 2001; Fingelkurts et al., 2005; Schnitzler & Gross, 2005). Gamma, high beta and beta waves are associated with selective attention, transient binding of cognitive features, and conscious perception of visual objects (Hughes, 2008). Increased gamma power has been linked to working memory maintenance (Tallon-Baudry et al., 1998; Lutzenberger et al., 2002; Kaiser et al., 2003; Jokisch & Jensen, 2007).

In line with the “neural efficiency” hypothesis, in later stages of skill acquisition or motor performance, once contingency mappings have become consolidated, frontal structures (F3/F4) exhibit a reduction in activity, while *posterior regions* (P3/P4) demonstrate increased activity. Shifts in neural control occur as a function of practice so that the details of a motor task become gradually controlled by the *basal ganglia circuit* (P3/P4), which includes the *supplementary motor cortex*, the *motor thalamus*, and the *hippocampus* (indexed by C3/C4). Beta de-synchronisation and phase lags between different cortical areas are reported once a motor skill is completely internalised and controlled entirely by the *basal ganglia circuit* and little prefrontal activity is required, freeing up working memory and allowing executive attention (indexed by F3/F4) to fill its premium computational space with other environmentally relevant content that requires higher order processing.

Using the above information, a probable model to describe the neurophysiology of the flow state postulates that individuals performing at peak levels, and thus experiencing flow, exhibit improved executive control over the *fronto-meso-limbic circuit* through modulation by the *dorsolateral prefrontal cortex* (F3). Consequently, individuals will experience decreased activation of the *amygdala* (less anxiety) and increased activation of the *hippocampus* (smoother motor control) in the *limbic system*. In terms of EEG data, the above process will be characterised by decreased synchrony between F3 and C3, reducing neuromotor "noise" and interference with task-relevant motor functions. The resultant emotional reactivity (less anxiety), in turn, will lead to higher fronto-midline (F3) theta power, increased alpha power and synchrony in the *left temporal* (T3), *sensori-motor* (C3) and *parietal* (P3) regions along with decreased cortico-cortical communication (power) between these regions and the motor planning centres (Fz/F3). Higher parietal (P3) theta power (associated with higher skill level) is expected. The EEG at site T3 will show higher levels of alpha power (8–12 Hz) (lower task demand) as well as lower levels of beta and gamma power at Fz/F3, implying less explicit (conscious) and more implicit (unconscious) attention to task execution. Beta rhythm de-synchronisation and phase lags will occur between the various cortical areas involved in motor control. This interpretation is consistent with the well-established notion of "automaticity" during skilled motor performance in which advanced performers are unconscious of the details of their performance as they execute "in the moment" (Fitts & Posner, 1967; Schneider & Chein, 2003). The above regulation of the *cerebral cortex* will lead to consistent input to the motor loop resulting in consistent cortico-spinal output and motor performance.

The proposed neurophysiological model for flow is illustrated in Figure 21 (below):

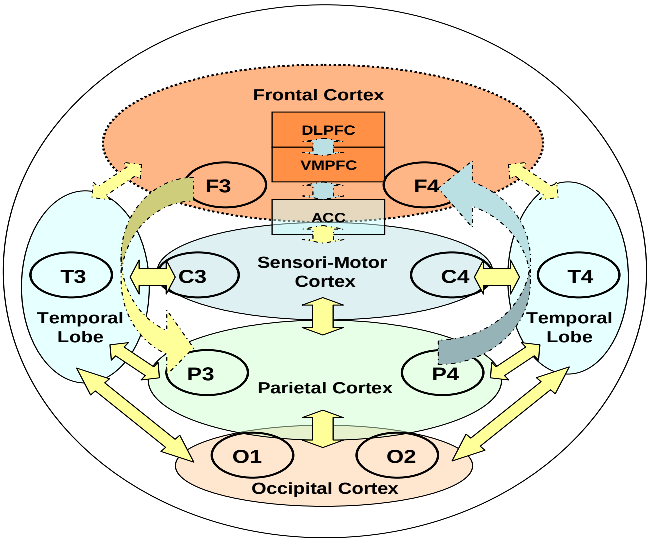


Figure 21. A neurophysiological (EEG) model for flow

The model indicates the indexing of brain structures and other anatomical features according to the International 10-20 System of Electrode Placement. It also illustrates the reduction (indicated by dotted line arrows) in cortical activity in *fronto-parietal-limbic structures* in parallel to increased (indicated by solid line arrows) posterior activity producing consistent input to the motor loop resulting in consistent cortico-spinal output and motor performance characteristic to the perception of "automaticity" in effortless skill execution during peak performance and flow.

In summary, it is hypothesised that the occurrence of flow, as a result of peak performance during a visuomotor task, will present the following EEG characteristics (excluding temporal):

(1) higher frontal (F3) and parietal (P3) theta power

(2) higher alpha power at sensori-motor (C3) and parietal (P3)

(3) lower beta and gamma power at F3

(4) increased alpha synchrony between the sensori-motor (C3) and parietal (P3) areas

(5) de-synchronisation of beta between the frontal (F3), sensori-motor (C3) and parietal (P3) areas

4.6. CONCLUSION

The aim of this study is to determine the EEG correlates of flow under conditions of peak performance. The EEG's will be recorded only in the pre-frontal-, sensori-motor-, parietal-, and occipital cortices. No measurements will be done in the temporal regions.

Given the above context, the proposed neurophysiological model for flow hypothesises that individuals performing at peak levels, and thus experiencing flow, exhibit increased frontal (F3) and parietal (P3) theta power, increased sensori-motor (C3) and parietal (P3) alpha power, and decreased frontal beta and gamma power, as well as increased alpha synchrony between the sensori-motor (C3) and parietal (P3) regions along with beta rhythm de-synchronisation between the frontal (F3), *sensori-motor* (C3) and *parietal* (P3) areas.

Based on the above postulations, the following hypotheses are formulated and tested in the study:

H1: There is a relationship between peak performance and psychological flow.

H2: There is an increase in PFC (F3) EEG Theta power in high flow.

H3: There is an increase in PPC (P3) EEG Theta power in high flow.

H4: There is an increase in PPC (P3) EEG Alpha power in high flow.

H5: There is an increase in SMC (C3) EEG Alpha power in high flow.

H6: There is a decrease in PFC (F3) EEG Beta power in high flow.

H7: There is a decrease in PFC (F3) EEG Gamma power in high flow.

H8: There is an increase in Alpha synchrony between C3 and P3 in high flow.

H9: There is a decrease in Beta synchrony between C3 and P3 in high flow.

H10: There is a decrease in Beta synchrony between F3 and P3 in high flow.

H11: There is a decrease in Beta synchrony between F3 and C3 in high flow.

The research design and methodology to test the above hypotheses will be discussed in the next chapter.

CHAPTER 5

RESEARCH DESIGN AND METHODOLOGY

5.1 INTRODUCTION

The overall aim of this study is to establish an EEG marker for flow that can serve as an objective measure for this intangible phenomenon. The previous chapter concluded with hypotheses to test assumptions regarding the expected pattern of the flow marker. This chapter focuses on the research design and methods used to operationalise the test variables and to organise, collect, analyse and interpret the data for testing the hypotheses that will provide valid and reliable evidence to an EEG marker for flow.

A straightforward correlational design is not possible as the research requires collecting EEG signals from the brain whilst the participant is performing a flow inducing task, not knowing when the person is in flow. Since an EEG marker for flow is unknown, the challenge is to know when flow occurs during a test session without interrupting the participant, causing the flow state to disappear. Without an EEG marker for flow the most common way to establish whether someone experienced flow is by means of a post-hoc questionnaire, which provides subjective information. Literature indicates that flow occurs under conditions of personal peak performance, however peak performance may not always accompany flow and thus may not assume the role of proxy variable for flow. Unlike flow, peak performance and the electrical activity in the brain may be observed, the former by a direct behavioural measure (such as time to complete a task) and the latter indirectly via EEG equipment.

To this end 20 participants were subjected to a flow inducing task while their EEG's were being monitored. The task is a visuomotor computer game, requiring participants to complete a two-lap race around a racing track. Participants were asked to complete 10 races. The time taken per race is used as an indicator of task performance. Participants complete an Abbreviated Flow Questionnaire (AFQ) after each race and a Game Flow Inventory (GFI) after having finished all 10 races. These questionnaires were used, ad hoc, to obtain an indication of each participant's conscious experience of flow during the task.

EEG recordings during task performance were monitored in four locations, namely the prefrontal, sensori-motor, parietal and occipital cortices. Seven frequency bands (alpha, theta, delta, lobeta, beta, hibeta and gamma) were recorded in each location, giving a total of 28 observations per participant per recording.

5.1.1 General design outline

Strictly speaking the study employs a time-series design consisting of 10 points of observation. However, this is simplified to a repeated measures format in which EEG's during a high flow condition are compared with EEG's during a low flow condition.

Although the repeated measures format is straightforward the actual comparisons between the repeated EEG observations are not. These comparisons do not merely entail the difference between an initial and a repeated measure of the 7 EEG frequencies at the same brain location (same location comparisons). It also involves cross-comparisons among 4 brain locations, that is, the difference between an initial observation at one location and a repeated observation at another location (different location comparisons). Although the study does not call for all possible comparisons (28x28=784) the number of required comparisons is quite extensive. This calls for a large sample, which is impractical due to the time consuming testing procedure. It was decided, therefore, to conduct a qualitative analysis of the comparisons. This approach is not unreasonable as the observed frequency bands constituted patterns (i.e. qualities) that are expected to display variations anticipated by underpinning theory.

A single group repeated measures design was used to collect data from the 20 subjects who were each required to repeat the dynamic task 10 times. On completion, performance times and associated flow scores were standardised where after the sample was segmented into two sub-samples reflecting two levels of the flow variable per subject, namely a high flow - peak performance level and a low flow - low performance level. The first race completed by each participant was used as a "baseline" (and indicative of a low flow state) for comparison with their own personal fastest race/highest flow score combination, indicative of a high flow state. This was required to extract the EEG data associated with each level for further statistical analysis and interpretation.

The relationship between flow and EEG was expressed in terms of the difference between the two levels. EEG power scores were compared (mean differences) by site and frequency, as well as the EEG patterns (correlates) between sites and by frequency. It was expected that EEG patterns on the lower end of the flow measure (low flow - low performance condition) should differ from the EEG patterns on the higher end (high flow - peak performance) of the flow measure. The EEG patterns on the high end were qualitatively compared with the patterns predicted by the theoretical model.

5.1.2 A quasi-experimental approach

The research design is quasi-experimental. It follows a formal, quantitative, laboratory-type scientific method and investigates specific hypotheses based on assumptions made about brain activity and the accompanying subjective experiences of the subjects, during their performances on a visuomotor task.

It was not possible, however, to have definitive experimental vs control groups for comparison as in strict experimental designs, since there was no intervention or manipulation of an independent variable for one group and not the other. Rather, two sets of data representing the 20 highest flow/performance and 20 baseline flow/performance scores, for each individual, were assigned to separate sets of scores for comparison. Each set of data included both the behavioural and EEG data.

The table that follows provides a summarised view of the research process that unfolds from a consideration of the variables that were operationalised and tested, through data collection and processing, to the data output and hypotheses testing.

Table 1

Summary of the research design and procedures

RESEARCH DESIGN					
Variables	The 3 test variables		Flow (intangible)		**Sample**
		↙	↓	↘	
		Electrical activity of brain (EEG) (Neurophysiological) ↓	Peak Performance (Behavioural) ↓	Experience of flow (Experiential) ↓	Subjects selected: 20 adult, male, regular gamers, all right handed.
The Test	The Task		Visuomotor computer game (racing)		Repeated Measures x 10
	Data Collected	Simultaneous EEG output in mV's for 7 frequencies and 4 sites.	Time in seconds to complete each task	1. 5pt. ratings on AFQ after each task 2. 7pt. ratings on GFI after all 10 tasks.	200 sets of data 20 measures
Data Processing and Analysis	Data Type	Ratio	Ratio	Interval	
	Descriptive Statistics	Mean Frequencies (7) by sites (4)	Total per task ranked fastest to slowest	1.Mean & sd for total sample & sub-groups for each task (x10) 2.Mean & sd for total sample & sub-groups for all 10 tasks	
	Standard-isation	None	All 10 performance times per individual.	All scores	Z-scores
	Bi-variate Statistics (probability	CORRELATION OF BEHAVIOURAL DATA To indicate the strength and direction of the relationships			All data from fastest and first task performances for

	testing)	existing between the various behavioural indicators, flow and performance, in order to establish that high performance is indeed associated with high flow and low performance with low flow. None All 20 subjects All	each individual (x 20 subjects).
	Multi-variate and Univariate Statistics (probability testing)	MANOVA/ANOVA On the basis of the correlation findings in the previous step it was shown that it was statistically valid to segment the data into two main groups, “high” and “low” flow, for further comparison. A MANOVA was conducted to test for differences between means of all test variables, including EEG power scores, in a single statistical technique that brings together both neurophysiological and behavioural data at the two levels of flow in order to establish that the two levels differs significantly. A univariate report on differences between the means of each variable was also conducted, which include an effects size analysis to provide more detailed information of the magnitude and direction of the changes in the means between low and high flow states. Outcome: f ratios and p values to indicate differences and their statistical significance at a $p \leq 0.05$ level and Eta^2 for effect sizes. CORRELATION OF EEG DATA To determine the marker for flow, the EEG data from the two flow levels are correlated by frequency and scalp position. **Outcome:** the correlation coefficients r and p values indicate the strength of the relationships between the 7 EEG frequencies at each of the 4 brain sites, by flow level. The differences between the two sets of data, representing high and low flow will already have been established and the high flow condition now emerges as the EEG marker for flow in 4 brain-sites, under conditions of peak performance.	This uses 2 flow datasets per subject for higher and lower flow conditions. ie total sample of 40 observations in 2 conditions.

Interpretation	Hypothesis testing.	The hypotheses that were based on the literature review are tested. They are based on assumptions about the flow condition and its EEG and behavioural characteristics at peak performance. **Outcome:** Each hypothesis determines, with statistical verification, whether the assumptions made about flow are confirmed or not.	

5.2 DEFINITION OF THE RESEARCH VARIABLES

Flow is operationalised in terms of performance level (the participant's personal best performance, compared with initial performance time) and subjective experience (indicators of flow derived from the literature).

Performance level, in turn, is operationalised in terms of time taken to complete the visuomotor task. The performance time is then linked with a subjective flow score obtained via two questionnaires that tap into the personal experience of the performer during the task.

EEG is operationalised in terms of measurements of potential differences between electrical locations on the scalp and these in turn are operationalised in terms of percent power displayed by location and synchrony patterns between scalp locations

Figure 22 below illustrates the main research variables and how they were operationalised.

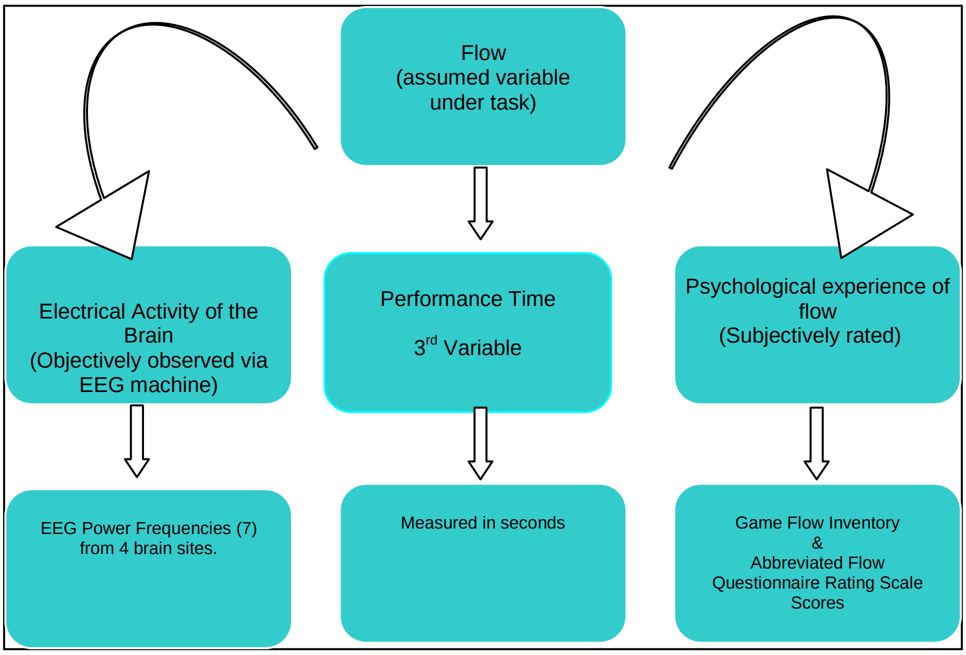


Figure 22. Main research variables and how they are operationalised

5.2.1 The psychological and behavioural test variables

The Game Flow Inventory (GFI) was derived from a validated flow questionnaire of 13 items, and identified three main psychological factors that indicated flow, under task - absorption, enjoyment and intrinsic motivation.

The Abbreviated Flow Questionnaire (AFQ) was derived from five critical flow related factors identified in the psychological literature. These were included as items for feedback after the completion of each race, as abbreviated indicators of flow, viz. perception of time passing, cognitive engagement, the match between skill and challenge, personal control and intrinsic reward or satisfaction.

Performance time (in seconds) was recorded for each race and included as a variable to be tested in association with the AFQ flow score recorded for each.

5.2.2 The neurophysiological (EEG) test variables

The electrical activity of the brain was recorded by electrodes placed at four brain sites, i.e. F3-F4; C3-C4; P3-P4; and O1-O2 in a four channel bi-polar montage with both grounds at A1 (ear clips), as follows:

(1) Channel 1 (CH 1 – F3) or pre-frontal cortex
(2) Channel 2 (CH 2 – C3) or sensori-motor cortex
(3) Channel 3 (CH 3 – P3) or parietal cortex
(4) Channel 4 (CH 4 – O1) or occipital cortex

Each channel recorded data in frequency bands grouped into the following classification:

(1) 1-3Hz (delta)
(2) 4-7Hz (theta)
(3) 8-12Hz (alpha)
(4) 12-15Hz (lobeta)
(5) 15-20Hz (beta)
(6) 20-30Hz (hibeta)
(7) 38-42Hz (gamma)

The data is displayed in micro-volts or percent power, which is explained in more detail in section 5.7.3.

5.2.3 Process variables

In addition, the design identifies the following process variables that have the potential to influence the outcome of the study by acting as moderator variables. These were taken into consideration at the sample selection stage, to control for potential variance from these sources.

(1) Gender – the human brain is lateralised for gender
(2) Handedness - the human brain is lateralised for handedness
(3) Level of computer gaming skill
(4) Age – the human brain is only fully developed at the age of 16 years
(5) Cultural background, which includes language background

5.3 THE SAMPLE

A non-probability sample was chosen, given the special characteristics of the experimental task. The sample was selected in a deliberative and non-random fashion to achieve the goal of eliciting flow during the execution of a computer based, visuomotor task. The sample was a purposive sample as the subjects were selected for theoretical reasons. Selection took place according to age, handedness and gender to keep these moderator variables constant and minimise variance. The subjects were volunteers who complied with strata and consent requirements, the latter also for ethical reasons.

5.3.1 The sample characteristics

The sample characteristics take into cognisance the potential for bias listed in section 5.2.3 (above). The cultural background was not considered to vary much in this sample that is from a mixed South African population in terms of cultural origin. The levels of education and computer skills were expected to minimise variance that might arise from cultural and language differences.

All subjects volunteered to participate and signed consent forms. This willingness to participate was indicative of the level of co-operation and motivation of the individuals sampled to minimise variance that might arise from a general lack of interest in the test situation.

5.3.2 The sample size

A minimum sample of 30 subjects per sub-group is commonly recommended for small samples, because as the sample size decreases the ranges of the mean and standard deviation increase, thus increasing the risk of sample error (Allen, 1982). Given the above guideline, a very large sample would be required for this study (number of subgroups x 30), which is impractical given that participants have to be observed individually, and each observation takes approximately one hour. Qualitative studies require smaller samples (around 10) and are based on the principle of level of saturation, when each participant no longer contributes new information. It was decided to settle on 20 because some inferential statistical tests were required in order to arrive at the qualities to be analysed.

5.4 TEST SESSIONS

Test sessions were conducted in a laboratory-type setting, in which uninterrupted sessions could take place and with the equipment set up in preparation for each one. Attention was required to details that included:

(1) adequate lighting
(2) absence of loud noises
(3) the removal of any potential sources of electrical interference
(4) checking that the laptop computer (for data collection) and the *BrainMaster* were functioning correctly
(5) the availability of conducting gel used for electrode placement
(6) the availability of consent forms, AFQ and GFI questionnaires, and necessary stationery
(7) Gaming skill rating form, using a 5-point scale of 1 (poor) to 5 (excellent).

An hour-long appointment was made with pre-selected participants, to include preparation time for giving instructions and electrode placement, the 10 x test races and a cleaning up period for removal of the electrodes and cleaning the subject's hair of conducting gel.

A PC video game was chosen because of its propensity to induce flow and its comparability with work elements such as computyping, security video monitoring, driving vehicles and flying aircraft. The PC DVD version of "Need for Speed - Carbon" (collector's edition) was chosen to provide a continuous visuomotor response task capable of producing flow. The video game consists of a virtual reality, driving scenario in which a car is driven through a pre-set street circuit for a specified distance. The game is supported with a game controller and video/audio feedback. The subject's task is to record the fastest possible time for the chosen two-lap race, which was set at the medium-level of difficulty. The instructions, nature and design of the game are such that they conform to Csikszentmihalyi's general conditions that purportedly facilitate flow experiences, as follows:

(1) *Clear goals* (record the fastest time).

(2) *Concentrating and focusing* (negotiating track challenges and traffic in such a way that it produces the quickest lap time).

(3) A *loss of the feeling of self-consciousness* (becoming immersed in racing).

(4) Distorted *sense of time* (lose track of actual time).

(5) Direct and immediate *feedback* (real-time visual and audio performance feedback).

(6) *Balance between ability level and challenge* (medium difficulty level in conjunction with a very fast car).

(7) A sense of *personal control* over the situation or activity (control through game controller together with sufficient skill to meet the challenge).

(8) The activity is *intrinsically rewarding* (achieving faster times and meeting performance goals).

(9) *Action awareness merging* (total absorption - becoming part of the game).

This particular PC video game was chosen because of its superior video graphics, fluency, virtual experience, and time feedback it produces. All settings, such as the type of car, track, track conditions, and feedback, were used in the same way for all participants in order to produce consistent results and eliminate any performance variances other than the skill/challenge trade-off. The game controller was also standard for all participants. The PC game was run on an *Acer Travelmate 6292* laptop computer attached to a 17-inch colour monitor using *Windows XP Pro* as operating system. The time, in seconds, taken the participant to complete the two-lap race was used as a measure of performance (time output). In order to allow for learning and skill refinement, as well as enough opportunity to get into flow, each participant was given 10 races to complete.

5.5 DATA COLLECTION

The intangible nature of the flow variable has already been mentioned and central to this design is the need to collect data under task and to set-up a testing situation accordingly. The need to repeat races up to 10 times allows for the potential effect of learning. However, given the subjects’ pre-existing gaming skill levels, it is unlikely that further repetition, in a single test session will result in any further increase in learning or performance. The session design thus gave all subjects sufficient opportunity to improve their performance to peak level. Flow was expected to occur at some stage during the 10 races.

Figure 23 below provides a visual illustration of the data collection process.

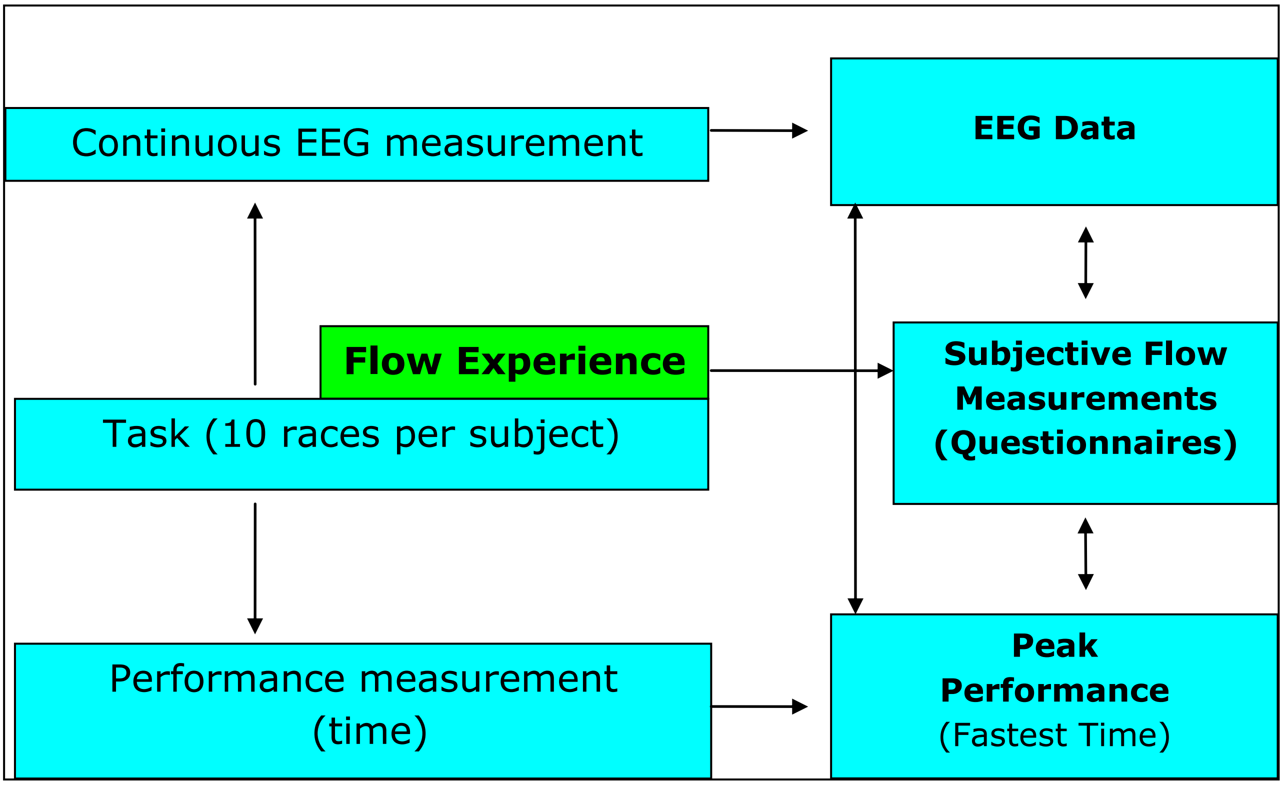


Figure 23. Conceptual framework for data collection

5.5.1 Data collection techniques and instruments

A mixed methodological approach was followed and data collected through both observational (EEG recordings) and self-report (questionnaire-based) techniques in a controlled test situation, in a one-off session per subject. The measures provided by each instrument are now described, with the subjective and objective components of the study represented by their own specific test variables and appropriate measures for collection of the data.

5.5.1.1 The psychological experience of flow

The subjective (conscious) experience of flow was measured by using two different paper-based questionnaire techniques. These questionnaires were administered by the researcher during and immediately after the test sessions – an abbreviated flow questionnaire (the AFQ) administered after each run and the Game Flow Inventory (GFI) administered at the end of all 10 runs.

a. The abbreviated flow questionnaire (AFQ)

In order to capture the experience of the subject after each race the participant was asked to rate his experience of the race using an Abbreviated Flow Questionnaire (AFQ) consisting of five questions measured on a five-point semantic differential scale (see Appendix E) to measure:

(1) time perception
(2) cognitive engagement
(3) skill /challenge match
(4) personal control
(5) intrinsic reward

These measures refer to the underlying dimensions that are considered crucial to achieve flow and that are labelled by Csikszentmihalyi (1990) as flow characteristics. The AFQ is not a validated instrument. Although there are other available flow questionnaires, they are all lengthy and not game play oriented. One such scale is the Flow State Scale, developed by Jackson and Marsh in 1996, which assesses flow on a scale of 9 factors using a total of 36 items. The factors were derived from the work of Csikszentmihalyi and include: challenge-skill balance, action awareness merging, clear goals, unambiguous feedback, concentration on the task at hand, sense of control, loss of self-consciousness, transformation of time, and autotelic experience. Another adaptation of Csikszentmihalyi’s concept of flow and relating to specific experiences of computer users, was produced by Rheinberg, Vollmeyer, and Engeser (Engeser & Rheinberg, 2008), using two factors. The first factor refers to the feeling of utmost concentration and focusing, control over the activity, clarity of the operations, and smooth and automatic cogitations. The second factor refers to the feeling of full involvement, a distorted sense of time, optimal challenge, and absent-mindedness. Both the above questionnaires were deemed unsuitable since it was too lengthy to complete ten times in-between races.

As an alternative, the five-question AFQ was deemed by the author as a more suitable instrument to provide quick, accurate feedback regarding the flow experience directly after each race. The five questions were considered independent of each other and carried equal weight in the resulting AFQ score. In the final analysis the one scale measuring "perceived time" was dropped and the AFQ4 version used. This followed a judgement call made by the researcher who was not convinced that the experience of time passing was a truly subjective one, since all subjects were racing against time. A timer was clearly visible on the screen and they also received feedback about their performance in time. This time-consciousness could result in misleading information about perceived time and the flow experience, where it is expected that there is a forgetting about time, as immersion in the task occurs. The function of the AFQ is to provide feedback, in a measured way, about the subject's "symptoms" of flow and the strength of that experience. This information identifies the amount of perceived flow associated with each race.

b. The Game Flow Inventory (GFI)

The WOrk-reLated Flow inventory (WOLF) was originally used to measure employees' flow in the workplace. It was developed by Bakker (2008) and adapted by him to suit the gaming situation, subsequently known as the Game Flow Inventory (GFI). As an index of the flow state (Bakker, 2005), the WOLF questionnaire, and thus the GFI (see Appendix D), measures (i) absorption, that is a state of total concentration, when a person is totally immersed in an activity. Time passes quickly and people forget everything around them; (ii) enjoyment or happiness, as the outcome of cognitive and affective evaluations of the flow experience. It has been shown that employees who enjoy their work and feel happy make positive judgments about the quality of their working life; and (iii) intrinsic motivation, that is performing a certain work-related activity with the aim of experiencing the inherent pleasure and satisfaction in the activity (Bakker, 2008).

Bakker (2008) reported that

> … the internal consistency or reliability of the scales for absorption, work enjoyment and intrinsic work motivation have been proved to be acceptable. In seven samples, the coefficients ranged between 0.75 and 0.85 for absorption, 0.88 and 0.95 for work enjoyment, and 0.53 and 0.82 for intrinsic work motivation. Only the scale for the assessment of intrinsic work motivation performed somewhat unsatisfactorily in one of the seven samples (the agency for temporary work), with a coefficient of 0.53. Nevertheless, the test–retest reliability in this sample was very good for each of the scales, with stability coefficients of about 0.75. This means that flow can be measured reliably and that the answers of employees to questions about flow correlate strongly with their responses six weeks later.

Construct validity and predictive validity of the WOLF were also satisfactory, however, in terms of the latter, absorption proved to be an unreliable predictor of performance during flow (Bakker, 2008).

It was expected that the GFI would achieve similar results to the WOLF since it was mainly a matter of replacing the word “work” with “race”. The GFI was administered at the end of the entire session of all 10 races. This measurement of flow is thus retrospective and reflects on the total experience after all 10 races.

5.5.1.2 EEG recordings

The EEG’s are recorded and measured using *BrainMaster* equipment. According to the manual, the *BrainMaster* is a scientifically sound and accurate instrument designed for the recording, analysis, and display of EEG signals (electroencephalograms). It performs functions similar to typical digital EEG systems and certain devices such as the Lexicor NRS-2D, Lexicor POD, BrainTracer, NeuroCybernetics, or ProComp.

Figure 24. Atlantis I (4+4) and data cable

The data collection, or recording, takes place on a separate laptop computer loaded with *BrainMaster* 3.0 software using *Atlantis* I “4+4” design (4 EEG and 4 Bio-potential channels) performing 1024 samples per second (with continuous impedance monitoring) internal and 256 samples per second external (to laptop PC). Electrodes used were moulded gold cup electrodes placed at F3-F4; C3-C4; P3-P4; and O1-O2 in a four channel bi-polar montage with both grounds at A1 using the international 10/20 referencing system.

Impedance for each electrode placement is kept under 5000 ohms (Ω) in order to eliminate interference and optimise sensor sensitivity. The raw EEG signal collects at a sampling rate of 256Hz, digitised and passed through a 60Hz notch filter to remove ambient electrical activity. Fast Fourier Transform (FFT), separates the raw data (similar to how white light is separated into colours by a prism) into individual frequency bands.

5.6 THE TEST SESSION

The test sessions were conducted at two locations, one in the office of the researcher and the other in a computer room at the Industrial Engineering Department of the Durban University of Technology. Both locations were prepared in such a way as to provide laboratory-type conditions, in particular, all other electrical appliances were switched off, so that minimal electrical interference would be experienced and to avoid artefacts during EEG recordings. Both rooms were well lit and free of outside interference from other people and loud noises.

Each subject was seated and made comfortable, briefed regarding the nature, sensitivity and workings of EEG, and requested to remain as still as possible during recordings. They were requested not to blink their eyes excessively, grind their teeth, or move their heads. Each subject was briefed about the aim of the research without being informed about the meaning or characteristics of flow. Emphasis was placed on the recording of electrical activity in the brain during the playing of a PC video game. Following the briefing, informed consent was obtained in writing (signed form) from each subject. While a subject was busy completing the biographical questionnaire, electrodes were placed at F3-F4; C3-

C4; P3-P4; and O1-O2 in a four channel bi-polar montage with both grounds at A1 (ear clips).

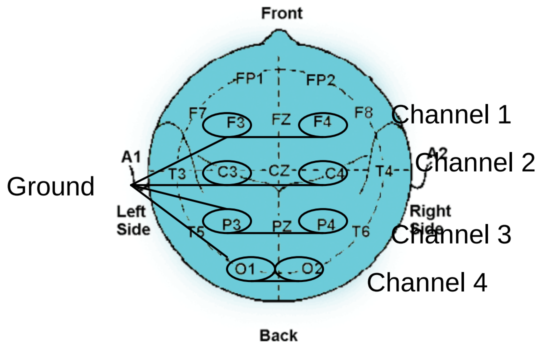


Figure 25. Electrode placements and channels

Once the electrodes were attached, the following sequence of events took place:

(1) Instructions on how to proceed with the game. The subject is given instructions on how to play the game and how the session would unfold. The objective is to complete the race in the quickest time possible.

(2) Trial Run. Each subject is allowed to perform a trial run to get familiarised with the game controller, the behaviour of the car, the track conditions and the layout of the circuit.

(3) Repeated reminder of the goal. Following the trial run the subject is asked to relax and reminded of the goal being to record the fastest possible time.

(4) Test runs. Each subject is given 10 races to produce a best result. The game is started by the subject, but the race is started by a virtual female character in the game, that also set the clock rolling. The subject races against five other virtual drivers in the game. The race ends when the subject completed the second lap.

(5) Feedback after the race. Feedback is provided to the subject in terms of his race position and the time he took to complete the race.

(6) Recording the time and starting the next race. Following each race the time is recorded and the subject asked to rate his experience on each question of the AFQ. Thereafter the subject is instructed to relax. His time on the previous race, as well as the goal, is repeated before he is instructed to engage the next race.

(7) Completing the GFI. Following the conclusion of the tenth race the subject is requested to complete the AFQ for the last race and the GFI for the whole session.
(8) Ending the session. The subject is cleaned (conductive paste is removed) and thanked for his participation.

Figure 26. Photo of subject during a test session

Visible in the photograph above is the laptop computer running the PC video game and the screen displaying a scene from the driving experience. Also visible are some of the electrodes attached to the subject's head and the two sets of cables that feed the data via the *Atlantis* to the second laptop computer (not visible).

5.7 THE DATA AND DATA ANALYSIS

This section examines the data and process of analysing it.

5.7.1 Characteristics of the data

Two different kinds of data, behavioural (performance time and perceived flow scores) and neurophysiological (EEG) were collected and recorded employing their own methods in a single test session, to provide evidence for both the conscious experiences of the subjects and the accompanying electrical activity in the brain. The EEG data and performance time data was continuous and suitable for further statistical manipulation and interpretation by normal distribution methods. The data from both the GFI and AFQ, however, is categorical and not continuous ratio data.

5.7.2 The behavioural raw data

The subject's conscious experience of flow was measured on five-point rating scales in a series of post hoc interviews following each test trial and a 13-item questionnaire following the whole session. The AFQ was used in the former and the GFI in the latter instance. Performance time was automatically recorded for each race, in seconds.

An electronic record (*Excel* worksheet) was created for each subject to capture the raw data, as follows:

(1) biographical data (age in years, population group, perceived gaming skill level, gender and dominant hand)
(2) each raw score obtained for each item on the AFQ
(3) each raw score obtained for each item on the GFI
(4) performance time (in seconds).

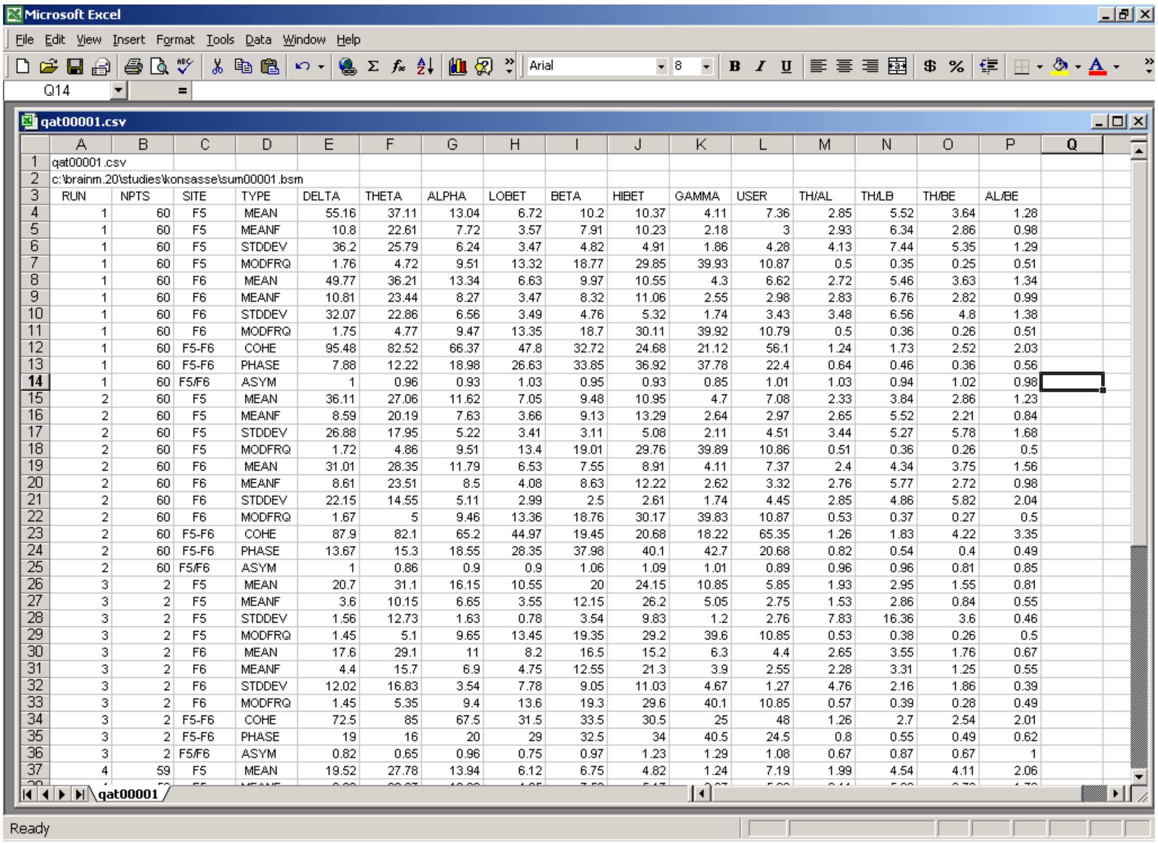
This record further enables data manipulation in *Microsoft* and *NCSS* software programmes (Hintz, 2001). Descriptive statistics, consisting of mean (average) scores and standard deviations were calculated for the AFQ and GFI.

5.7.3 The EEG output data

EEG recordings produce a continuous stream of EEG scores that are summarised by customised software to produce statistical output information relating to the whole session. Consequently, there is no access to real-time changes that take place in the brain, only to the summarised statistical output per session. As an organ the brain produces activity that is orchestrated from moment to moment. It is the nature of the brainwaves and their inter-relationships within and between specific sites, in particular, their synchrony or co-variance that provides key measures for recording and interpreting brain behaviour. The data in each channel cover all frequency bands and ratios between frequencies, together with the data from all the other channels. *BrainMaster* also provides inter-channel statistics but does not cover all inter-channel combinations.

Since the *BrainMaster* provides data that have already been processed by its own internal statistical processes, the output data, in a bi-polar montage, consist of a set of summarised statistics, which reflect the amount of electrical activity measured between two electrodes in a channel, as F3 - F4, for example.

The data from each recording (200 data sets) are saved as a *MS Excel* file in the format shown overpage.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	qat00001.csv																
2	c:\brainm.20\studies\konsasse\sum00001.bsm																
3	RUN	NPTS	SITE	TYPE	DELTA	THETA	ALPHA	LOBET	BETA	HIBET	GAMMA	USER	TH/AL	TH/LB	TH/BE	AL/BE	
4	1	60	F5	MEAN	55.16	37.11	13.04	6.72	10.2	10.37	4.11	7.36	2.85	5.52	3.64	1.28	
5	1	60	F5	MEANF	10.8	22.61	7.72	3.57	7.91	10.23	2.18	3	2.93	6.34	2.86	0.98	
6	1	60	F5	STDDEV	36.2	25.79	6.24	3.47	4.82	4.91	1.86	4.28	4.13	7.44	5.35	1.29	
7	1	60	F5	MODFRQ	1.76	4.72	9.51	13.32	18.77	29.85	39.93	10.87	0.5	0.35	0.25	0.51	
8	1	60	F6	MEAN	49.77	36.21	13.34	6.63	9.97	10.55	4.3	6.62	2.72	5.46	3.63	1.34	
9	1	60	F6	MEANF	10.81	23.44	8.27	3.47	8.32	11.06	2.55	2.98	2.83	6.76	2.82	0.99	
10	1	60	F6	STDDEV	32.07	22.86	6.56	3.49	4.76	5.32	1.74	3.43	3.48	6.56	4.8	1.38	
11	1	60	F6	MODFRQ	1.75	4.77	9.47	13.35	18.7	30.11	39.92	10.79	0.5	0.36	0.26	0.51	
12	1	60	F5-F6	COHE	95.48	82.52	66.37	47.8	32.72	24.68	21.12	56.1	1.24	1.73	2.52	2.03	
13	1	60	F5-F6	PHASE	7.88	12.22	18.98	26.63	33.85	36.92	37.78	22.4	0.64	0.46	0.36	0.56	
14	1	60	F5/F6	ASYM	1	0.96	0.93	1.03	0.95	0.93	0.85	1.01	1.03	0.94	1.02	0.98	
15	2	60	F5	MEAN	36.11	27.06	11.62	7.05	9.48	10.95	4.7	7.08	2.33	3.84	2.86	1.23	
16	2	60	F5	MEANF	8.59	20.19	7.63	3.66	9.13	13.29	2.64	2.97	2.65	5.52	2.21	0.84	
17	2	60	F5	STDDEV	26.88	17.95	5.22	3.41	3.11	5.08	2.11	4.51	3.44	5.27	5.78	1.68	
18	2	60	F5	MODFRQ	1.72	4.86	9.51	13.4	19.01	29.76	39.89	10.86	0.51	0.36	0.26	0.5	
19	2	60	F6	MEAN	31.01	28.35	11.79	6.53	7.55	8.91	4.11	7.37	2.4	4.34	3.75	1.56	
20	2	60	F6	MEANF	8.61	23.51	8.5	4.08	8.63	12.22	2.62	3.32	2.76	5.77	2.72	0.98	
21	2	60	F6	STDDEV	22.15	14.55	5.11	2.99	2.5	2.61	1.74	4.45	2.85	4.86	5.82	2.04	
22	2	60	F6	MODFRQ	1.67	5	9.46	13.36	18.76	30.17	39.83	10.87	0.53	0.37	0.27	0.5	
23	2	60	F5-F6	COHE	87.9	82.1	65.2	44.97	19.45	20.68	18.22	65.35	1.26	1.83	4.22	3.35	
24	2	60	F5-F6	PHASE	13.67	15.3	18.55	28.35	37.98	40.1	42.7	20.68	0.82	0.54	0.4	0.49	
25	2	60	F5/F6	ASYM	1	0.86	0.9	0.9	1.06	1.09	1.01	0.89	0.96	0.96	0.81	0.85	
26	3	2	F5	MEAN	20.7	31.1	16.15	10.55	20	24.15	10.85	5.85	1.93	2.95	1.55	0.81	
27	3	2	F5	MEANF	3.6	10.15	6.65	3.55	12.15	26.2	5.05	2.75	1.53	2.86	0.84	0.55	
28	3	2	F5	STDDEV	1.56	12.73	1.63	0.78	3.54	9.83	1.2	2.76	7.83	16.36	3.6	0.46	
29	3	2	F5	MODFRQ	1.45	5.1	9.65	13.45	19.35	29.2	39.6	10.85	0.53	0.38	0.26	0.5	
30	3	2	F6	MEAN	17.6	29.1	11	8.2	16.5	15.2	6.3	4.4	2.65	3.55	1.76	0.67	
31	3	2	F6	MEANF	4.4	15.7	6.9	4.75	12.55	21.3	3.9	2.55	2.28	3.31	1.25	0.55	
32	3	2	F6	STDDEV	12.02	16.83	3.54	7.78	9.05	11.03	4.67	1.27	4.76	2.16	1.86	0.39	
33	3	2	F6	MODFRQ	1.45	5.35	9.4	13.6	19.3	29.6	40.1	10.85	0.57	0.39	0.28	0.49	
34	3	2	F5-F6	COHE	72.5	85	67.5	31.5	33.5	30.5	25	48	1.26	2.7	2.54	2.01	
35	3	2	F5-F6	PHASE	19	16	20	29	32.5	34	40.5	24.5	0.8	0.55	0.49	0.62	
36	3	2	F5/F6	ASYM	0.82	0.65	0.96	0.75	0.97	1.23	1.29	1.08	0.67	0.87	0.67	1	
37	4	59	F5	MEAN	19.52	27.78	13.94	6.12	6.75	4.82	1.24	7.19	1.99	4.54	4.11	2.06	

Figure 27. Example of data file

As demonstrated above, the following data are recorded in one-minute averages and reported by means of the following indicators:

(1) Column A indicates the recording in minutes; B displays seconds, C are the various sites or scalp locations; D is the type of statistic; E – K are the frequency

bands; L is a frequency band defined by the user; M – P are ratios of frequencies relative to each other.

(2) Statistics are displayed in digital (displaying amplitude data in micro-volts) or in percent power (displaying amplitude data from Fast Fourier Transformed data).

(3) MEAN : the average amplitude in micro-volts.

(4) MEANF : the mean fraction of EEG energy in a band, also referred to as power or percent power, from FFT. Power is a measure of wave strength.

(5) STDDEV : the standard deviation from the MEAN.

(6) MODFRQ : the modal frequency (dominant frequency) from FFT. This is a measure of wave intensity.

When 2 channels are gathered, the following inter-channel data are also provided by the *BrainMaster* system:

(1) COHE : coherence value (in percent); displaying the degree of wave similarity between the two channels (using mean amplitude). Coherence is synonymous to a Pearson correlation coefficient.

(2) PHASE : phase value (in percent phase: 0 = in-phase, 100 = 180 degrees out of phase); displaying the degree of wave synchrony between the two channels (using mean amplitude).

(3) ASYM : asymmetry, which is similar to COHE, but from a different source (using MEANF data).

For the purpose of this study the main unit of measurement is from the FFT system using MeanF, the power score that indicates the percent power per frequency band. Power is an indication of energy or neural activity represented in a frequency band. More importantly, synchrony (coherence or asymmetry) is a measurement of synchronous neural activity between brain locations. Synchrony was calculated by using Pearson correlations since the *BrainMaster* system provides insufficient data coverage in terms of inter-correlations between brain sites.

Since each individual EEG recording produces millions of scores that are not accessible to the experimenter on a real time basis, use of these summary scores is essential. This has implications for the design of this research and the analyses conducted, as comparing pairs of summarised location data only is possible, rather than inter-correlations based on the real-time scores of individuals. Ultimately, the intent is to confirm the hypothesised brain locations and activity involved in and associated with flow, and to bring this information together in an illustrative format with statistically relevant support.

Alba, Marroquin, Arce-Santana and Harmony (2010) maintain that one of the challenges in EEG synchrony analysis lies in the design of an adequate visualisation system, allowing the exploration of synchronous dynamics across a wide time and frequency range versus fixed time illustrations in a matrix. However, no matter how visually appealing and creative illustrations may be they need to be accurate and statistical analyses are required to supplement the illustrative information and prove the true significance of the observations. The chosen illustrative format is discussed later in the chapter (see section 5.8.6.2).

As mentioned earlier, the EEG data were grouped into four Channels, ie. Channel 1 (CH 1 – F3), or pre-frontal cortex; Channel 2 (CH 2 – C3), or sensori-motor cortex; Channel 3 (CH 3 – P3), or parietal cortex, and Channel 4 (CH 4 – O1), or occipital cortex.

5.8 DATA ANALYSIS

The research study was based on a single group and repeated measures design collecting data from 20 subjects who were each required to repeat a dynamic task 10 times. The sample is then segmented into two sub-samples to set up two levels of the flow variable per subject, namely a high flow - peak performance level and a low flow - low performance level, in order to test whether these two levels (conditions) differed with regard to the EEG variable. Data analysis follows a six-step process which unfolds as follows.

Step 1. Total sample analyses

Demographic and behavioural data from all 20 subjects are summarised using descriptive statistical techniques (means, standard deviations and range) to provide an overview of the sample characteristics and test scores, as a whole. The data, captured from all 10 races from all 20 subjects and focussing on the relationship between the experience of flow (measured on the GFI and AFQ), and performance (race times), was organised into a single database.

Step 2. Addition of the EEG data

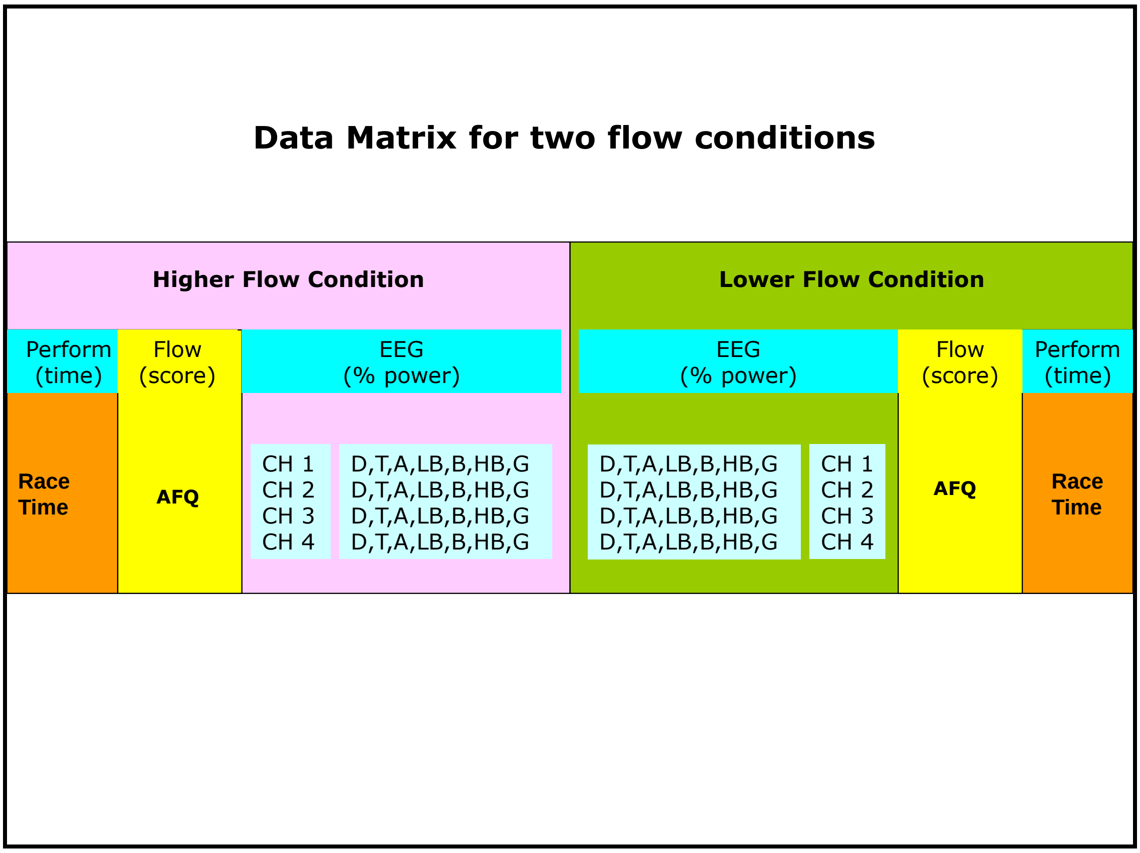
The MeanF (power) scores across the seven frequencies at the four brain sites were added to the database, along with the behavioural data, by race number within subject. Each subject's set of data per race was then ranked from lowest (fastest) to highest (slowest) performance time.

Step 3. Segmentation into higher and lower flow sub-samples

It was expected that the EEG pattern presented by the 20 high flow races versus the 20 initial/baseline (low flow) races would be a valid indicator of a "signature" pattern or marker for flow. This necessitated segmentation of the data into higher and lower flow sub-samples to extract peak performance data and a relevant set of baseline data for comparison.

Using the rank-ordered data per subject, the sample was segmented into higher and lower flow sub-samples using the initial race as baseline/low flow and highest flow/fastest race data per subject for the high flow sub-set. The assumption was that, since it is not possible to know when a person experiences flow in real time, it is expected that flow will manifest during peak performance and that the EEG produced during such performance will represent a realistic marker for flow. A further assumption is that it is unlikely that flow will manifest during the first performance and that the EEG produced during such performance will differ from the EEG produced under conditions of peak performance and thus will not represent a realistic marker for flow.

The data matrix below illustrates the main data groupings after segmentation.



Data Matrix for two flow conditions

Higher Flow Condition				**Lower Flow Condition**			
Perform (time)	Flow (score)	EEG (% power)		EEG (% power)		Flow (score)	Perform (time)
Race Time	**AFQ**	CH 1 CH 2 CH 3 CH 4	D,T,A,LB,B,HB,G D,T,A,LB,B,HB,G D,T,A,LB,B,HB,G D,T,A,LB,B,HB,G	D,T,A,LB,B,HB,G D,T,A,LB,B,HB,G D,T,A,LB,B,HB,G D,T,A,LB,B,HB,G	CH 1 CH 2 CH 3 CH 4	**AFQ**	**Race Time**

Figure 28. Data matrix indicating the data groupings for comparing the higher flow and the lower flow conditions

5.8.4 Step 4. Standardisation of performance and flow scores

Following segmentation, the data were standardised on an individual subject basis for performance and flow over all 10 races. Because of the different skill levels amongst subjects, some peak performances were slower than the poorest ones of other subjects, therefore it was necessary to standardise the data so that, for every individual subject, each score is represented in terms of standard deviations from their individual means. Another reason for standardising the data was to transform it all to a common scale and to bring all of the variables into proportion with one another so as to eliminate unequal weights. Additionally, although not a normalising technique, by standardising the data it became more normally distributed with the added advantage that it allowed using a MANOVA that is based on the assumption that the data is normally distributed.

5.8.5 Step 5. Test for significant behavioural and EEG differences between higher and lower flow conditions

In order to establish a neurological pattern that is unique to high flow and a marker for flow, it was necessary to determine that the two levels of flow were indeed significantly different from each other. A one way repeated measures MANOVA (Multi-variate analysis of variance) was conducted on the behavioural (performance and flow) and EEG power data (seven EEG frequencies at four brain locations), which provided the key to determining that the two sets of data were different. A univariate report on differences between the means of each variable was also produced, which included an effects size analysis to provide more detailed information of the magnitude and direction of the changes in the means of all data between low to high flow. One of the main advantages of reporting effect sizes together with p-values is that they provide an answer to the “how much” question.

The advantage of using the MANOVA is that it provides one overall test of equality of mean vectors for all groups simultaneously. The test statistic used in the MANOVA is the F-ratio, which indicates whether or not the variances in the two (high and low flow) samples are equal. In this case it takes into account not only the variance between the two groups (as in ANOVA) but also variance within the groups. A statistically significant F-ratio will indicate that there is a significant level of variance between the two groups.

When using the MANOVA the following assumptions have to be met as outlined in the SPSS Manual (IBM Software Group, 2013) :

(1) Dependent variable data must be continuous.
(2) Two or more independent variable categories must be used.
(3) Independence. The group data should consist of independent sets of observations, that is the participants in each group should not be related to each other in any way so as to rule out variation patterns that are due to a familial effect rather than the main effect(s) being tested.
(4) The sample size should be adequate.
(5) Sample sizes should be equal.

(6) Outliers will compromise the analysis as MANOVA is particularly sensitive to them.
(7) All data must be normally distributed.
(8) A linear relationship between each pair of dependent variables for each group of the independent variable must exist.
(9) Homogeneity of variance.
(10) There is no multicollinearity

With reference to this study, the data set included performance, flow and EEG data, which were all continuous data. Performance was measured as time in seconds (ratio); the flow data consisted of tests scores from interval rating scales and the EEG power scores also consisted of ratio data. Two independent variable categories were used in the MANOVA analysis – the baseline (first race) and the fastest race (peak performance) of each individual subject from 9 other races was selected out. Independence of sample participants is important when testing for differences between means due the danger of Type 1 error (false positive) being committed, especially in the use of an ANOVA, if the participants are related in any way. The MANOVA is an extension of the ANOVA and is considered to have the same problem with independence. The ANOVA uses the mean sum of squares to indicate the amount of variance in the group data and dependent relationships may be responsible for violating circularity or sphericity (the assumption of homogeneity of variance between groups) on repeated measures and not taking into account the pattern of variance from within the source of the data. In the MANOVA test the f-ratio is the test statistic. MANOVA is an alternative to a repeated measures ANOVA since repeated measures are treated as co-variates of each other.

O'Brien and Kaiser (1985) contends that tests in repeated-measures designs based on MANOVA are free of sphericity assumptions, and with modern computing software, MANOVA is straightforward to use, even for complex designs and nontraditional hypotheses. It may also be argued that since it is the intention of the researcher to reject the null hypothesis (that here is no significant difference between the two groups) in favour of the alternative hypothesis that the two groups (high and low flow) are in fact different, the MANOVA will treat the differences conservatively and, therefore, a significant difference will be a robust result.

In terms of the sample size, it is generally considered that the larger the sample size, the better. The question of an adequate sample size is relevant. According to the NCSS manual (Hintz, 2007), 20 degrees of freedom in the univariate F-test is adequate to ensure robustness. In this study a sample of 20 participants was selected. Strictly speaking this would result in 20-1 degrees of freedom but may be considered an adequate sample size for the use of the MANOVA. The same size sample was used for both high and low flow data sets. At all times the total sample remained at 20 respondents and there were no missing values.

Extremes of variation in raw scores would pose a threat to the analysis as MANOVA is particularly sensitive to outliers. Given the nature of the experimental task, it was expected that some extreme scores would occur due to participants making driving errors. However, the fact that only the baseline and peak performance races were used, the risk of outliers was reduced. Figure 40, a scatterplot in the next chapter, indicates the clustering of scores around the regression line. Further, the standardisation of the raw scores would have further reduced the outlier effect by having each respondent's response set conform to a normal distribution of scores.

All data must be normally distributed. A Type 1 (incorrect rejection of the null hypothesis) error is likely to occur if the data is not normally distributed because skewed data may distort the mean sum of squares resulting in higher variance. Donaldson (1966) showed, however, that that the F-Test is conservative in showing up variance and that it improves in this regard as sample size increases, so that the effect of non-normally distributed data is less severe than previously thought. Furthermore, the performance and flow (AFQ4) raw scores from each individual were standardised.

With regards to the assumption of linearity, in this study the high flow and low flow group data for the dependent variables, peak performance and flow (AFQ4 total score and sub-scores), were all linear. A side-by-side structure was observed in the database used for analysis. According to the NCSS Manual, homogeneity of variance is assumed when an equal number of observations occur in each cell, which were the case in this study. Multicollinearity did not occur. Ideally, the dependent variables should be moderately correlated, however if the correlation(s) are too high (greater than 0.9), multicollinearity may occur. In this study the dependent variables were moderately intercorrelated.

With regards to the effect size analysis, the Eta^2 effect size was used to further enhance the statistical analysis. The univariate report that accompanied the MANOVA, included an Eta^2 effects size analysis that provided information on the magnitude and direction of the changes in the means of all data between low to high flow. Eta^2 is the proportion of variance that is explained by differences between the means of the groups (Tredoux & Durrheim, 2013). The general rules of thumb given by Cohen (1988) for interpreting Eta^2, i.e. small (0.01), medium (0.06), and large (0.14), were used.

5.8.6 Step 6. EEG analysis of power and synchrony as correlates of flow

This step comprised two parts.

5.8.6.1 Analysis of EEG power

In terms of power spectrum analyses, the frequency spectrum Delta to Gamma was analysed in terms of power differences between the two conditions (sub-samples), by scalp location, in order to compare with the patterns predicted by the theoretical model. The difference in power was established by a MANOVA test for differences between means of the two groups by frequency (7) and per scalp position (4). The resultant F-ratios were further tested for significance to establish which differences were statistically significant or otherwise, in terms of the theory of probability. This was followed by a main effects analysis which provided further information on the direction and magnitude of changes between low and high flow, regardless of whether they were statistically significantly different or not.

5.8.6.2 Analysis of EEG synchrony

In terms of synchrony analyses, the frequency spectrum Delta to Gamma was analysed in terms of patterns of synchronous EEG activity among identified scalp locations (F3 x C3, F3 x P3, F3 x 01, C3 x P3, C3 x 01, P3 x 01) for both flow conditions in order to compare with the patterns predicted by the theoretical model. According to Alba, et al. (2010), synchronisation is typically measured between pairs of narrow-band EEG electrodes. Various measures are proposed in the literature, including coherence (Pearson correlation) and measures based on certain statistics of the phase difference such as the circular variance, or the average magnitude. Most of these measures yield values between 0 (no synchrony) and 1 (perfect synchrony) or -1 (perfect synchrony, but 180° out of phase).

In this study, the EEG analysis was performed on the MeanF (power) data using the Pearson Product Moment Correlation Test (r). All 7 EEG frequencies, across 4 brain-locations, were correlated for each condition. A test of significance was used to interpret the p-values that indicate the strength of the correlation, or association, in terms of its probability of co-occurrence. The results of this test are computer generated using the *NCSS* programme. Significance was accepted at the 0.05% level, or below, meaning that the probability of the correlation being null is only 5 out of 100 and, therefore the null hypothesis is rejected and the alternative accepted.

Alba, et al. (2010) maintains that when using EEG in cognitive experiments, interest is usually directed towards how inter-electrode couplings change over time and frequency. Such analysis may involve the computation of a relatively large data set, which specifies the degree of synchronisation for each electrode pair, at each time sample and each frequency band. Therefore, one of the challenges in EEG synchrony analysis lies in the design of an adequate visualisation system, which allows the neuroscientist to explore the synchronisation dynamics across a wide time and frequency range.

In this study, correlations were used to demonstrate synchronous EEG activity between two or more brain locations, indicating that such locations were involved in the same activity, which is associated with a particular neurological function. According to the theoretical model, flow is characterised by a hypothesised set of EEG patterns associated with flow behaviour. In state space dynamics, at a critical point of state transition, such as going into flow, the neural network undergoes a significant reconfiguration which, among other features, is expressed as change of the correlation function between locations. The correlation function characterises how the value at one point in state space is correlated with the value at another point, reflecting the network's structure (Werner, 2008). Therefore, the 'test' for difference between the higher-flow and lower-flow conditions is that the EEG patterns (correlates) of those on the lower end of the flow measure differ from the EEG patterns of those on the higher end of the flow measure. The EEG patterns of those on the high end were compared with the patterns predicted by the theoretical model.

In order to illustrate synchronised vs de-synchronised EEG behaviour in various brain locations visually, the EEG data are presented graphically and topographically indicating neural bindings within a specified frequency band. In the diagram below (Figure 29) solid lines indicate synchronous (correlated) bindings and dotted lines indicate de-synchronisation. The percentages indicate the strength of the binding as per the correlation coefficient (r) and the level of significance (p) indicates synchronisation (significant) or de-synchronisation (non-significant).

Figure 29 illustrates an example of a topographic illustration of synchronous and de-synchronised connections between locations, as they are presented in this study.

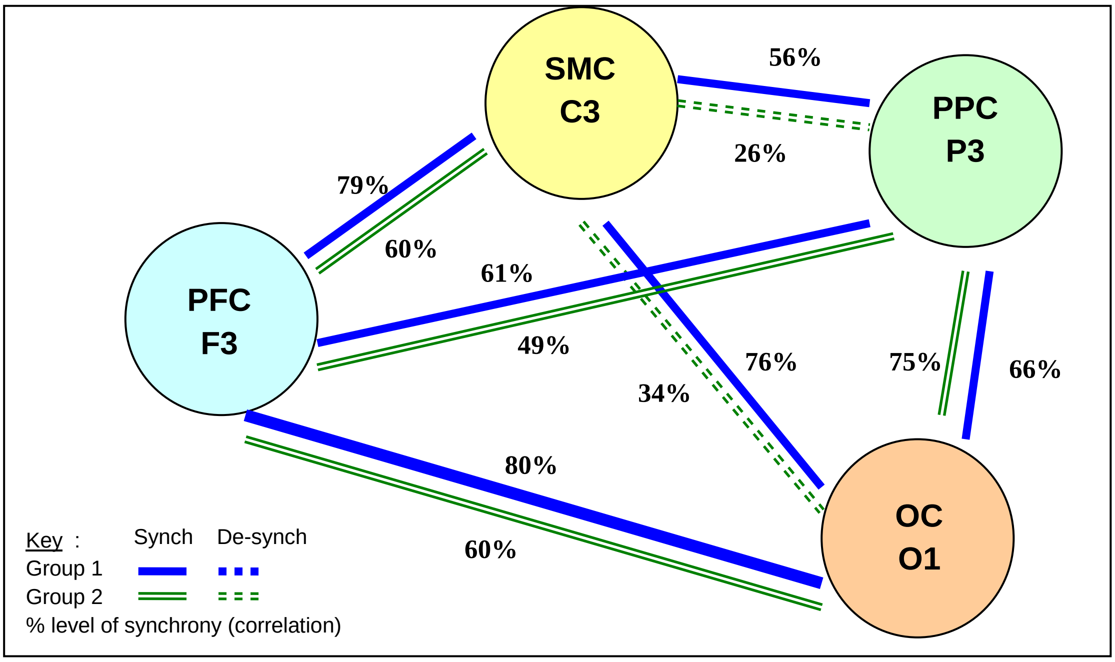


Figure 29. Example of topographic illustration of neurological activity

5.9 VALIDITY AND RELIABILITY OF THE STUDY

In this section the validity and reliability of the study is discussed. Validity is discussed in terms of internal validity and external validity. Internal validity reflects the extent to which the confidence in the correctness of the research findings is enhanced by elimination of systematic error or extraneous variables. External validity has to do with the generalisability of the research findings. The rule of thumb is to balance the measures deployed to enhance internal validity and external validity since enhancing the one normally causes a reduction in the other. Reliability of the study is about repeatability or replicability of the study, the measures taken to ensure consistency in measurement and reliability and validity of instruments and statistical methods.

5.9.1 Internal validity

The internal validity of research designs requires that other factors be ruled out as rival explanations of the observed association between the variables under investigation. In this study there are three variables under investigation in a quasi-experimental single sample repeated measures design. Flow is investigated under conditions of peak performance while the accompanying EEG correlates are studied in order to identify a valid EEG marker for flow. Although the relationships between the variables are studied, causality is not under investigation. Nonetheless, possible biases that could influence the internal validity of the study are discussed below.

5.9.1.1 Confounding variables

Confounding variables in this research design may arise from the effect of individual differences in learning and in the subject's own expectations of their performance. These variables have the potential to threaten the internal validity of the data by distorting the effect of flow.

a. Individual differences in learning as confounding variable

Subjects were selected for the sample on the basis of, inter alia, being experienced video gamers. In this study, each participant was given 10 repetitions to allow learning to take place, to produce a best performance, and allow flow to manifest. However, since all subjects had different pre-existing gaming skill levels they were likely to learn at varying tempos and achieve varying levels of performance. Therefore, a potential problem was that the raw scores attained between subjects fell within varying ranges, depending on individual differences in their response rates, so that the lowest score attained by one subject might be the highest attained by another. Each subject had their own personal response rate leading to peak performance. To reduce the biasing effect of these individual differences and to allow a statistically appropriate comparison between subjects, it was necessary to transform the raw scores by adjusting the mean of each individual's repertoire to 0 and re-distributing their scores around this mean in terms of a normal distribution.

The interpretation of the adjusted scores was then the position of a specific individual's response repertoire relative to the scores of all others in the sample. This process of standardisation, therefore, reduced the bias introduced by individual levels of response and the potential for skewed results within each subject's set of scores as they moved to higher levels in pursuit of achieving peak performance on successive races. By expressing each individual's set of scores as standard units a more statistically appropriate relationship between the group scores was established.

b. Expectations of their own performance may bias the subjective ratings of participants

At relatively high levels of performance, highly skilled performers may have greater expectations of their own performance and consequently rate themselves lower than lesser skilled performers. This possible confounding variable is dealt with in the statistical treatment of the data through the use of standard scores, as discussed above, to establish a "personal" repertoire for each individual participant. The within-subject standardised scores provide units of data that are better distributed over each individual's response repertoire, providing more appropriate data input for further analysis.

5.9.1.2 Other potential contaminating variables

The potential sources of variation that are not applicable to this research are history, maturation and mortality (attrition). All subjects were required to attend a one-off test session, therefore they could not be influenced by history and had no time to mature over time or disappear completely from the sample. Nor were sources of variation related to studies with an intervention and a control group, such as diffusion of treatment or contamination of the control group, compensatory rivalry, resentful-demoralisation of the control group, and non-adherence to protocol, applicable to this study.

Discussed below are other sources of potential bias applicable to this study

a. Sample selection

Bias due to factors such as age, gender and brain laterality that could moderate responses and prove to be contaminating variables is controlled. Subjects were selected from a volunteer group and only right handed males over the age of 16 years who are familiar with computer gaming were chosen. These factors are thus held constant.

b. Test instruments

A number of instruments were used.

(1) BrainMaster instrument

The validity of the data collected from the *BrainMaster* instrumentation is without dispute as it is specifically designed for the purpose of collecting the electrical output of the brain as EEG's. Impedance for each electrode placement is kept under 5000 ohms (Ω) in order to eliminate interference and optimise sensor sensitivity. This level is the accepted standard for scientific research (Demos, 2005). Other possible contaminating factors that could affect the accuracy and "pureness" of the EEG data, such as cable swing, blinking, and muscle movement in the facial area were limited by educating the subjects regarding the nature, sensitivity, and workings of EEG and requested to remain as still as possible during recordings. They are requested not to blink their eyes excessively, grind their teeth, or move their heads.

(2) The GFI (Game Flow Inventory)

The GFI is a validated questionnaire. The WOrk-reLated Flow inventory (WOLF) that measures employees' flow in the workplace, developed by Bakker (2008), was adapted to suit the gaming situation and is called the Game Flow Inventory (GFI). The WOLF, and thus the GFI, measures absorption, work enjoyment and intrinsic work motivation as an index of the flow state (Bakker, 2005). Absorption refers to a state of total concentration (level of immersion in the game); enjoyment refers to positive judgments (happiness) regarding playing the game; and intrinsic motivation refers to performing a certain work-related activity (the PC video game) with the aim of experiencing the inherent pleasure and satisfaction in the activity (Bakker, 2008). Reliability and validity of this instrument were discussed in section 5.5.1.1 above.

(3) The AFQ (Abbreviated Flow Questionnaire)

The AFQ is not a validated questionnaire, nor have the items been formally tested on a larger sample or validated statistically against relevant criteria, but rather were constructed specifically to serve the needs of this research after a thorough research of the literature. The five test items were selected to provide immediate feedback after each race to indicate if, and how strongly, attributes of flow, as reflected in flow theory (Csikszentmihalyi, 1990) were experienced according to a five-point rating scale. Because of the once-off nature and duration of the test sessions it was impractical to pre-validate the test, so validation was carried out afterwards.

The AFQ provides a useful and quick tool to test the subjects' subjective experience of flow after each race in a repeated measures scenario. It is important to capture each subject's perception immediately after each race using as short as possible questionnaire in order to keep the subjects focussed on the main task of achieving a best performance. It is a post hoc measure but less so than the GFI which is a longer test (more items) and refers to the entire session (the experience across all ten races).

5.9.2 External validity

External validity is concerned with the degree to which research findings can be applied to the real world, that is the issue of generalisability. The purpose of developing an EEG marker for flow stems from its intangible nature and the ability of modern technology to overcome that barrier. EEG technology has recently made immense strides, from being a medical instrument to being an instrument of multiple uses in everyday life, more so in the computer gaming environment (see discussion in Chapter 7). In recent years, also became a much talked about and desired mental state, which holds benefits to mental health and peak performance. Determining an EEG for flow will thus make a useful contribution to a wide range of interest groups, from which the computer gaming population will probably gain the most. This study aims to provide an EEG marker for flow that is generalisable to the computer gaming population, with application across a wider population.

Imposed controls to enhance internal validity often restrict the generalisability of the research results, therefore the sample was restricted to a group of right-handed, male computer gamers over the age of 16. As this is pioneering research and the intention is to determine an EEG marker for flow under conditions of peak performance, it is important to trade higher internal validity for a lesser degree of external validity. Once the EEG marker was established, future research can expand the generalisability and external validity of this initial research to a larger variety of tasks and populations.

For the purpose of this study, the following design features were applied to limit potential biases:

(1) An adequate sample size reduces potential sources of random error. In this study both qualitative and quantitative methods were used to determine an EEG marker for flow. In quantitative studies a sample of at least 30 subjects is required to reduce random error in a single variable from a probability, or random, sample. Qualitative studies require smaller samples (around 10) and are based on the principle of level of saturation. It was decided to settle on a sample of 20 subjects because some inferential statistical tests are required in order to arrive at the qualities to be analysed. The composition of the sample will further reduce the chance of error.

(2) Individual differences are controlled by a repeated measures design. In this research the 20 gamers are required to complete 10 races, each one under instruction to do produce a best performance. The nature of flow is that it occurs when a peak performance is reached. Once flow occurs it will only re-occur when a new peak performance is achieved. The way in which the gamers manage their own behaviour will include individual differences which cannot all be controlled. Likewise, their exposure to other sources of random error is unknown. The single sample repeated measures design reduces the influence of individual differences compared to designs with more heterogeneous samples where the difference between inter-participant correspondence versus intra-participant comparisons are greater (i.e. more within group differences than between group differences).

5.9.3 Reliability

Reliability is measured by the repeatability of the study and the extent to which it will obtain similar results to the first. To ensure that the EEG marker is a reliable indicator of flow for people performing a visuomotor task, carefully controlled conditions need be adhered to in order to ensure that not only are the results valid and measure what they are intended to measure, but also that the conditions under which they occur are understood and followed. The consistency, accuracy and predictability of the findings must be assessed by the use of instruments and statistical methods that reduce their chance of being influenced by random errors. To this end the following research protocols are applied:

(1) Careful sample selection in accordance with the requirements for a valid sample.

(2) Strict instructions followed so that the test conditions may be repeated in future studies.

(3) Standardised test conditions. The experimental task is administered in the same consistent way for all subjects, in the same physical conditions, with the same instructions, using the same EEG equipment (with known reliability) and performing the same task.

(4) Potential bias caused by electrical interference with the *BrainMaster* equipment is controlled by removing all possible sources of interference from the test environment.

(5) EEG sampling consistency is ensured by the *BrainMaster* equipment. Fast Fourier Transform (FFT) separates the raw data into individual frequency bands. Importantly, impedance for each electrode placement is kept under 5000 ohms (Ω) in order to eliminate interference and optimise sensor sensitivity.

(6) Standardised instructions, instruments and procedures are followed and rapport established with the subject prior to the commencement of the tasks.

(7) Experimenter bias is reduced by having a suitably skilled and experienced psychologist (the author of this thesis) administer all the test sessions.

(8) All data records are checked for accuracy and completion before and after being transferred to *Excel* spreadsheets.

(9) Analyses are conducted using recognised data processing packages, in this case *Excel* and *NCSS*.

(10) The choice of statistical analyses is appropriate for the type of data being analysed and conducted after the individual behavioural data is converted to standard scores.

(11) Standardising the data within each subject's own personal repertoire of results is required to compare data collected from the personal best and first race. Standardising the performance time and the AFQ data uses the formula Z = (x-X)/sd for each individual's unique set of results.

5.10 CONCLUSION

This study has introduced a new dimension to the measurement of flow behaviour, using EEG. It has not, however, included advanced statistical techniques using pattern recognition or artificial neural networks (ANNs) that are currently gaining more attention in the scientific literature. Pattern recognition software and accompanying EEG equipment are expensive and not easily obtainable, but rather the equipment and software used in this study are standard neurofeedback training equipment that is commonly used in everyday practice. The data gathered is compatible with other standard neurofeedback training equipment and applications.

The data from this study can be used as input to the development of EEG measuring and monitoring devices for application during training, coaching, leisure or normal work performance feedback situations. The EEG flow marker can be used in neurofeedback training to enhance the propensity to assume flow and to monitor the time spent in flow. Inducing flow under normal working conditions should lead to improved work performance, work enjoyment and work motivation.

In the next chapter the research results and findings are presented and discussed.

CHAPTER 6
RESEARCH RESULTS AND FINDINGS

6.1 INTRODUCTION

The purpose of this chapter is to present the results and findings of the empirical study. The overarching research design is a single group repeated measures design involving the collection of data from the 20 subjects who were each required to repeat the dynamic task 10 times. On completion, performance times and associated flow scores were standardised where after the sample was segmented into two sub-samples reflecting two levels of the flow variable per subject, namely a high flow - peak performance level and a low flow - low performance level. The first race completed by each participant was used as a “baseline” (and indicative of a low flow state) for comparison with their own personal fastest race/highest flow score combination, indicative of the high flow state. This was required to extract the EEG data associated with each level for further statistical analysis and interpretation.

The relationship between flow and EEG was expressed in terms of EEG differences between two levels of flow, high and low flow. EEG power scores were compared (mean differences) by site and frequency. The EEG patterns (correlates) between sites were compared by frequency. It was expected that the EEG patterns on the lower end of the flow measure (low flow - low performance condition) should differ from the EEG patterns on the higher end (high flow - peak performance) of the flow measure. The EEG patterns on the high end were qualitatively compared with the patterns on the low end as well as with that predicted by the theoretical model.

The findings of the study are discussed below. The behavioural data are presented first, followed by the EEG data. Lastly the set hypotheses were tested and the findings were compared with the theoretical model.

6.2 SAMPLE STATISTICAL INFORMATION

The sample for the study consisted of 20 male South African volunteers from diverse cultural backgrounds, between the ages of 16 and 50. All participants were right-handed to ensure consistency of hemispheric differences. Of the 20 participants, 10 rated their computer gaming skills as "good", while 8 rated themselves as "moderate" and only 2 rated themselves as "basic". Table 2 below summarises the sample details.

Table 2

Biographical data

Biographical Data (n = 20)	**Levels**	**Frequency Totals**
Age	16	9
	20	6
	25	1
	30	1
	35	1
	40	1
	45	1
	50	0
Gender	Male	20
	Female	0
Population	White	9
	Coloured	0
	Black	7
	Indian	4
	Other	0
Gaming Skill Level	Poor	0
	Basic	2
	Moderate	8
	Good	10
	Excellent	0

The sample was skewed in terms of age, with 75% of the subjects being between the ages of 16 and 24 years. This was largely because computer games are technology driven and evolved in the past 20 – 30 years. However, the age skew was not considered relevant as the human brain matures by the age of 16 years (Demos, 2005). Nor was there correlation between performance and age (r = 0.023; p= 0.53956).

Prior to participation subjects rated their computer gaming skill on a five-point scale from 1 (poor) to 5 (excellent). The following table summarises the subjects' actual best performance times against their self-rating scores.

Table 3

Perceived gaming skill level

Subject no	**Gaming skill level (5-pt scale)**	**Fastest race (Secs)**	**Age (years)**
16	4	89	40
2	4	90	16
13	4	91	20
15	4	91	45
5	4	91	20
3	4	92	16
18	4	94	16
1	3	96	16
9	3	96	20
17	4	98	20
19	3	102	20
8	3	108	20
10	3	108	16
12	4	115	16
4	3	118	30
6	4	120	16
11	2	123	16
7	3	134	16
14	2	152	35
20	3	166	25
Range	2-4	89-166	16-45
Mean	3.3	108.69	22
SD	0.68	21.66	7.82

Each subject’s fastest race was identified and the whole sample averaged 108.69 seconds at peak performance. A correlation based on peak performance (fastest) time versus reported gaming skill level, for the total sample, had a correlation coefficient r = -0.62, indicating a moderately high inverse relationship, indicating that as performance time (in seconds) decreased the subjects’ perceived level of their gaming skills increased. This was significant at the 0.01 level. The data are displayed below.

Table 4

Performance and perceived gaming skill level

Correlation between perceived gaming skill level and fastest, baseline and average performance

	Fastest	Baseline (1st)	Average	Gaming Skill Level
Fastest Race		0.917373	0.987415	-0.619892
		0.000000	0.000000	0.003552
Baseline (1st Race)			0.942642	-0.551619
			0.000000	0.011690
Average				-0.662558
				0.001456

Note. N = 20. Cronbach’s Alpha = 0.842897; Standardized Cronbach’s Alpha = 0.448386

From the above data, the subjects’ self-rating of their own gaming skill level (average score = 3.4 on a 5-point scale) was also inversely and significantly correlated with their average performance over all 10 races (r = -0.66; p = 0.002). This data suggests that subjects mostly performed according to their own expectations but that their perceived level of skill was more closely related to their average, than to their peak performance. Nor did they regard themselves as performing in line with their baseline performance to the same extent as they did with their average or fastest performance (r = -0.55; p = 0.012)

6.3 PERFORMANCE AND FLOW

Performance was measured in seconds and the experience of flow by means of rating scales on two separate questionnaires.

6.3.1 Performance

Performance was measured as duration of a race. The resulting times taken over all 200 races and averaged for each subject are summarised in Figure 30 (below). The results are arranged in rank order from fastest to slowest.

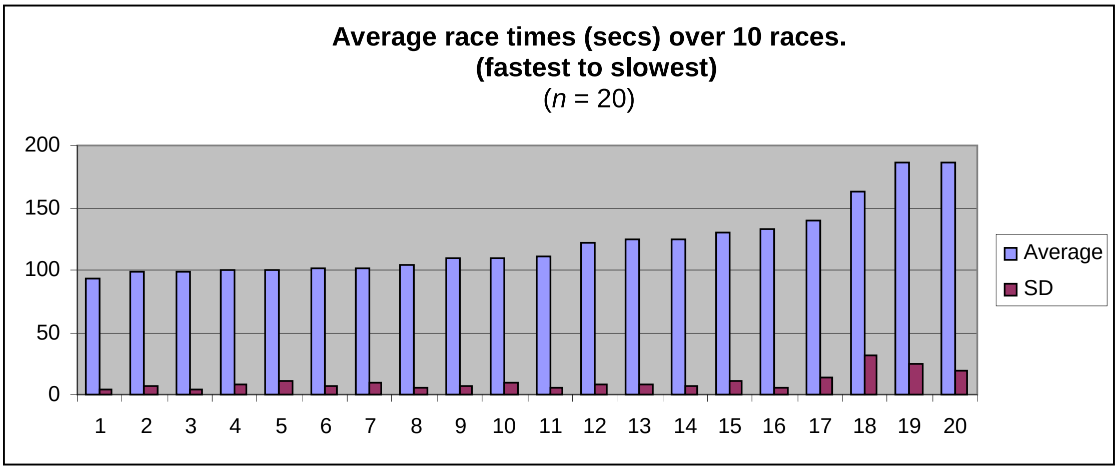


Figure 30. Average performance times and variance, per subject

The shortest average time taken (the best overall performer’s score) was 93.1 seconds, whilst the subject who performed worst overall averaged 186.7 seconds over all 10 races.

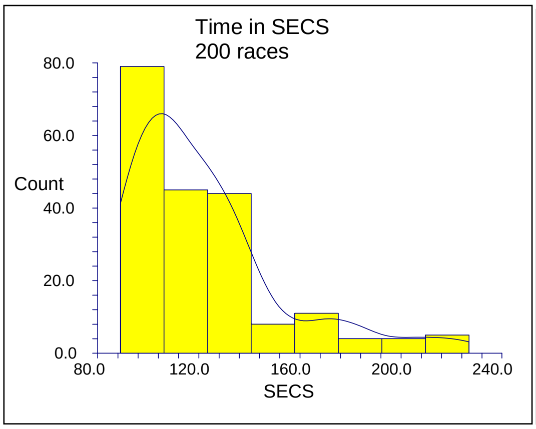
When all 200 races were analysed the range was extended, since averaging obscures the extreme scores within each subject’s repertoire of results. The slowest race overall took 227 seconds and the fastest 89 seconds. The overall average time was 121.95 seconds. A summary of the data is presented below.

Table 5

Descriptive statistics of overall, baseline and peak performance

Total Sample (*n* = 20)	**Mean**	**Standard Deviation**	**Standard Error**	**Minimum**	**Maximum**	**Range**
Time in seconds over 200 races	121.95	29.79	2.11	89	227	138
Baseline Time	133.75	38.13	8.53	99	227	128
Fastest time	108.7	21.66	4.84	89	166	77

The baseline (race 1) performance times ranged from 99 to 227 seconds and averaged 133.75 seconds, which represents a higher (slower) average and a greater variation than was found over all 200 races or at peak performance. When the shortest, or peak, times taken (fastest races) were analysed the average was 108.7 seconds with the slowest subject taking 166 seconds and the fastest subject 89 seconds. The above data clearly indicate a substantial difference between the baseline results and the peak results.



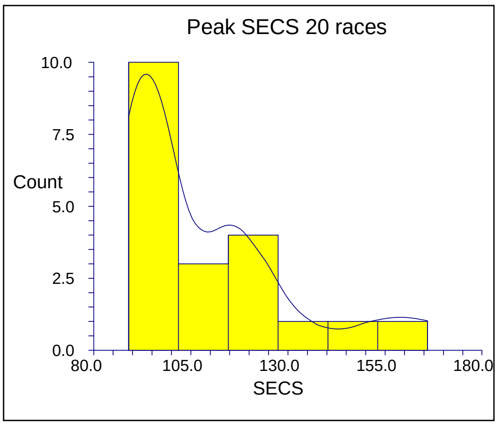


Figure 31. Racing times over 200 races

Figure 32. Peak times (20 races)

The two distributions compared in Figures 31 and 32 show that there is less variability but a chance of slightly more sampling error in the distribution for peak performance than in the distribution for all 200 races. Both distributions show evidence of two main groups, a slow and a faster**,** either side of the average scores.

6.3.1.1 Performance time over trials

Subjects were given ten trials each to produce a best performance. The tabulated data shows that only two subjects (6 and 12) achieved their best performance, or fastest time, within the first five trials, while 75% (15 subjects) achieved their best performance in the last three trials.

Two subjects who reached their peak early did so in more than the average time (120 and 115 seconds compared with the group average of 108.69 seconds). The other subject who reached peak early (89 seconds in race four) was the best performer and also the most consistent, showing a standard deviation of only 3.34 seconds. He admitted being familiar with this particular game.

Table 6

Performance time (seconds) for all races

Subject No.	**Race times in seconds (slowest times are shaded and fastest times are in bold).**											
	R 1	**R 2**	**R 3**	**R 4**	**R 5**	**R 6**	**R 7**	**R 8**	**R 9**	**R 10**	**Mean**	**Std Dev**
1	116	108	111	106	102	103	101	97	103	**96**	104.3	6.15
2	127	103	103	103	94	106	91	**90**	95	91	100.3	11.13
3	112	106	99	93	99	96	94	94	95	**92**	98	5.95
4	142	138	140	119	142	120	122	135	**118**	123	135.9	17.91
5	115	105	107	96	94	111	99	91.6	**91.1**	91.9	100.5	8.59
6	138	140	**120**	136	133	130	130	133	131	136	132.7	5.60
7	227	184	196	142	144	170	155	**134**	140	135	162.7	31.08
8	128	125	128	132	129	123	109	112	125	**108**	121.9	8.85
9	109	103	123	119	118	100	**96**	113	101	118	110	9.51
10	128	124	126	135	124	**108**	135	125	129	119	125.1	8.03
11	141	138	170	139	135	154	131	128	135	**123**	139.3	13.60
12	137	117	125	124	**115**	125	131	128	126	125	125.3	6.27
13	101	101	98	106	96	118	98	**91**	105	103	101.7	7.24
14	208	168	220	219	168	175	205	168	177	**152**	188	26.96
15	105	105	100	95	98	116	91	**91**	96	120	101.7	9.91
16	99	93	90	**89**	91	94	99	92	91	93	93.1	3.45
17	110	119	118	105	112	100	112	116	**98**	106	109.6	7.25
18	103	101	101	96	102	97	96	**94**	102	94	98.6	3.53
19	115	112	118	113	104	109	116	114	113	**102**	111.6	5.15
20	214	224	191	188	172	174	171	**166**	173	194	186.7	19.58

6.3.1.2 Standardising the performance scores

The performance scores show a clear tendency to cluster towards the lower end of the time continuum. This is inevitable given that the purpose of the task was to achieve peak performance. Also, because of the different skill levels amongst subjects, some peak performances were slower than the poorest performances of others. It was, therefore, necessary to standardise the data so that, for every individual subject, each score is represented in terms of standard deviations from their individual means. Additionally, as a consequence of the standardisation the data distribution approached normality. Each subject's set of 10 scores was standardised using the formula:

$$z = \frac{x - \mu}{\sigma}$$

where:

x is a raw score to be standardized (individual per race score)

μ is the mean of the population (overall individual total score)

σ is the standard deviation of the population (per individual data set)

The summary below is of descriptive statistics for all 200 races:

Table 7

Descriptive statistics for all 10 races (in seconds) and standardised race scores

Total Sample (n = 200)	**Mean**	**Standard Deviation**	**Standard Error**	**Minimum**	**Maximum**	**Range**
Race times in seconds	121.95	29.79	2.11	89	227	138
Race times standardised	-0.00045	0.95	6.73	-2.27	2.4	4.67

Illustrations of the performance data distributions of all 200 races before and after standardisation are shown in Figures 33 and 34 (below).

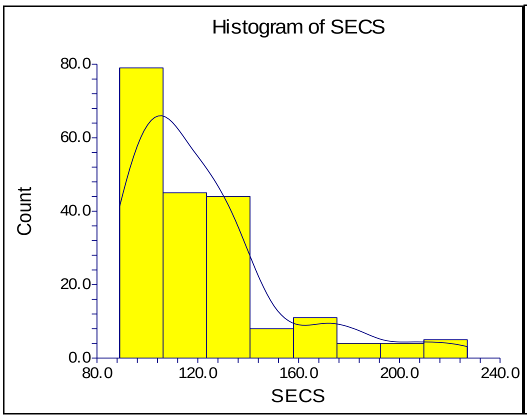


Figure 33. Time in seconds

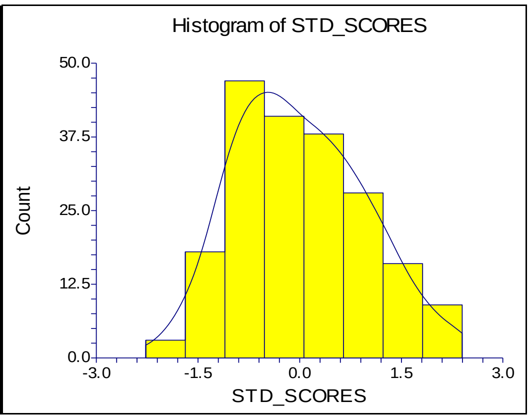


Figure 34. Standard race times

Following standardisation, each subject's performance data is now compared with that from other subjects and also with each subject's accompanying standardised flow and EEG scores.

6.3.2 The overall flow experience : the Game Flow Inventory (GFI)

The overall flow experience was measured using the Game Flow Inventory (GFI), a validated measure of flow. The questionnaire was used to provide evidence of what level of flow was experienced overall during the total session. The Game Flow Inventory (GFI) consists of 13 questions, rated on 7-point scales and was administered only once, at the end of the session, after the conclusion of all 10 races.

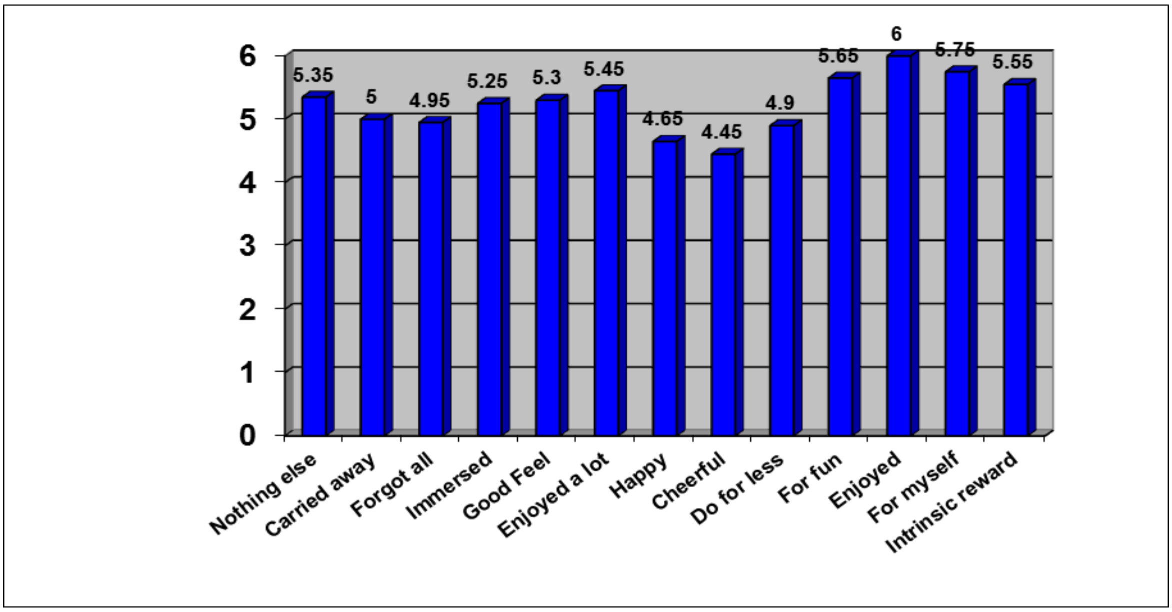


Figure 35. Total sample average scores for each GFI item

The GFI poses, in question for rating form, the following statements (to be rated on a 7-point scale):

(1) When I was racing, I thought about nothing else
(2) I got carried away by the race
(3) When I was racing, I forgot everything else around me
(4) I was totally immersed in the race
(5) The race gave me a good feeling
(6) I was racing with a lot of enjoyment
(7) I felt happy during the race
(8) I felt cheerful during the race
(9) I would still do this activity, even if I received less reward
(10) I would like to continue racing, just for the fun of it
(11) I raced because I enjoyed it
(12) When I was racing, I was doing it for myself
(13) I got my motivation from the race / activity itself, and not from the reward for it.

The full questionnaire is to be found in Appendix D.

The single GFI score, per subject, is the result of the summation and rendering as percentages of the three main factors that constitute the GFI, i.e. absorption (items 1-4), enjoyment (items 5-8), and intrinsic motivation (items 9-13). On average, the sample scored 75.03, with a minimum of 48, a maximum of 98 and a range of 50. The standard deviation was 13.5, showing a fair amount of variability within the GFI amongst the subjects.

Table 8

GFI total sample distribution statistics (N = 20)

Mean	**Standard Deviation**	**Standard Error**	**Minimum**	**Maximum**	**Range**
75.03	13.5	3.02	48	98	50

It is logical that the GFI will vary more than the AFQ in its measurement of flow as there is more opportunity for additional sources of variance to come between the experiences of flow and reporting on it. It is not possible to capture the “moment in time” and memory factors, such as recency, interference, and individual differences in overall expectations, self-esteem and self-evaluation are also likely to play a greater part in an “overview” situation than in an immediate response, after a fast-moving task. However, overall, the subjects indicated whether they had experienced flow during the 10 sessions, albeit the data cannot be linked to a specific race, other behavioural data, or the EEG’s in more precise time.

The question arises as to what extent the AFQ and GFI results overlap, or differ? This is dealt with in this chapter after the AFQ results have been discussed.

The results show the GFI as an instrument presented with a Standardised Cronbach’s Alpha of 0.91, revealing very high internal consistency. It is therefore, considered a reliable instrument for measuring perceived flow during the PC video game. The inter-correlations for the items are tabulated below.

Table 9

Inter-correlation of all 13 GFI Items

	GFI											
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Q1	-											
Q2	0.64 ***											
Q3	0.41 -	0.7 ***										
Q4	0.67 ***	0.61 ***	0.65 ***									
Q5	0.29 -	0.56 **	0.62 ***	0.56 **								
Q6	0.64 ***	0.68 ***	0.65 ***	0.39 -	0.47 *							
Q7	0.37 -	0.31 -	0.55 **	0.39 -	0.18 -	0.56 **						
Q8	0.42 -	0.55 **	0.53 **	0.39 -	0.6 **	0.64 ***	0.66 ***					
Q9	0.31 -	0.32 -	0.6 **	0.34 -	0.34 -	0.34 -	0.72 ***	0.61 ***				
Q10	0.12 -	0.39 -	0.57 **	0.18 -	0.25 -	0.44 *	0.66 ***	0.41 -	0.56 **			
Q11	0.41 -	0.35 -	0.64 ***	0.39 -	0.45 *	0.59 **	0.41 -	0.24 -	0.42 -	0.62 ***		
Q12	0.49 **	0.67 ***	0.49 **	0.23 -	0.48 **	0.75 ***	0.27 -	0.47 **	0.19 -	0.57 **	0.63 ***	
Q13	0.44 *	0.45 *	0.31 -	0.21 -	0.31 -	0.3 -	0.1 -	0.23 -	0.31 -	0.09 -	0.21 -	0.37 -

Note. Cronbachs Alpha = 0.910203; Standardized Cronbachs Alpha = .913435

*** $p \leq .001$; ** $p \leq .01$; * $p \leq .05$

When the 13 questions were reduced to the three component scores of Absorption, Enjoyment and Motivation they were also highly and significantly inter-correlated (Table 10 below). The data indicate that the GFI is a uni-factorial construct. The three underpinning constructs are highly inter-correlated, thus they are not separate constructs.

The data also confirms that the GFI is a reliable measure of flow and that the dimensions of Absorption, Enjoyment, and Intrinsic Motivation underpin the flow construct.

Table 10

Correlation matrix of the GFI main factors (N = 20)

GFI	Performance Time (std)	Absorption	Enjoyment	Motivation
GFI Total r =	0.26			
p =	0.27			
Absorption r =		1		
p =		0		
Enjoyment r =		0.726905	1	
p =		0.000283	0	
Motivation r =		0.642962	0.727262	1
p =		0.002229	0.00028	0

The results show that all component GFI factors have moderate to good inter-relationships. Enjoyment and Motivation and Enjoyment and Absorption are more closely correlated, both at r = 0.73 and both are highly significant. Also highly significant but slightly lower as a correlation (r = 0.64; p = 0.002) is that between Absorption and Motivation. However, since Motivation, in itself, is well associated with Enjoyment, the three are clearly well interrelated.

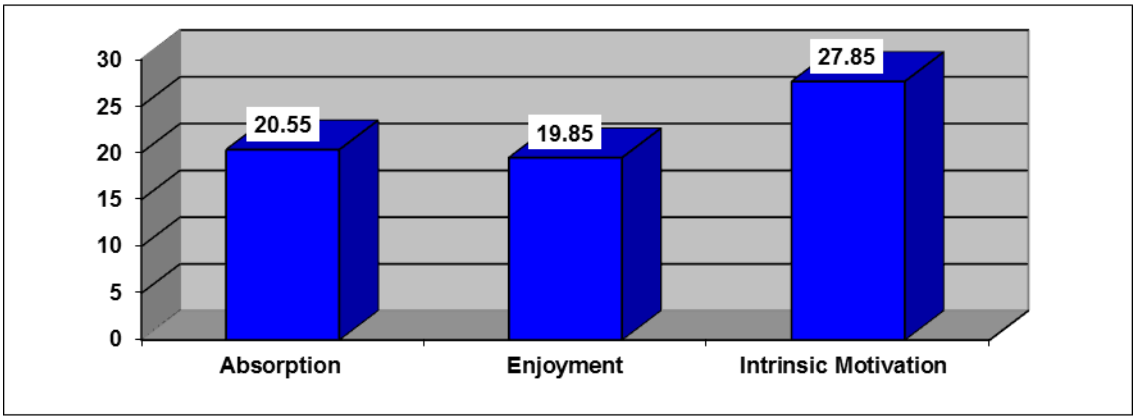


Figure 36. GFI mean scores for main factors by total sample (N = 20)

Intrinsic Motivation was the highest rated flow characteristic, perhaps influenced by the objective of obtaining the fastest possible race time.

Table 11

GFI Descriptive statistics by total sample (N = 20)

	Mean	**Standard Deviation**	**Standard Error**	**Minimum**	**Maximum**	**Range**
Absorption	20.55	4.7	1.05	11	28	17
Enjoyment	19.85	4	0.9	13	27	14
Intrinsic Motivation	27.85	4.9	1.1	19	35	16

A further breakdown of the GFI results by baseline and fastest race was not possible since the GFI rating applied to all races in retrospect.

With regards to performance, an inspection of individual scores showed that the subject's rank position at peak performance versus his competitors and the associated GFI rating are subject to individual interpretation. It was expected that the better their performance the higher their respective GFI scores would be, however, when the performance scores were arranged on a continuum from best to poorest the GFI result did not follow the same pattern along the continuum. The relationship was erratic across all the individual subjects, as shown in the following graph.

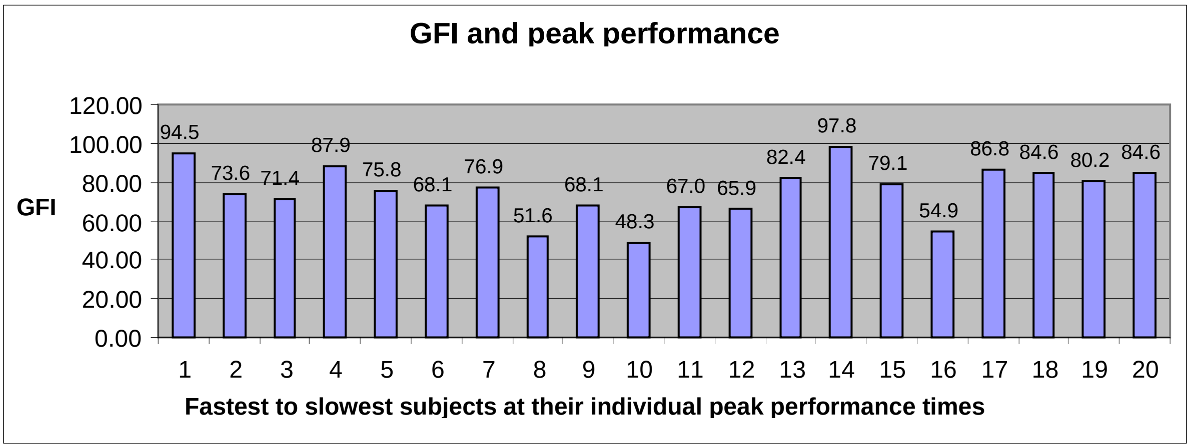


Figure 37. GFI and peak performance (fastest to slowest) by individual subjects

The correlation between overall performance and the GFI is weak (r = 0.26) and not significant (p = 0.27). The fastest performance time also has a low correlation, with the total GFI (r = 0.28; p = 0.23).

Correlations were conducted in terms of fastest time and GFI score on the top 10 performers compared to the bottom 10 performers. The results show that the top 10 performers have a significant inverse relationship (r = -0.83, p = 0.003) between the GFI and their fastest time.

Table 12

Correlations of GFI and higher performers at their peak performance (N = 10)

Correlations : GFI vs High Performers at Peak Performance

	GFI	**Absorption**	**Enjoyment**	**Intrinsic Motivation**
Performance	-0.83	0.77	0.82	0.66
p-	0.003*	0.009**	0.004**	0.040*
GFI	-	0.91	0.88	0.899
p-	-	0.000***	0.001**	0.004**
Absorption		-	0.73	0.68
p-		-	0.016*	0.029*
Enjoyment			-	0.704
p-			-	0.023*

Note. *** p ≤ .001; ** p ≤ .01; * p ≤ .05

The lower performing group's correlation, in comparison, was low and not significant (r = 0.30, p = 0.42). Flow therefore, as measured by the GFI (overall experience), was associated with peak performance only for the top performers. This indicates that performance was a confounding variable within the flow-performance relationship as measured after all ten races were completed. This was to be expected because the better performers (top 10) were better skilled drivers and achieved more fast races (made less mistakes, experienced less frustration) than the lesser skilled drivers (bottom 10). The top 10 thus experienced more enjoyment, were more absorbed in the game and experienced higher internal motivation (doing it for the pleasure) than the bottom 10 subjects.

However, all subjects have high within GFI associations amongst the three main factors. Enjoyment was the main factor common to both groups, although the low performers enjoyed it less, were less absorbed and even less motivated.

Table 13

GFI and low performers at their peak performance (N = 10)

Correlations : GFI vs Low Performers at Peak Performance				
	GFI	**Absorption**	**Enjoyment**	**Intrinsic Motivation**
Performance	0.3	0.34	0.4	0.09
p-	0.42	0.34	0.25	0.813
GFI		0.84	0.96	0.92
p-		0.002**	0.00***	0.00***
Absorption		-	0.74	0.6
p-			0.014*	0.065*
Enjoyment				0.84
p-				0.003*

Note. *** p ≤ .001; ** p ≤ .01; * p ≤ .05

It was felt that the GFI is not a suitable instrument to measure flow on a short repetitive activity since it takes too long to complete, becomes a distraction in-between activities, and gets boring to repeat. The AFQ4 was recruited for this purpose.

6.3.3 Immediate post-performance flow experience: the Abbreviated Flow Questionnaire (AFQ4)

The AFQ4 measures flow indicators on five-point scales, where 1 represents a low flow state and 5 is associated with high flow. The questionnaire was administered after each of the 10 races per subject, resulting in 200 scores for each of the five flow attributes tested. The summed scores made up the AFQ score. Initially there were five items, but one was discarded during the analysis, hence the reference to AFQ4.

In the final analysis the AFQ4 consists of four and not five items to measure the flow experience, covering the flow characteristics of Engagement, Skills-Challenge Match, sense of Control, and Accomplishment. It is not a standardised questionnaire and the questions were dealt with on an equal weight basis, that is, each variable scored on the five-point scale was treated as contributing equally to the total flow score. A single AFQ result per subject was originally intended to be based on the summation of the five scores for each subject per race. The item measuring a sense of “Time Passing Quickly” was included in the original test and produced a high score, similar to the other four. However, the researcher, who also administered the test, was concerned that some of the subjects’ interpretations of the experience of time passing quickly were influenced by potentially contaminating factors and subjects may have found that time went too quickly for reasons other than the possibility of their having experienced flow. A timer was visible on the computer screen as the subjects were racing and there was a strong deliberate focus on time throughout the races. The races, too, were over after a very short period, in the order of one to two minutes, therefore, this score was left out of further analyses that were based on the total summed AFQ score of the remaining four indicators of flow.

The intention of this questionnaire was to provide brief (without much distraction) “top-of-the-mind” post-performance feedback, to indicate the experience, or otherwise, of psychological flow immediately after each race. The instrument provided vital data for segmenting the database of all 200 races into those in which high and low/no flow was experienced. The AFQ4 provided a platform whereby the associated EEGs could be linked to a flow score and a level of performance. The flow data collected between trials, together with the performance data, were used to segment the sample into two main groups, one indicating a lower level of flow (it was decided to use the first race, based on an assumption is that flow is unlikely to occur during the first attempt) and the other being the higher level of flow associated with peak performance (the fastest race - the assumption that flow is likely to occur after several practice attempts with the most likely during the best performance). Once these groups had been identified their EEGs were compared for differences that indicated a marker for flow.

From a purely illustrative perspective, the graphs below display the dynamic interplay between performance and flow (using the AFQ) per individual subject across all ten races.

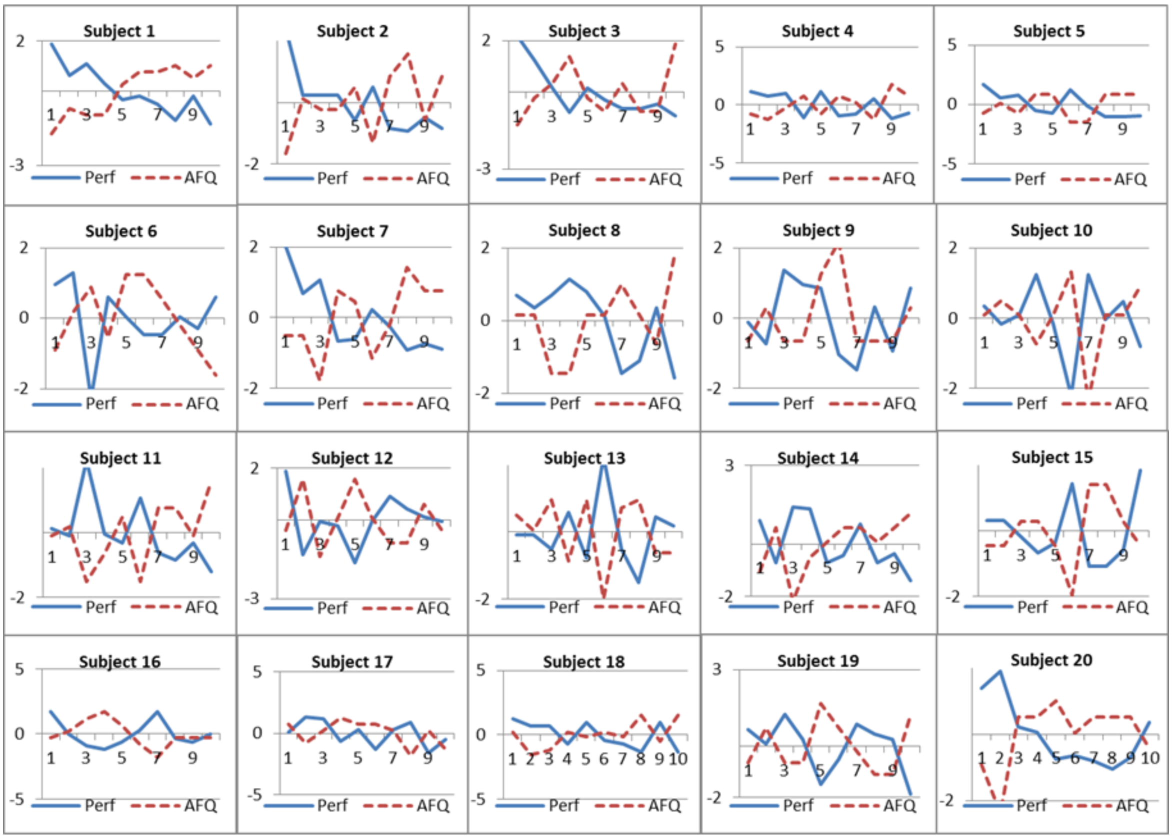


Figure 38. Performance vs flow (AFQ) per individual subject across all ten races

In the above illustration, subject 1 displays a “textbook” repertoire, showing a gradual build-up in performance and flow with a peak on both variables on the last race. In general it is observed that flow scores improved in line with performance.

From a statistical perspective, the discussion on the AFQ and performance follow. The mean AFQ component scores for the total sample are indicated below.

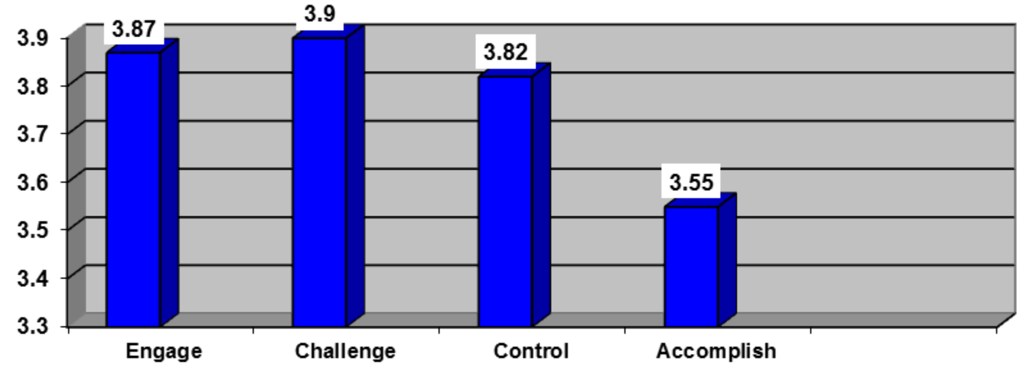


Figure 39. AFQ4 mean scores for four items by total sample

Table 14

AFQ4 Descriptive statistics (N = 20)

AFQ4	**Mean**	**Std.Deviation**	**Std. Err**	**Minimum**	**Maximum**	**Range**
Engage	3.87	0.93	6.62	1	5	4
Challenge	3.9	0.987	0.07	1	5	4
Control	3.82	0.833	5.89	1	5	4
Accomplishment	3.55	1.026	7.25	1	5	4

The Skills-Challenge match was the most important factor associated with the performance of the visuomotor task overall, followed by Engagement. The feeling of Control was next and finally a sense of Accomplishment. In the latter case this is the person's own perception of accomplishment against what they think, or feel, they are capable of, since no direct competition against each other was undertaken. The sessions were completely individual. It was evident that some subjects judge themselves more harshly than others and not only is the overall mean lower but also the standard deviation shows more variability.

Table 15

Inter-correlation of AFQ4 items (N = 200)

Inter-correlation report of AFQ Items for all 200 races

	Engage	**Challenge**	**Control**	**Accomplish**
Engage		0.42 0.00***	0.41 0.00***	0.39 0.00***
Challenge			0.42 0.00***	0.37 0.00***
Control				0.61 0.00***

Note. Cronbachs Alpha = 0.751477; Standardized Cronbachs Alpha = 0.756059
*** $p \leq .001$; ** $p \leq .01$; * $p \leq .05$

The AFQ4 presented with a Standardised Cronbach's Alpha = 0.756059 when all 4 questions were inter-correlated showing adequate internal consistency, and therefore reliability, amongst the separate items. It was kept in mind that there are only four questions since the Cronbach's Alpha is sensitive to the number of items and tends to increase with larger number of test items. The above Cronbach's Alpha also makes some contribution toward test validity since it meets the reliability criteria as pre-requisite for test validity.

6.3.4 The relationship between the AFQ and the GFI

Table 16

Correlation matrix for GFI and AFQ (N = 20)

Correlation between AFQ and GFI		
	AFQ	GFI
AFQ r =	1	0.0340
p =	0	0.8868
GFI r =	0.0340	1
p =	0.8868	0

Table 16 displays the correlation between the GFI and AFQ for the total sample of 20 subjects to be very low (r = 0.03) and insignificant (p = 0.88) and suggest they each measure different interpretations of flow.

Table 17 shows the inter-item correlations between the GFI's and AFQ's components for the total sample. The GFI has strong within-item inter-correlations, as already noted, but the AFQ items are relatively independent items.

Table 17

Correlation matrix AFQ and GFI items (N = 200)

Inter-Item correlations between the GFI and AFQ over all 200 races

GFI/AFQ	Absorption	Enjoyment	Motivation	Time	Engage	Challenge	Control	Accomplish
Absorption r =	1							
p =	0							
Enjoyment r =	0.73	1						
p =	0.00***	0						
Motivation r =	0.65	0.73	1					
p =	0.00***	0.00***	0					
Time r =	-0.16	-0.291	-0.006	1				
p =	0.489	0.213	0.980	0				
Engagement r =	0.22	-0.03	-0.044	-0.018	1			
p =	0.002**	0.65	0.53	0.939	0			
Challenge r =	-0.05	-0.25	-0.172	-0.022	0.42	1		
p =	0.50	0.000***	0.015	0.927	0.00***	0		
Control r =	-0.06	-0.20	-0.104	0.125	0.41	0.42	1	
p =	0.41	0.004**	0.14	0.600	0.00***	0.00***	0	
Accomplish r =	-0.02	-0.057	0.06	0.374	0.39	0.37	0.61	1
p =	0.76	0.42	0.40	0.104	0.00***	0.00***	0.00***	0

Note. *** p ≤ .001; ** p ≤ .01; * p ≤ .05

As a result of these findings the GFI and AFQ results were used separately and for different analytical purposes. The AFQ provides feedback that gives a measure of flow per race, specifically for identifying those races where stronger versus weaker flow was experienced. The GFI provides further insight into the total but less directly related experience of flow after all races had been completed.

A single GFI score was repeated 10 times to match the individual AFQ scores as it was assessed only once in 10 races. The findings show that none of the GFI and AFQ individual items inter-correlate, yet highly significant inter-item agreement was found *within* both the GFI and AFQ, except for Time, which was discarded in any event as mentioned earlier. The low correlation with the other four AFQ items was another reason to justify its exclusion. These high levels of internal consistency suggest that both instruments are reliable measures of flow. Both instruments are also considered valid instruments for measuring flow, since the GFI is a validated instrument (Bakker, 2008) and the AFQ's test items are directly grounded in the flow research published by Csikszentmihalyi and others.

A factor analysis of the results from the total sample shows even more precisely that the two instruments are measuring different aspects of flow. This was based on the average AFQ (with 5 items) score and the GFI score per subject. Table 18 (below) shows clearly that the AFQ and GFI loaded on two factors. The GFI loaded more heavily on factor 1 and the AFQ on factor 2.

Table 18

GFI and AFQ factor analysis

Factor Analysis Report. Communalities after Varimax Rotation

Variables	**Factor1**	**Factor2**	**Communality**
AFQ Time	0.004206	0.186463	0.190669
AFQ Engage	0.012891	0.163897	0.176787
AFQ Challenge	0.081030	0.349762	0.430792
AFQ Control	0.045167	0.668085	0.713252
AFQ Accomplish	0.000087	0.576155	0.576242
GFI Absorption	0.728532	0.017479	0.746011
GFI Enjoyment	0.797914	0.037424	0.835338
GFI Intrinsic Motivation	0.620769	0.000035	0.620804

Bar Chart of Communalities after Varimax Rotation

<table>
<tr><th>Variables</th><th>Factor1</th><th>Factor2</th><th>Communality</th></tr>
<tr><td>AFQ Time</td><td>|</td><td>||||</td><td>||||</td></tr>
<tr><td>AFQ Engage</td><td>|</td><td>||||</td><td>||||</td></tr>
<tr><td>AFQ Challenge</td><td>||</td><td>|||||||</td><td>|||||||||</td></tr>
<tr><td>AFQ Control</td><td>|</td><td>||||||||||||||</td><td>|||||||||||||||</td></tr>
<tr><td>AFQ Accomplish</td><td>|</td><td>||||||||||||</td><td>||||||||||||</td></tr>
<tr><td>GFI Absorption</td><td>|||||||||||||||</td><td>|</td><td>|||||||||||||||</td></tr>
<tr><td>GFI Enjoyment</td><td>||||||||||||||||</td><td>|</td><td>|||||||||||||||||</td></tr>
<tr><td>GFI Intrinsic Motivation</td><td>|||||||||||||</td><td>|</td><td>|||||||||||||</td></tr>
</table>

Factor Structure Summary after Varimax Rotation	
Factor1	**Factor2**
GFI Enjoyment	AFQ Control
GFI Absorption	AFQ Accomplish
GFI Intrinsic Motivation	AFQ Challenge
	AFQ Time
	AFQ Engage

The reliability of the measures over time cannot be assessed since no repeat testing is conducted. However, it is clear from the available information that, on the whole, the two questionnaires measure different aspects of flow. The GFI is more behaviourally orientated and the AFQ more performance-based.

The division into AFQ and GFI factors indicates the need to treat the two instruments separately in the interpretation of their findings. Although there is some overlap they are measuring aspects of the flow experience in two different contexts. The GFI score indicates that the subject experienced flow sometime during the ten races and he felt enjoyment (happy about result), internal motivation (doing the activity for the pleasure) and absorption (being immersed) in doing so, while the AFQ indicates that the subject experienced his highest level of flow on a particular race and he felt a sense of being in control, accomplished (satisfied with result), being up for the challenge (a perfect match of skill and challenge), and feeling totally engaged while performing the activity.

The AFQ4 was therefore used as measure to segment the sample into two flow groups.

6.4 SEGMENTATION OF THE SAMPLE INTO TWO FLOW GROUPS

Central to the study was setting up two levels of the flow variable, namely a high-flow and a low-flow set of results, in order to test whether they differ with in both the experience of flow and the associated EEG profiles under task. This segmentation was achieved using the first race as baseline data set (Group 2) for low performance/low flow and accompanying EEG and the fastest race/highest flow score as data set (Group 1) for flow and EEG under peak performance condition.

The AFQ4 was used to provide the flow score that accompanied both the performance score and the EEG data for each race per subject. The set of AFQ4 scores was standardised using the same formula as for the performance data. The need to standardise the data was discussed earlier in this chapter. The resulting total sample distribution is summarised below and shows the proximity to normally distributed scores that was achieved by this process with the total sample data, that is for all subjects across all races (n = 200).

Table 19

Standardised AFQ based on the average AFQ over 10 races for all 20 subjects

	Mean	**Standard Deviation**	**Standard Error**	**Minimum**	**Maximum**	**Range**
AFQ Standardised	**-0.07**	**1.51**	**0.19**	**-2.38**	**2.17**	**4.55**

The data representing the high flow condition and designated as Group 1 was compared with the corresponding low flow condition and designated as Group 2, and the regression line, as illustrated in Figure 40 (below), clearly displays how differently the two groups were positioned relative to each other.

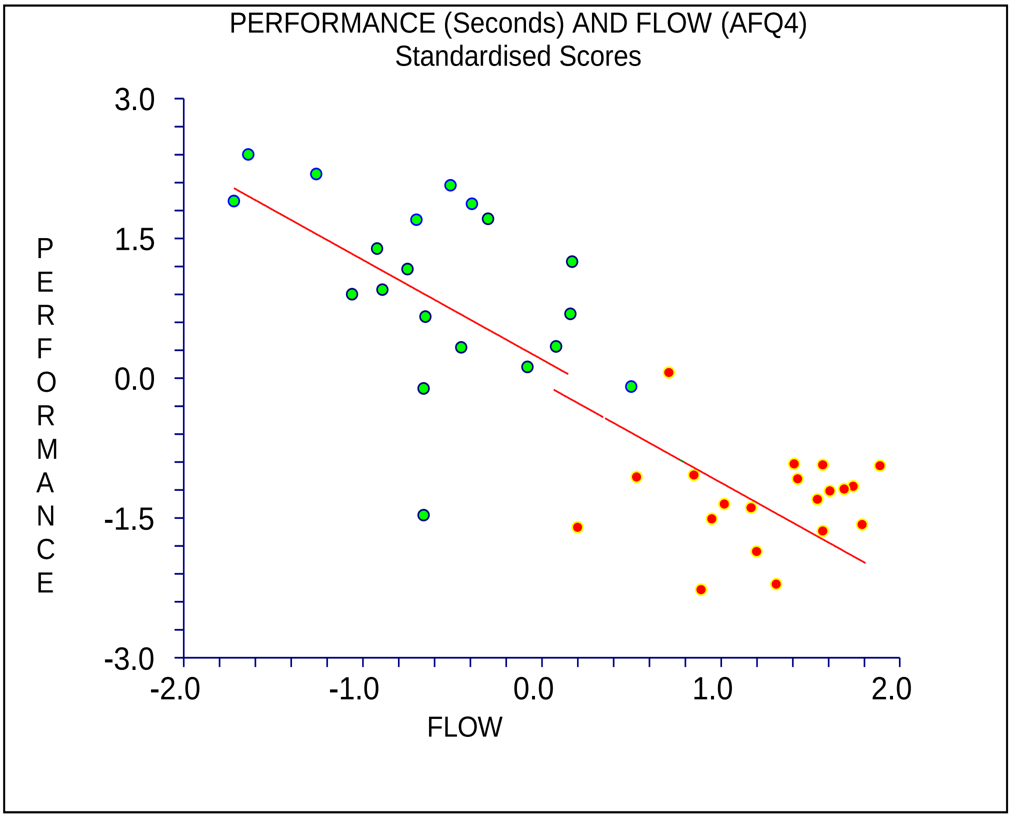


Figure 40. The performance-flow relationship for fastest (blue) and baseline (red) races (N = 20)

A correlation of -0.82 (p = 0.00) between the two sets of data shows that the less time taken to complete the race, the higher the flow. This is a strong correlation, in the predicted direction, and it is highly significant at the 0.001 level.

The table below shows the average raw data and standard scores for the performance and AFQ4 flow variables.

Table 20

Performance and AFQ4 averages for high and low flow races

N = 20	**Mean performance (in seconds)**	**Mean flow AFQ4 (Maximum 20)**
Higher flow races **(Fastest race)**	Mean =108.7 (std score = -1.385)	Mean = 18.1 (std score = 1.185)
Low flow races **(Baseline)**	Mean = 133.75 (std score = 1.075)	Mean = 13.9 (std score = - 0.518)

The average time taken to complete races in high flow was 108.7 seconds, in contrast to 133.75 seconds in low flow. This indicates that in terms of performance the high flow group, with a standard score of -1.385, was more than a standard deviation quicker than the low flow group, with a standard score of 1.075. The AFQ4 (with a maximum of 20 points) has a mean of 18.1 in the higher flow condition and drops to 13.9 in the lower condition. The AFQ4 standard scores indicate that high flow races have a standard deviation of approximately 1.2 above the mean against a low flow score of -0.518 below the mean. In this instance the mean for the AFQ 4, converted to a standard score, was 0.

When the AFQ scores for Group 1 and Group 2 are compared it is clear that on all four components the experience of flow is higher when they are performing at peak than when they are not. The differences are all significant at the 0.05 level of significance. Given that flow reportedly occurs when higher performance is demanded to move to the next level it is interesting that in the high flow races Challenge and Engagement are experienced slightly higher than Control and Accomplishment, and that the sense of being “in control” is reportedly higher than the other three attributes in the low flow situation, with a sense of Accomplishment being the least experienced.

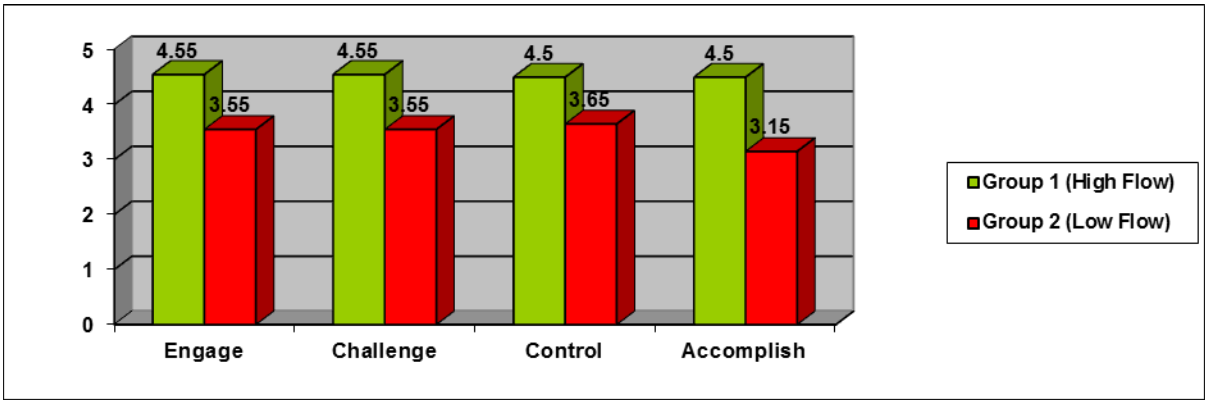


Figure 41. AFQ4 mean scores for high and low flow races (N = 20)

Table 21

AFQ4 items distribution statistics for high flow

Group 1. High Flow Group					
N=20	**Mean**	**Standard Deviation**	**Standard Error**	**Minimum**	**Maximum**
Engage	4.55	0.83	0.19	2	5
Challenge	4.55	0.69	0.15	3	5
Control	4.5	0.61	0.14	3	5
Accomplish	4.5	0.61	0.14	3	5

The results for individual AFQ4 items show clearly the higher reporting of flow in Group 1 compared with Group 2.

Table 22

AFQ4 items distribution statistics for low flow

Group 2. Low Flow Group					
n= 20	**Mean**	**Standard Deviation**	**Standard Error**	**Minimum**	**Maximum**
Engage	3.55	0.95	0.21	2	5
Challenge	3.55	0.99	0.22	1	5
Control	3.65	0.93	0.21	1	5
Accomplish	3.15	1.09	0.25	1	5

The average AFQ4 scores for the two groups are z = 1.2 for high flow and z = -0.52 for the low flow. Once again this is in the predicted direction and there is a clear difference between the two sets of data in both performance and flow, as measured on the AFQ4.

Table 23

AFQ4 Standard score descriptive statistics for high and low flow (N = 20)

Group 1 **AFQ4 High flow standard descriptive statistics.**					
Standard	**Standard**				
Mean	**Deviation**	**Error**	**Minimum**	**Maximum**	**Range**
1.185	0.617333	0.1380398	-0.66	1.89	2.55
Group 2 **AFQ4 Low flow standard descriptive statistics**					
-0.518	0.6516344	0.1457099	-1.72	0.71	2.43

When performance and flow were correlated within each group the results reported in Table 24 were obtained.

Table 24

Correlation matrix for performance and flow (AFQ4) for Group 1 (high flow / high performance condition)

Group 1 **High Flow**	Performance	Engage	Challenge	Control	Accomplish
Performance	1.00	-0.04	**-0.50**	**-0.76**	-0.42
p=	0.00	0.86	**0.03**	**0.00**	0.07
Engage		1.00	0.27	0.16	0.16
p=		0.00	0.24	0.51	0.51
Challenge			1.00	**0.57**	0.19
p=			0.00	**0.01**	0.42
Control				1.00	**0.57**
p=				0.00	**0.01**
Accomplish					1.00
p=					0.00
AFQ4	**-0.58**	**0.64**	**0.73**	**0.78**	**0.64**
p=	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**

Note. Cronbachs Alpha =- 0.281148; Standardized Cronbachs Alpha = 0.515608

In the high flow condition (Group 1) a moderate negative correlation was found between performance and flow measured on the AFQ (r = -0.58; p = 0.01), all the AFQ sub-items were also significantly correlated with the AFQ4. Challenge (r = 0.73) and Control (r = 0.78) were more highly inter-related than Engagement (r = 0.64) and Accomplishment (r = 0.64). Performance was significantly correlated only to Challenge and Control.

In contrast, the low flow group has a lower overall negative correlation (r = -0.47; p = 0.04) indicating that as performance time increases so flow increases and vice versa but it is more variable than when flow is higher. All main flow indicators were significantly moderately correlated with the AFQ4 overall. Accomplishment was the more highly associated factor in the lower flow condition (r = 0.73), followed by Engagement (r = 0.56), Control (r = 0.58) and then Challenge (r = 0.56).

Table 25

Correlation matrix for performance and flow (AFQ4) for Group 2 (low flow / low performance condition)

Group 2 **Low Flow**	Performance	Engage	Challenge	Control	Accomplish
Performance	1.00	-0.02	0.01	**-0.70**	**-0.46**
p=	0.00	0.93	0.97	**0.00**	**0.04**
Engage		1.00	0.39	-0.07	0.22
p=		0.00	0.09	0.77	0.35
Challenge			1.00	-0.01	0.02
p=			0.00	0.97	0.94
Control				1.00	**0.52**
p=				0.00	**0.02**
Accomplish					1.00
p=					0.00
AFQ4	**-0.47**	**0.61**	**0.56**	**0.58**	**0.73**
p=	**0.04**	**0.00**	**0.01**	**0.01**	**0.00**

Note. Cronbachs Alpha =- 0.164115; Standardized Cronbachs Alpha = 0.491471

A MANOVA was performed to indicate the differences in mean scores between Groups 1 and 2. The results are reflected in Table 26 (below). In addition, a one-way analysis of variance (ANOVA) for all variables was performed, including an effect size analysis, the results of which are reflected in Table 27 (below).

Table 26

MANOVA results for performance, flow (AFQ4) and EEG's between low (Group 2) and high flow (Group 1)

MANOVA	**Test Value**	**DF1**	**DF2**	**F-Ratio (Critical value F=4.098)**	**Sig. of F**	**Decision (≤0.05)**
Wilks' Lambda	0.02985	30	9	9.75	0.001	Reject
Hotelling-Lawley Trace	32.50179	30	9	9.75	0.001	Reject
Pillai's Trace	0.97015	30	9	9.75	0.001	Reject
Roy's Largest Root	0.97015					

Table 27

One-way ANOVA and effect size results between low to high flow

One-way Analysis	**Test Value**	**DF1**	**DF2**	**F-Ratio (Critical value F=4.098)**	**Sig. of F**	**Decision (≤0.05)**	**Effect Size. Eta^2**
Performance (in secs)	60.516	1	38	150.06	0.000	Reject	**.94**
AFQ4 (flow)	29.002	1	38	71.99	0.000	Reject	**.89**
F3 Delta	22.515	1	38	1.88	0.179	Accept	**.17**
F3 Theta	5.264	1	38	0.2	0.657	Accept	.02
F3 Alpha	1.905	1	38	0.28	0.602	Accept	.03
F3 Lobeta	5.845	1	38	2.47	0.124	Accept	**.22**
F3 Beta	57.840	1	38	3.65	0.064	Accept	**.29**
F3 Hibeta	21.054	1	38	0.78	0.382	Accept	.08
F3 Gamma	0.037	1	38	0.02	0.892	Accept	.00
C3Delta	19.698	1	38	0.85	0.362	Accept	.09
C3Theta	0.681	1	38	0.02	0.895	Accept	.00
C3Alpha	17.332	1	38	2.8	0.103	Accept	**.24**
C3Lobeta	7.912	1	38	4.38	0.043	Reject	**.33**
C3Beta	44.394	1	38	2.48	0.124	Accept	**.22**
C3Hibeta	7.327	1	38	0.19	0.663	Accept	.02
C3Gamma	0.084	1	38	0.04	0.838	Accept	.01
P3Delta	35.100	1	38	2.71	0.108	Accept	**.23**
P3Theta	19.321	1	38	0.47	0.496	Accept	.05
P3Alpha	6.889	1	38	0.35	0.555	Accept	.04
P3Lobeta	1.414	1	38	0.23	0.635	Accept	.03
P3Beta	52.235	1	38	3.73	0.061	Accept	**.29**
P3Hibeta	40.040	1	38	0.51	0.479	Accept	.05
P3Gamma	1.222	1	38	0.14	0.714	Accept	.02
01Delta	45.946	1	38	1.11	0.300	Accept	.11
01Theta	1.743	1	38	0.04	0.848	Accept	.00
01Alpha	18.619	1	38	1.47	0.233	Accept	**.14**
01Lobeta	7.048	1	38	1.27	0.267	Accept	.12
01Beta	30.695	1	38	0.76	0.390	Accept	.08
01Hibeta	75.653	1	38	0.69	0.412	Accept	.07
01Gamma	0.927	1	38	0.12	0.728	Accept	.01

The F-ratio produced in this analysis is the ratio of the difference within and between the two flow groups. In this study, the critical value for F was 4.098. An F-ratio higher than the critical value indicates a significant difference at the 0.05 probability level. That is, there is at least a 95% chance that the differences observed between the two sets of scores were indicative of a real difference in behaviour which, given the same test conditions, may be repeated with the same, or very similar, results. An analysis of effect sizes is included with the one-way analysis of variance as it provides information about the size of change that took place in performance, perceived flow and EEG's from low to high flow.

The MANOVA results in Table 26 indicate clearly that the high and low flow data sets were from two significantly different levels of the flow condition, which justifies the segmentation of the data into high- and low flow groups. The F-ratio (F = 150.06) for the standardised group performance varied significantly between the high- and low flow conditions, showing that when each individual's comparative performance was taken into account this difference (significant at the 0.00 level of probability) was further highlighted. The very large effect size ($Eta^2 = 0.94$), as reported in Table 27, confirmed that the two levels differ by 94%. Also highly significant (p = 0.000) was the difference in reported flow with the overall AFQ4 F-ratio being 71.99. The very large effect size (Eta2 = 0.89) confirmed that the two levels differ by 89%. The null hypotheses that indicate, respectively, that the performance and flow scores from Groups 1 (high flow) and 2 (low flow) are the same is rejected and it is accepted that they are significantly different levels of flow.

The rest of the analyses for high- and low flow were based on these two groups of data, Group 1 and Group 2, where there was a clear relationship between flow and performance at two distinct levels, against which to examine and interpret the accompanying EEG data.

6.5 ANALYSES OF NEUROLOGICAL (EEG) DATA

As mentioned in Chapter 5, the EEG data were recorded for the frequency spectrum covering 1 – 42 Hz. Frequency bands were grouped into 1-3Hz (delta), 4-7Hz (theta), 8-12Hz (alpha), 12-15Hz (lobeta), 15-20Hz (beta), 20-30Hz (hibeta) and 38-42Hz (gamma). Data were extracted using the MEANF (mean fraction of EEG energy in each band) and expressed as percent power as derived from Fast Fourier Transform (FFT). Recordings were made at four scalp locations with the channels (electrode pairs) F3 – F4 (frontal lobes); C3 – C4 (sensori-motor cortex); P3 – P4 (parietal lobes) and O1 – O2 (occipital lobes).

Data from Groups 1 and 2 were compared in terms of EEG power and synchrony (correlations) and presented in a visual- and statistical way.

Hypotheses were tested using the following significance levels as decision rules to reject the null hypothesis:

(1) For testing difference (EEG power) f-ratios : $p \leq 0.05$
(2) For testing similarity (Synchrony) correlations (r) : $p \leq 0.05$

The results are presented by channel (designated for the left hemisphere position only) and express the state of electrical activity between the two scalp positions bilaterally. In line with the proposed neurophysiological model for flow, as presented in Chapter 4, the following electro-cortical changes in various areas of the brain were expected for the higher flow condition (Group 1).

Table 28

Expected model for flow at peak performance

Brain Site (s)	**Expected brain activity.**
Pre-frontal cortex (F3)	Decreased beta and gamma and increased theta power
Parietal cortex (P3)	Increased theta and alpha power.
Sensori-motor (C3)	Increased alpha.
Between the sensori-motor (C3) and parietal (P3) areas	Increased alpha synchrony
Between the pre-frontal and sensori-motor cortex (F3-C3), the pre-frontal and parietal (F3-P3) and the sensori-motor and parietal (C3 –P3).	De-synchronisation in beta.

To evaluate power changes, the power values for Group 2 were regarded as base values (as they were in the lowest flow state) and those of Group 1 as the high flow values. The high flow values were compared with the base values for each of the four locations by frequency.

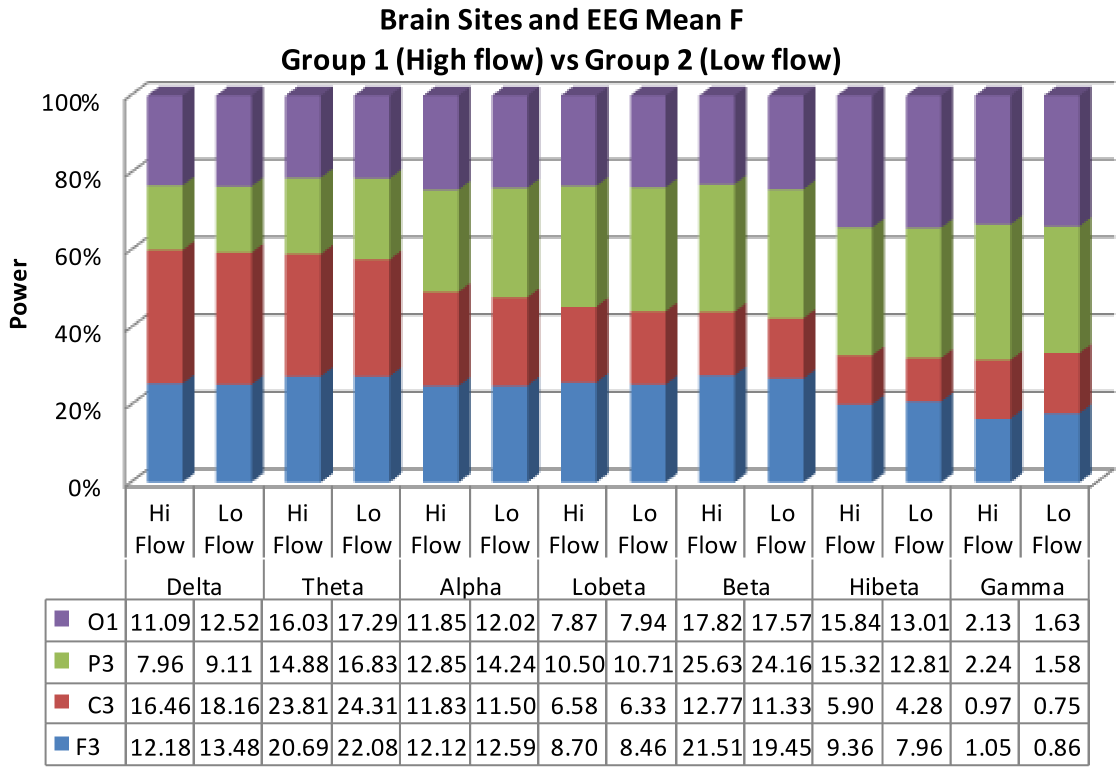
EEG power scores were analysed for inter-group differences by location, whereas synchrony changes were analysed in terms of patterns of inter-location synchrony (binding) or de-synchrony (no binding) within- and between groups. The patterns of synchronous and non-synchronous bindings of the higher-flow data were compared to the patterns predicted by the theoretical model.

6.5.1 EEG power data

EEG power spectrum analysis is important in order to observe the dominant frequency band for the spectrum being measured in a particular area. The frequency band with the highest power value is regarded as the dominant frequency and is associated with a particular state of mind in general or a particular function if more localised. Functions of frequencies change according to locality. In general:

(1) Delta rhythm is associated with states of wakefulness;
(2) Theta with creativity, spontaneity, integration, anxiety and inattention;
(3) Alpha with relaxed wakefulness;
(4) Lobeta with stillness and movement;
(5) Beta with being focused, analytic, externally oriented, or in a state of relaxed thinking;
(6) Hibeta is associated with peak performance;
(7) Gamma is associated with selective attention, transient binding of cognitive features, and conscious perception of visual objects.

A sample of 20 races per group was chosen as discussed earlier.



	Delta		Theta		Alpha		Lobeta		Beta		Hibeta		Gamma	
	Hi Flow	Lo Flow	Hi Flow	Lo Flow	Hi Flow	Lo Flow	Hi Flow	Lo Flow	Hi Flow	Lo Flow	Hi Flow	Lo Flow	Hi Flow	Lo Flow
🟪 O1	11.09	12.52	16.03	17.29	11.85	12.02	7.87	7.94	17.82	17.57	15.84	13.01	2.13	1.63
🟩 P3	7.96	9.11	14.88	16.83	12.85	14.24	10.50	10.71	25.63	24.16	15.32	12.81	2.24	1.58
🟥 C3	16.46	18.16	23.81	24.31	11.83	11.50	6.58	6.33	12.77	11.33	5.90	4.28	0.97	0.75
🟦 F3	12.18	13.48	20.69	22.08	12.12	12.59	8.70	8.46	21.51	19.45	9.36	7.96	1.05	0.86

Figure 42. EEG power scores (Mean F) across four sites and all EEG frequencies, in high and low flow

A one way analysis of variance (ANOVA) conducted on these two groups of scores and their accompanying EEG power (Mean F) scores yielded the results reported in Table 27 and are discussed below.

The null hypotheses, that there were no differences between the two groups, were rejected only for the lobeta frequency in the sensori-motor cortex (C3), where significant differences between high and low flow conditions were found. The differences for F3 and P3 in the beta frequency were at the 0.06 level of probability and fell just outside the significant range. All other frequencies in all other areas showed no significant differences between high and low flow.

However, since there were changes in other EEG variables between high and low flow and these changes are of interest in this particular study where patterns of data were under investigation. Some of the non-significant differences had large effect sizes. Figure 42 (below) illustrates the changes between low and high flow estimated by the Eta^2 statistic.

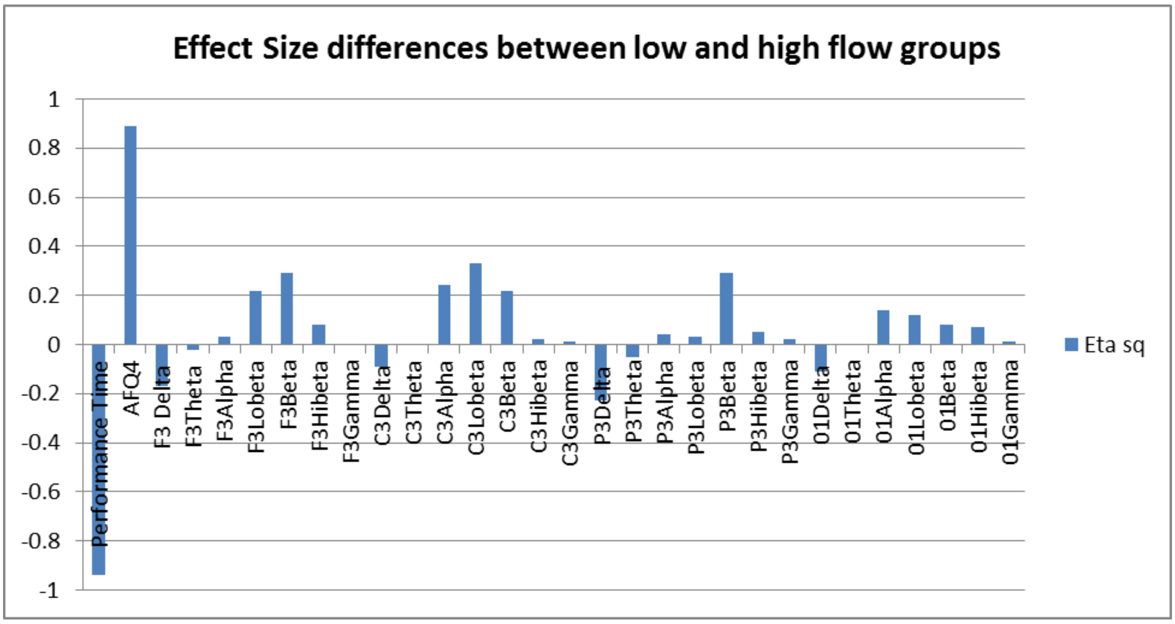


Figure 43. Effect size differences between low and high flow groups

From Figure 43, it was evident that performance and the flow (AFQ4) accounted for the greatest amount of variability from low to high flow states. C3 lobeta was next, and as mentioned earlier, the only significantly different EEG variable, followed by other (statistically non-significant) changes. It was observed that the beta frequency produced large effects (Eta$^2 \geq 0.14$) across three of the four cortices while the effect in O1 was only medium (Eta$^2 \geq 0.06$). In the pre-frontal cortex, large effect sizes were also observed in delta and lobeta. In the sensori-motor cortex large effect sizes were evident in alpha, lobeta, and beta, while in the parietal cortex it was in delta and beta. Alpha displayed a large effect size in the occipital cortex.

6.5.2 The Pre-frontal cortex (F3)

The PFC is the brain area associated with attention, logical reasoning, creativity, executive decision making, working memory and control. The dorsolateral pre-frontal cortex (as indexed by F3) has a generic function of real-time processing of information or working memory in the service of a wide range of cognitive functions; integrating attention, memory, motor, and affective dimensions of behaviour.

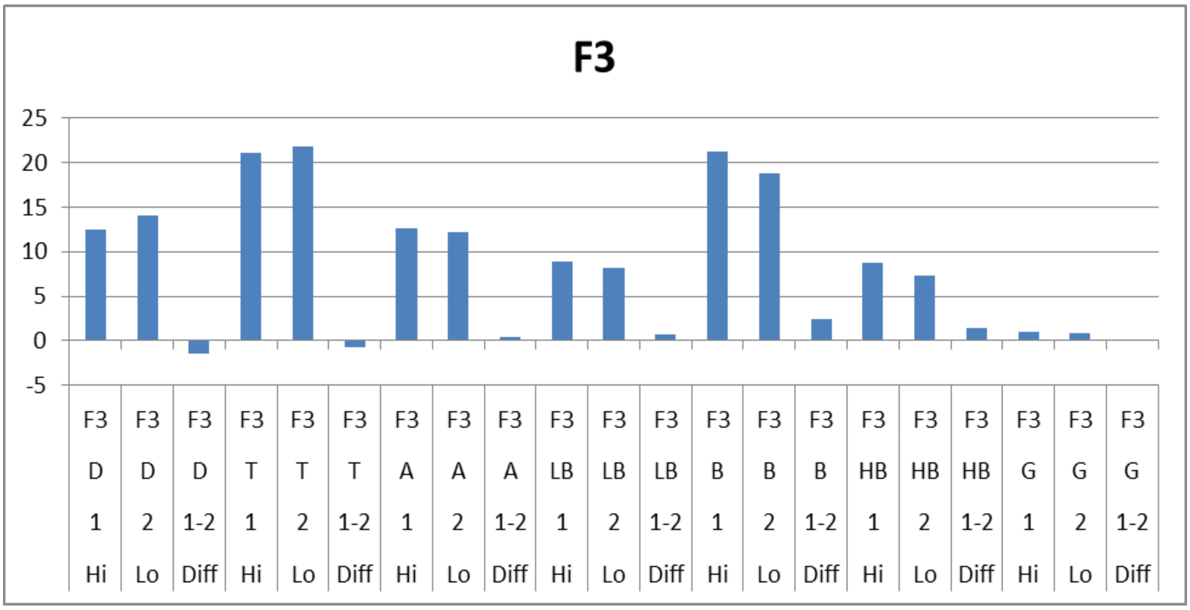


Figure 44. Bar chart showing differences in mean power between high vs low flow across frequencies in the pre-frontal cortex

Table 29

Pre-frontal cortex and high vs low flow differences in mean power across frequencies

F3	**Delta**	**Theta**	**Alpha**	**Lobeta**	**Beta**	**Hibeta**	**Gamma**
Hi Flow	12.49	21.05	12.66	8.86	21.22	8.75	0.92
Low Flow	13.99	21.77	12.22	8.10	18.81	7.30	0.86
Diff	-1.50	-0.73	0.44	0.76	2.41	1.45	0.06
F Ratio	1.88	0.2	0.28	2.47	3.65	0.78	0.02
P -Value	0.1788	0.6571	0.6018	0.1243	**0.0637**	0.3819	0.8917
Eta^2	**-0.17**	-0.02	0.03	**0.22**	**0.29**	0.08	0

From the above data, theta and beta were the most dominant power frequencies in both high and low flow conditions. Higher flow seems to be associated with reduction in delta and theta power together with increased power in alpha, lobeta, beta, hibeta, and gamma. None of the differences in power values between the two groups were significant. However, the increase in beta was in the opposite of the hypothesised direction (it was expected to decrease) at the 0.06 level of significance (F = 3.65; p = 0.0637). Although not statistically significant, the effect size for beta was large (Eta^2 = 0.29). Beta became the dominant frequency in the high flow condition while theta was dominant for the low flow condition. Lobeta showed a large increase (Eta^2 = 0.22), while delta showed a large (Eta^2 = -0.17) decrease as high flow was assumed.

The combination of higher beta and lobeta and decreased delta power in the frontal area may indicate that subjects in the high flow condition were more focused, analytical, externally oriented, and/or relaxed compared to subjects in the low flow group. It may also be an indication that executive processes have shifted from internal (implicit processes) to external (explicit processes) orientation. The effects of each frequency will be discussed in more detail later.

6.5.3 The Sensori-motor cortex (C3)

The sensori-motor cortex is associated with motor functioning and thus ultimately with skill execution. It shares in orchestrating both physical and mental processes and governs more than just sensory and motor functions.

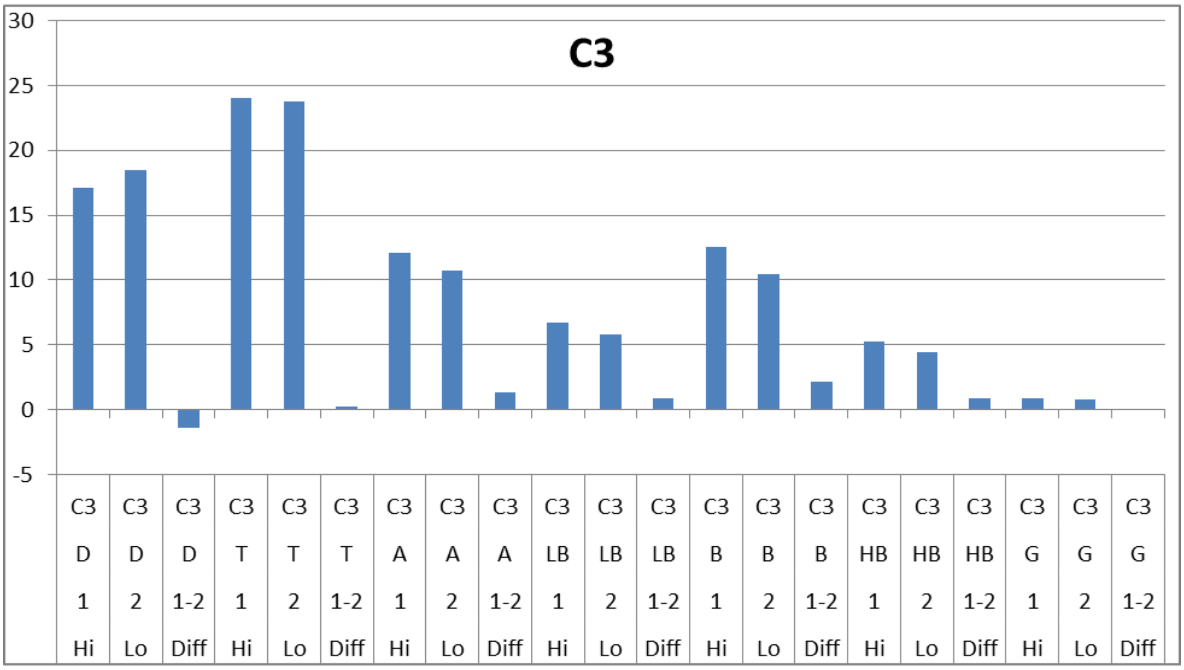


Figure 45. Bar chart showing differences in mean power between high vs low flow across frequencies in the sensori-motor cortex

Table 30

Sensori-motor cortex and high vs low flow differences in mean power across frequencies

C3	**Delta**	**Theta**	**Alpha**	**Lobeta**	**Beta**	**Hibeta**	**Gamma**
Hi Flow	17.10	24.05	12.08	6.72	12.53	5.27	0.86
Low Flow	18.51	23.78	10.76	5.83	10.42	4.41	0.76
Diff	-1.40	0.26	1.32	0.89	2.11	0.86	0.09
F Ratio	0.85	0.02	2.8	4.38	2.48	0.19	0.04
P -Value	0.3617	0.8950	0.1025	**0.0432**	0.1237	0.6627	0.8379
Eta2	-0.09	0	**0.24**	**0.33**	**0.22**	0.02	0.01

The above data indicate that the only significant difference in power change between the high- and low flow groups was observed in the lobeta band (F = 4.38; p = 0.0432). It also demonstrated the largest effect size (Eta^2 = 0.33) of all the changes in power. Research indicates that lobeta amplitude increases with stillness and decreases with movement (Othmer, et al., 1999, p. 267), which may reflect a state of being internally oriented. In other words, performance takes less effort since movement is fluent and automatic, which is a characteristic of the high flow condition. The data also indicate that theta was the dominant frequency in the sensori-motor area for both high- and low flow conditions. It showed an effect size of zero. This is probably because theta waves are generated in the limbic system and are prominent in the thalamus and hippocampus under conditions of alertness and arousal, and projects strongly in the sensori-motor cortex. Theta waves underpin unconscious automotoric processes.

The above data also indicated large effect sizes in alpha (Eta^2 = 0.24) and beta (Eta^2 = 0.22). The effects of each frequency will be discussed in more detail later.

6.5.4 The Parietal cortex (P3)

The parietal lobes are associated with mathematical reasoning, naming objects, complex grammar, and spatial awareness. Parietal lobes solve problems that have been conceptualised by the frontal lobes. They, together with the frontal lobes are the main components of the association cortex.

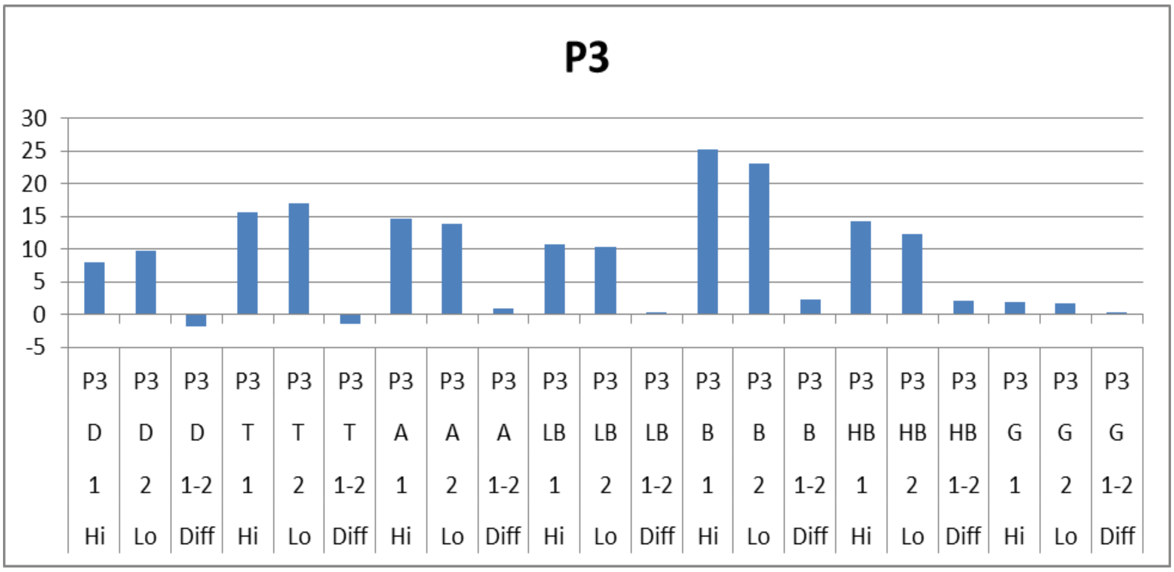


Figure 46. Bar chart showing differences in mean power between high vs low flow across frequencies in the parietal-motor cortex

Table 31

Parietal cortex and high vs low flow differences in mean power across frequencies

P3	**Delta**	**Theta**	**Alpha**	**Lobeta**	**Beta**	**Hibeta**	**Gamma**
Hi Flow	7.92	15.68	14.58	10.78	25.28	14.28	1.94
Low Flow	9.80	17.07	13.75	10.40	23.00	12.28	1.59
Diff	-1.87	-1.39	0.83	0.38	2.29	2.00	0.35
F Ratio	2.71	0.47	0.35	0.23	3.73	0.51	0.14
P -Value	0.1083	0.4962	0.5550	0.6346	**0.0608**	0.4793	0.7135
Eta^2	**-0.23**	-0.05	0.04	0.03	**0.29**	0.05	0.02

Beta was the dominant frequency in the parietal cortex for both high- and low flow conditions. There were no significant differences between the two groups in power changes in any of the frequencies. However, the increase in beta was at the 0.06 level of significance (F = 3.73; p = 0.0608) and has a large effect size (Eta^2 = 0.29). Beta plays an important role in the fronto-parieto-temporal attentional network and is known to be involved in target detection, visual attention, and working memory; processes that are required for the successful execution of any visually based task (Gross, et al., 2004). Delta displayed a large decreasing effect (Eta^2 = -0.23) as high flow was assumed. Decreasing delta will enhance alertness in support of increased attention.

6.5.5 The Occipital cortex (O1)

The occipital lobes are associated with the visual field that helps to locate objects in the environment, see colours, recognise drawings, and correctly identify objects.

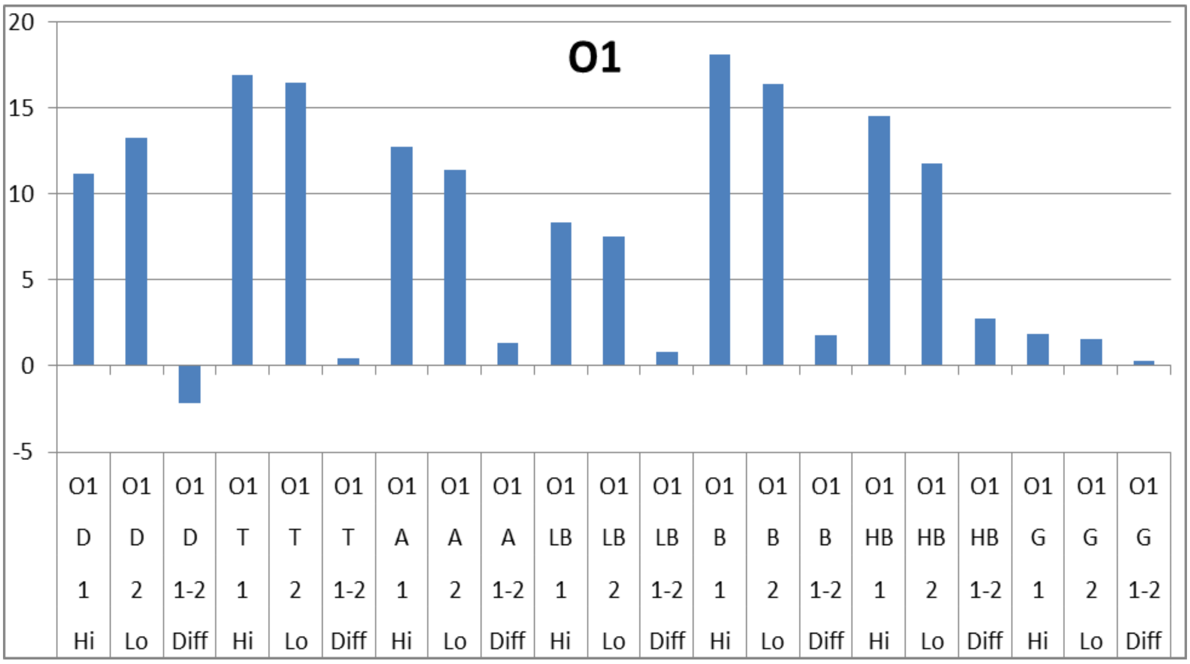


Figure 47. Bar chart showing differences in mean power between high vs low flow across frequencies in the occipital cortex

Table 32

Occipital cortex and high vs low flow differences in mean power across frequencies

O1	**Delta**	**Theta**	**Alpha**	**Lobeta**	**Beta**	**Hibeta**	**Gamma**
Hi Flow	11.15	16.89	12.76	8.35	18.15	14.55	1.87
Low Flow	13.29	16.48	11.40	7.51	16.40	11.79	1.56
Diff	-2.14	0.42	1.36	0.84	1.75	2.75	0.30
F Ratio	1.11	0.04	1.47	1.27	0.76	0.69	0.12
P -Value	0.2997	0.8477	0.2326	0.2668	0.3898	0.4125	0.7275
Eta^2	-0.11	0	**0.14**	0.12	0.08	0.07	0.01

There were no significant differences in power between the two groups in any of the measured frequencies in the occipital region. Beta seems to be the dominant frequency for the high flow condition while theta is dominant for the low flow group. However, alpha displayed the largest effect size ($Eta^2 = 0.14$) probably due to its involvement in top-down interactions between higher-order and primary areas of the visual cortex.

6.5.6 Power analyses by frequency

Although the above data revealed that the difference in power between the two flow conditions is only significant in lobeta at the sensori-motor area, it also revealed large effects in other frequencies and locations. These movement (change size and directions) trends will be further discussed by frequency band across scalp positions.

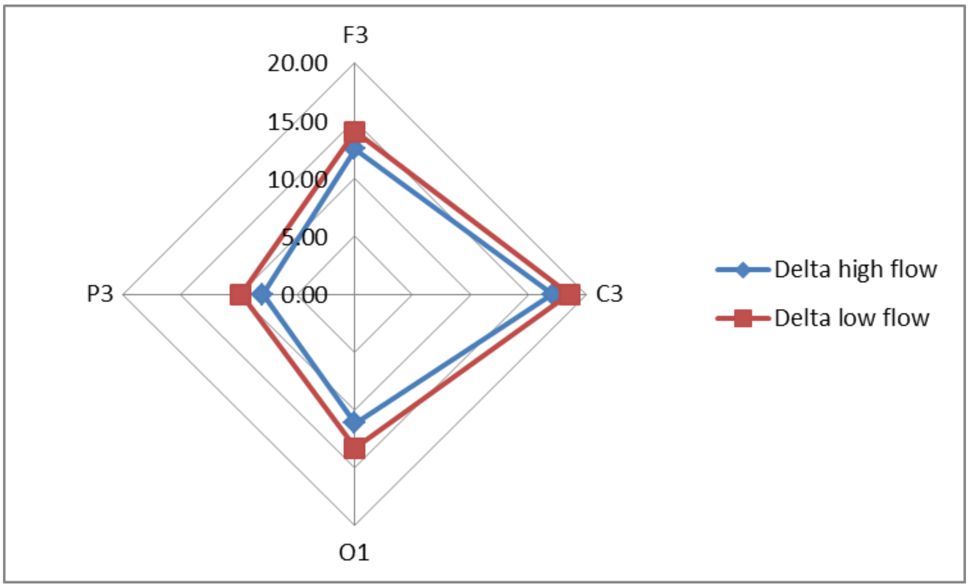


Figure 48. Delta power shift for high vs low flow groups

Figure 48 indicates that delta power reduced in all cortical areas in the high flow group. However, none was at a statistically significant level (F3 : p = 0.1788; C3 : p = 0.3617; P3 : p = 0.1083; O1 : p = 0.2997). However, large effect sizes were displayed in F3 ($Eta^2 = 0.-17$) and P3 ($Eta^2 = 0.-23$), and medium size in C3 ($Eta^2 = -0.09$) and O1 ($Eta^2 = 0.-11$). Delta was the most dominant in the sensori-motor area (C3). Vogel, et al. (1968) postulated two kinds of behavioural inhibition characterised by delta : (a) Class I inhibition refers to a gross inactivation of an entire excitatory process resulting in a relaxed, less active state, such as sleep, and (b) Class II inhibition refers to the selective suppression of inappropriate, or non-relevant, neural activity during mental task performance. The fact that delta decreased in all areas as flow increased may be a result of deactivation of Class 1 inhibition and activation of Class II inhibition, especially in the PPC and PFC.

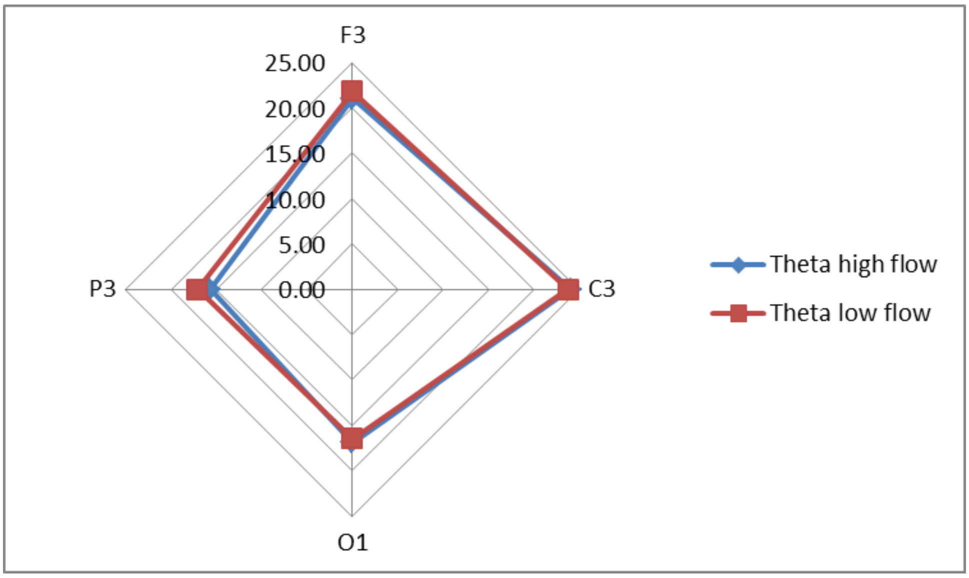


Figure 49. Theta power shift for high vs low flow groups

Figure 49 indicates that theta power remained fairly constant in all cortical areas, but reduced in the parietal area in the high flow group, however not at a significant level (P3 : p = 0.4962). In addition, all effect sizes in theta were small ($Eta^2 < 0.06$). Theta was the most dominant in the sensori-motor area. Both decreased and increased frontal theta activity have been linked to increased cognitive demands. Increased frontal theta is reported in a wide variety of tasks, such as mental arithmetic (Mizuki et al., 1980; Sasaki et al., 1996; Inanaga, 1998; Lazarev, 1998; Ishii et al., 1999; Smith et al., 1999), error detection (Luu et al., 2003; Luu et al., 2004), language comprehension (Bastiaansen et al., 2002; Hald et al., 2006) and working memory tasks (Gevins et al.,1997; Krause et al., 2000; Jensen & Tesche, 2002; Onton et al., 2005).

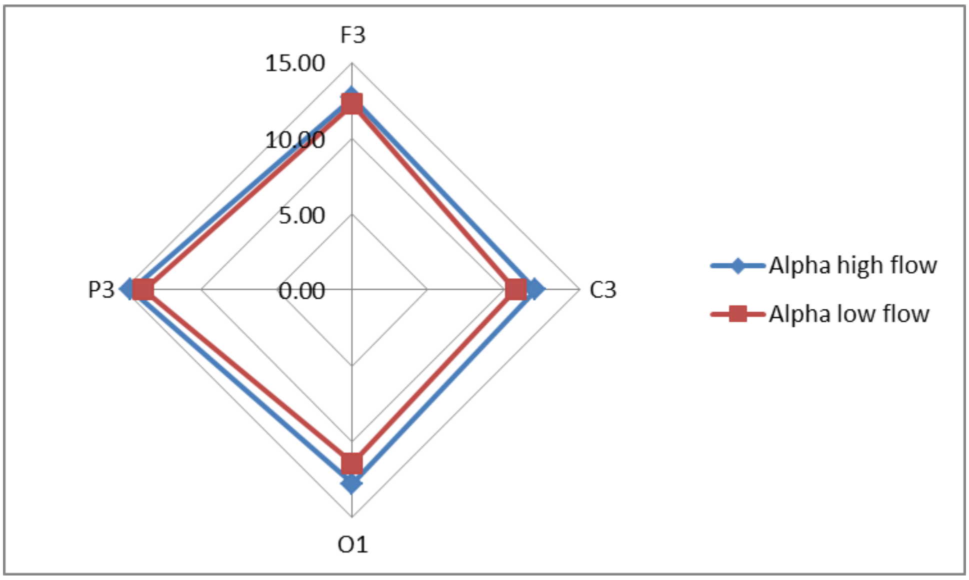


Figure 50. Alpha power shift for high vs low flow groups

Figure 50 indicates that alpha power increased in all cortical areas in the high flow group, especially in the sensori-motor and occipital areas. However none was at a statistically significant level (F3 : p = 0.6018; C3 : p = 0.1025; P3 : p = 0.5550; O1 : p = 0.2326). However, alpha showed large effect sizes in C3 (Eta^2 = 0.24) and O1 (Eta^2 = 0.14). Alpha was dominant in the parietal area. Rowe et al. (2007) postulated that alpha demonstrates positive correlations with information processing speed. Alpha is also involved in anticipatory attention, which involves top-down interactions between higher-order and primary areas of the visual cortex. Alpha power increases have been linked to active inhibition of neuronal activity that could otherwise disturb the working memory (WM) process (Jokisch & Jensen, 2007; Klimesch et al., 2007). Babiloni et al. (2008) postulated that alpha rhythms might represent a major physiological mechanism at the basis of “neural efficiency” during the judgment of observed actions. Working memory, information processing speed, anticipatory attention, and neural efficiency are all essential to successful visuomotor performance.

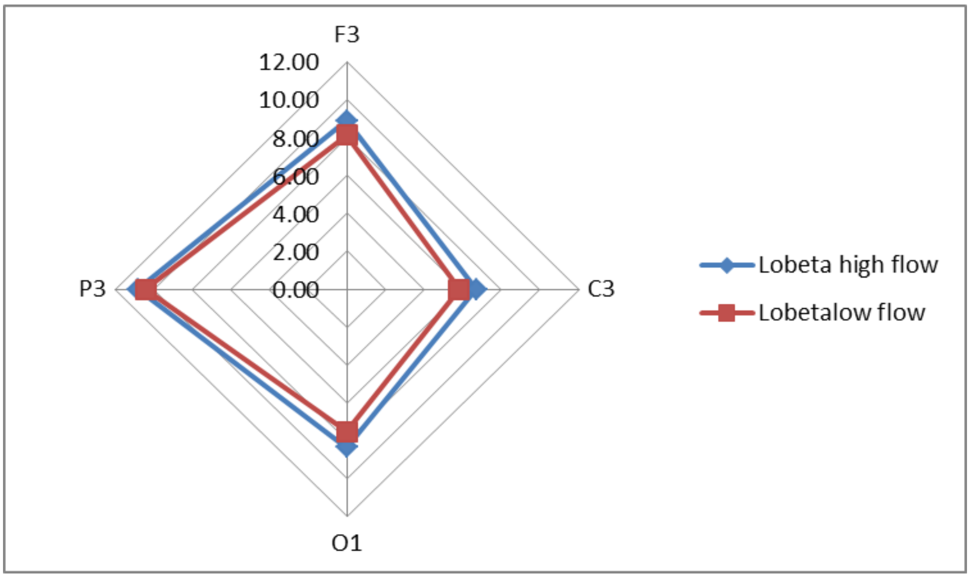


Figure 51. Lobeta power shift for high vs low flow groups

Figure 51 indicates that lobeta power increased in all cortical areas in the high flow group. The least increase was in the parietal area while the increase in the sensori-motor area was at a statistically significant level (C3 : p = 0.0432). The largest effect was also at C3 (Eta^2 = 0.33). However, a large effect was also observed at F3 (Eta^2 = 0.22) and a medium effect at O1 (Eta^2 = 0.12). SMR or lobeta predominates only in the sensori-motor cortex (sensori-motor strip). Lobeta increases with stillness and decreases with movement (Othmer, et al., 1999, p. 267). The significant shift in power in the sensori-motor area may be an indication that motor movement have smoothed out into fluent and synchronised motion as flow increased.

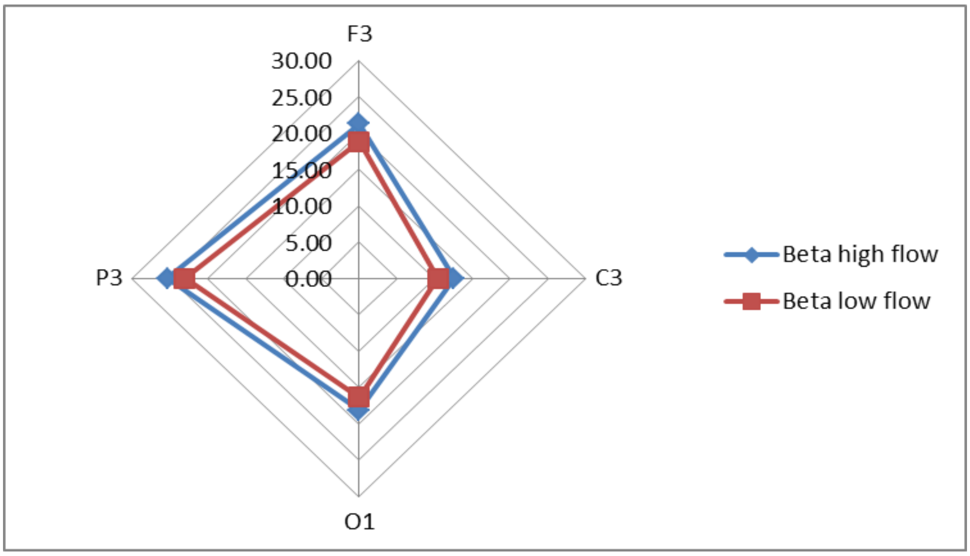


Figure 52. Beta power shift for high vs low flow groups

Figure 52 indicates that beta power increased substantially in all cortical areas in the high flow group. None was at a statistically significant level. However F3 (p = 0.0637) and P3 (p = 0.0608) were not only close to the significant range, it also demonstrated large effect sizes (F3 : Eta^2 = 0.29; P3 : Eta^2 = 0.29). A large effect size was also indicated at C3 (Eta^2 = 0.22), while the effect was only medium size at O1 (Eta^2 = 0.08). Beta has been associated with being focused, analytic, externally oriented, or in a state of relaxed thinking (Demos, 2005). Maximal beta amplitude is usually in the fronto-central regions, but it may be widespread. Increased beta activity has been related to the alertness level (Eoh, et al., 2005). Flow is characterised by being focused, externally oriented, and in a state of relaxed thinking.

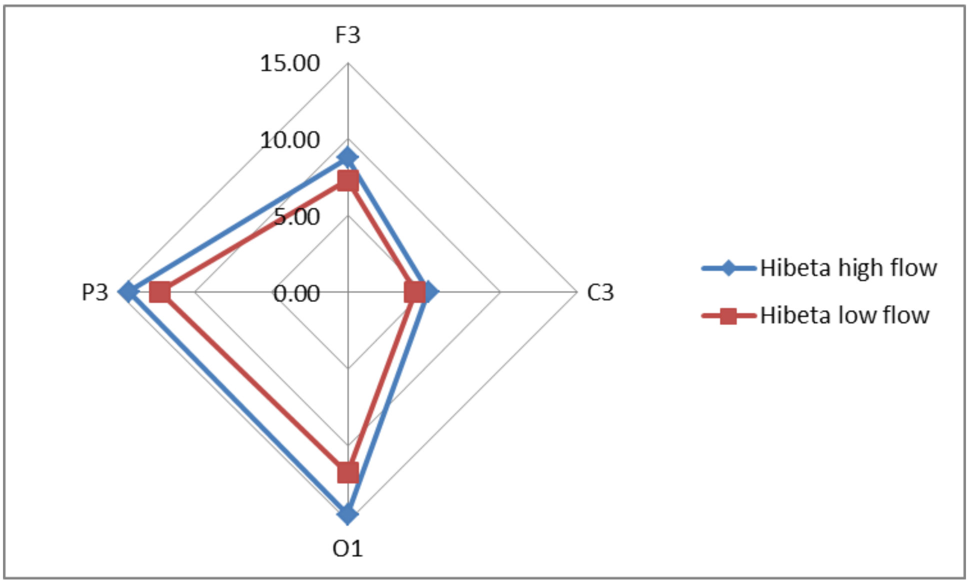


Figure 53. Hibeta power shift for high vs low flow groups

Figure 53 indicates that hibeta power increased substantially in all cortical areas in the high flow group, with the least being in the sensori-motor area. However none was at a statistically significant level (F3 : p = 0.3819; C3 : p = 0.6627; P3 : p = 0.4793; O1 : p = 0.4125). Medium effect sizes were demonstrated at F3 (Eta^2 = 0.08) and O1 (Eta^2 = 0.07). High beta is associated with peak performance, cognitive processing, worry, anxiety, over-thinking, and ruminating (Demos, 2005). The increase in hibeta power may be an indication of improved cognitive processing in lieu of peak performance.

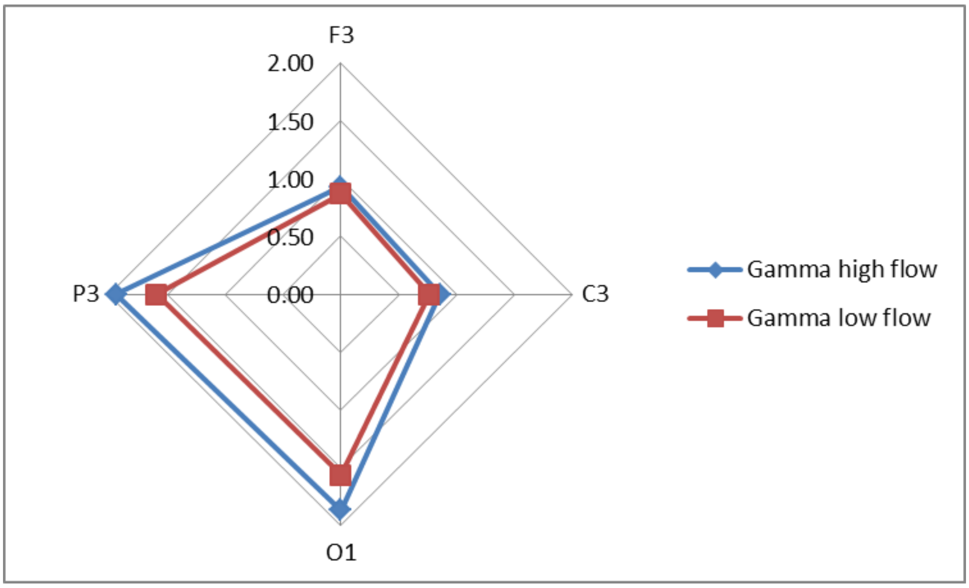


Figure 54. Gamma power shift for high vs low flow groups

Figure 54 indicates that gamma power increased in all cortical areas in the high flow group, especially in the parietal- and occipital areas. However none was at a statistically significant level (P3 : p = 0.7135; O1 : p = 0.7275). Effect sizes were also small at all locations. This indicates that gamma plays an equal role in both flow conditions. Gamma is prominent especially during high alertness and after sensory stimulation, likely contributing to the ‘‘binding” of diverse information into a single coherent percept. Gamma, high beta and beta waves seem to be associated with selective attention, transient binding of cognitive features, and conscious perception of visual objects (Hughes, 2008). Increased gamma power has also been linked to working memory maintenance (Jokisch & Jensen, 2007; Kaiser et al., 2003; Lutzenberger et al., 2002; Tallon-Baudry et al., 1998). Selective attention, transient binding of cognitive features, conscious perception of visual objects and working memory maintenance are important aspects in performance improvement while performing a visuomotor task such as video gaming.

6.5.7 EEG synchrony data

The proposed neurophysiological model for flow assumes that flow is marked by mental economy (Di Russo, et al., 2005), as it is in peak performance. This is achieved by the pruning of excessive cortico-cortical communication between analytical associative processes or attentional networks and motor regions resulting in enhancement and consistency of psychomotor performance (Hatfield & Hillman, 2001). This argument logically implies that, in its quest for optimal performance, the brain will continue to prune or shape (condition) its neural structure for improved performance with every repetition of the same task. This implies that flow will be underpinned by an optimal neural network.

With reference to state space dynamics, Werner (2008) argues that at a critical point of state transition, the system undergoes a significant reconfiguration which, among other features, is expressed as change of the correlation function between system elements. The correlation function characterises how the value at one point in state space is correlated with the value at another point, reflecting the micro level's fine structure.

Adopting a state space approach in this analysis, the expectation was that high correlations (synchrony) between sites may be viewed as signs of neural bindings or interlocking, in other words, there is a similar amount of energy flowing in a similar pattern within the two correlated areas, indicating that they operate in synchrony and, therefore relate to the same task or function. These bindings form operative neural networks through which essential areas of the brain perform their functions, in turn, providing the investigator with the opportunity to "view" the various pathways and to relate the observations to existing observations, theories and knowledge.

In this study, the critical question was whether the neural system under investigation (i.e. the PFC-SMC-PPC-O1 network) underwent a significant reconfiguration when flow was assumed. Even more critical was whether there was evidence of a neurological pattern suggesting a shift between the "implicit and explicit" systems, or a shift from the frontal networks to the posterior networks during peak performance. If so, this neurological pattern was then considered the EEG correlate of flow, which can be used as an objective measure of flow.

In the following section the neural network will be investigated using site and frequency inter-correlations that indicate the level of binding between the various brain areas, by presenting the EEG data graphically and topographically. The coefficient of correlation can vary from positive one (indicating a perfect positive relationship), to negative one (indicating a perfect negative relationship). Nought (0) signifies no correlation. Correlations were considered significant at probabilities equal or less than 0.05. Correlations were also interpreted in terms of the following power categories : between 0.00 and 0.30 were considered weak, between 0.30 and 0.70 were moderate and between 0.70 and 1.00 were high. Correlations of 0.30 to 1.0 or -0.30 to -1.0 were used as sufficient strength for bindings to be considered synchronous. This was the interpretation adopted in this analysis.

6.5.7.1 Total sample inter-correlations between sites and frequencies

Table 33

Total sample inter-correlations between sites and frequencies

Total Sample Correlations N = 200 races	**F3 - C3**	**C3 - P3**	**F3 - P3**	**C3 - 01**	**P3 - 01**	**F3 - 01**
Delta	0.93***	0.72***	0.70***	0.64***	0.85***	0.57***
Theta	0.90***	0.78***	0.82***	0.66***	0.82***	0.67***
Alpha	0.79***	0.59***	0.80***	0.63***	0.76***	0.70***
Lobeta	0.77***	0.47***	0.61***	0.58***	0.70***	0.72***
Beta	0.77***	-0.03	0.22	0.19	0.44***	0.33***
Hibeta	0.83***	0.77***	0.58***	0.52***	0.85***	0.44***
Gamma	0.92***	0.97***	0.92***	0.92***	0.96***	0.97***

Note. ***$p \leq 0.001$; **$p \leq 0.01$; *$p \leq 0.05$

The total sample inter-correlations, by location, showed highly consistent results over all 200 races, with the notable exception of beta between the sensori-motor and parietal, sensori-motor and occipital, and pre-frontal and parietal areas where very low correlations that were not significant were evident. All other correlations were highly significant at the

99% level. This indicates that beta, which is associated with motor control and attention shifting, and characterised by synchronisation – de-synchronisation and phase switching (Pfurtscheller & Andrew, 1999; Ivanitsky et al., 2001; Fingelkurts et al., 2005; Schnitzler & Gross, 2005), plays a pivotal role in visuomotor performance.

In terms of the strength of the bindings between the various sites and EEG frequencies, gamma was highly correlated across all sites for the total sample.

6.5.7.2 High and low flow differences in synchrony between sites and frequencies

From Table 34 it is evident that the patterns of inter-correlations between the high and low flow groups differed in only three instances. In lobeta, for the low flow group only, the C3 – P3 and C3 – O1 connections were de-synchronised and in beta the P3 – O1 connection was still synchronised compared to the high flow group. These differences will be further discussed later.

Table 34

Summary of inter- correlations for high and low flow

Freq.	**Group** (n= 20)	**F3 vs C3**	**C3 vs P3**	**F3 vs P3**	**C3 vs 01**	**P3 vs 01**	**F3 vs 01**
Delta	Group 1	0.92***	0.73***	0.70***	0.65**	0.87***	0.61**
	Group 2	0.95***	0.76***	0.71***	0.67***	0.82***	0.55**
Theta	Group 1	0.90***	0.75***	0.80***	0.57**	0.82***	0.66**
	Group 2	0.87***	0.78***	0.84***	0.60**	0.81***	0.61**
Alpha	Group 1	0.78***	0.56**	0.74***	0.65**	0.77***	0.79***
	Group 2	0.78***	0.58**	0.80***	0.58**	0.71***	0.56**
Lobeta	Group 1	0.80***	0.54**	0.52**	0.75***	0.70***	0.78***
	Group 2	0.65**	0.18	0.42**	0.27	0.52**	0.43
Beta	Group 1	0.84***	-0.09	0.16	0.17	0.40	0.29
	Group 2	0.73***	0.003	0.10	0.27	0.41	0.18
Hibeta	Group 1	0.85***	0.77***	0.60**	0.53*	0.86***	0.46*
	Group 2	0.85***	0.79***	0.62**	0.56**	0.84***	0.47*
Gamma	Group 1	0.92***	0.99***	0.92***	0.92***	0.94***	0.98***
	Group 2	0.94***	0.97***	0.93***	0.92***	0.97***	0.96***

Note. ***$p \leq 0.001$; **$p \leq 0.01$; *$p \leq 0.05$

6.5.7.3 Delta synchrony in high and low flow

Table 35

Delta synchrony across sites in high and low flow

Freq.	**Group**	**F3 vs C3**	**C3 vs P3**	**F3 vs P3**	**C3 vs 01**	**P3 vs 01**	**F3 vs 01**
Delta	Group 1 n= 20	0.92***	0.73***	0.70***	0.65**	0.87***	0.61**
	Group 2 n= 20	0.95***	0.76***	0.71***	0.67***	0.82***	0.55**

Note. ***p ≤ 0.001; **p ≤ 0.01; *p ≤ 0.05

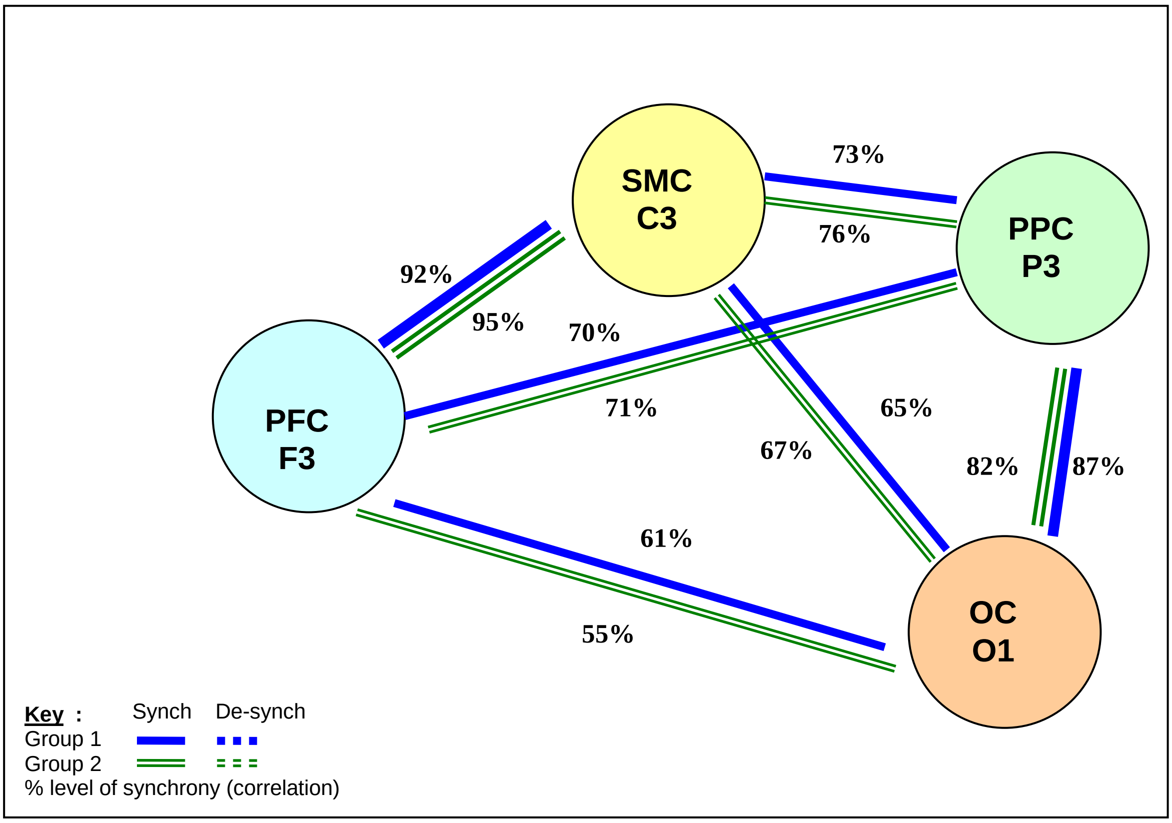


Figure 55. All significant and weakened inter-site neural bindings for Groups 1 and 2 in delta frequency

Delta synchrony was marked by the following characteristics:

(1) There were no significant differences in delta EEG synchrony between the brain sites tested, in both high and low flow conditions.

(2) Consistency within high- and low flow groups was so strong that correlations are significant at the 99% level in all connections.

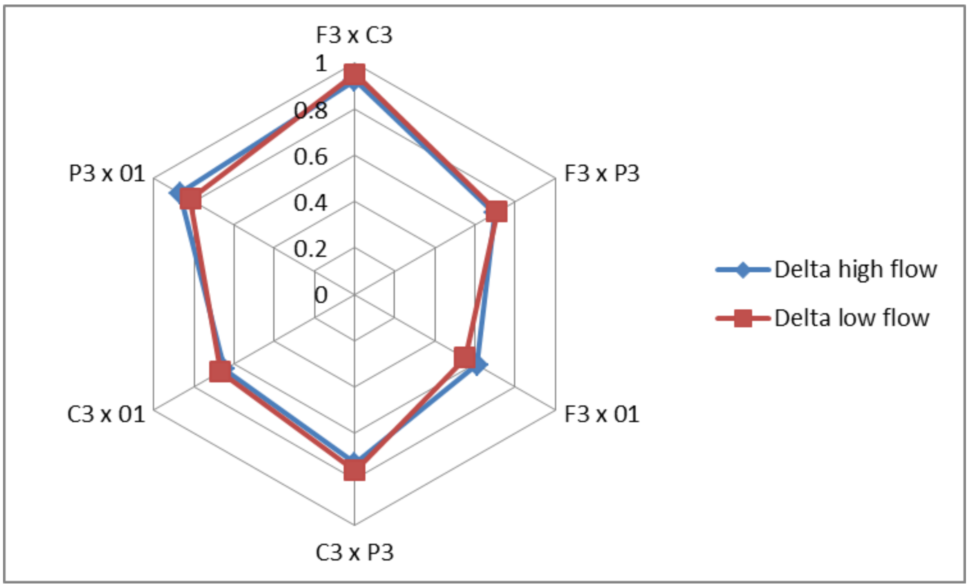


Figure 56. Delta synchrony high vs low flow groups

There were, however, differences in the levels of synchrony between sites.

(1) The prefrontal-sensori-motor connection (F3-C3) had the strongest delta synchrony in both conditions, with r = 0.92 in the high- and r = 0.95 in the low flow groups respectively.

(2) The parietal-occipital connection (P3-O1) was also highly correlated in both conditions (r = 0.87 in high flow and 0.82 in low flow).

(3) The largest differences between the two conditions occurred in the parietal-occipital (P3-O1) and the prefrontal-occipital (F3-O1) connections with the high flow condition showing the stronger bind.

(4) Increased delta synchronisation in the frontal- and occipital areas has been found to be related to inhibition of non-relevant stimuli during go/no-go tasks (Harmony et al., 2009).

6.5.7.4 Theta synchrony in high and low flow

Table 36

Theta synchrony across sites in high and low flow

Freq.	**Group**	**F3 vs C3**	**C3 vs P3**	**F3 vs P3**	**C3 vs 01**	**P3 vs 01**	**F3 vs 01**
Theta	Group 1 n= 20	0.90***	0.75***	0.80***	0.57**	0.82***	0.66**
	Group 2 n= 20	0.87***	0.78***	0.84***	0.60**	0.81***	0.61**

Note. ***p ≤ 0.001; **p ≤ 0.01; *p ≤ 0.05

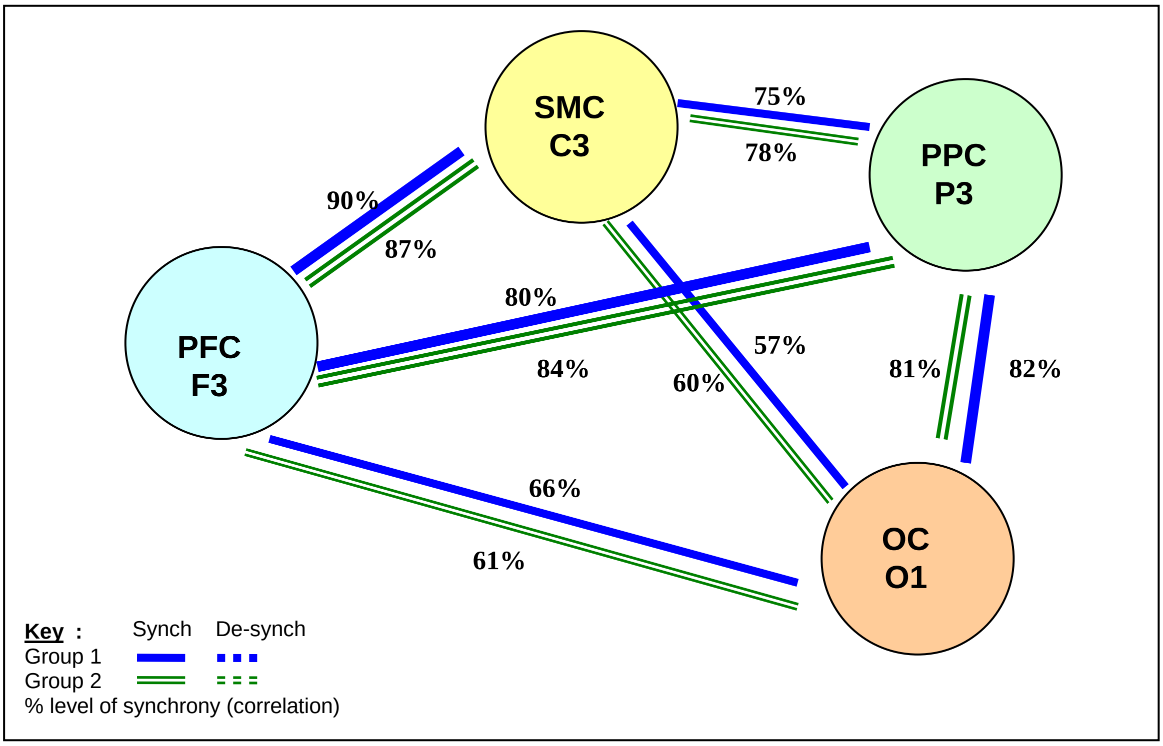


Figure 57. All significant and weakened inter-site neural bindings for Groups 1 and 2 in theta frequency

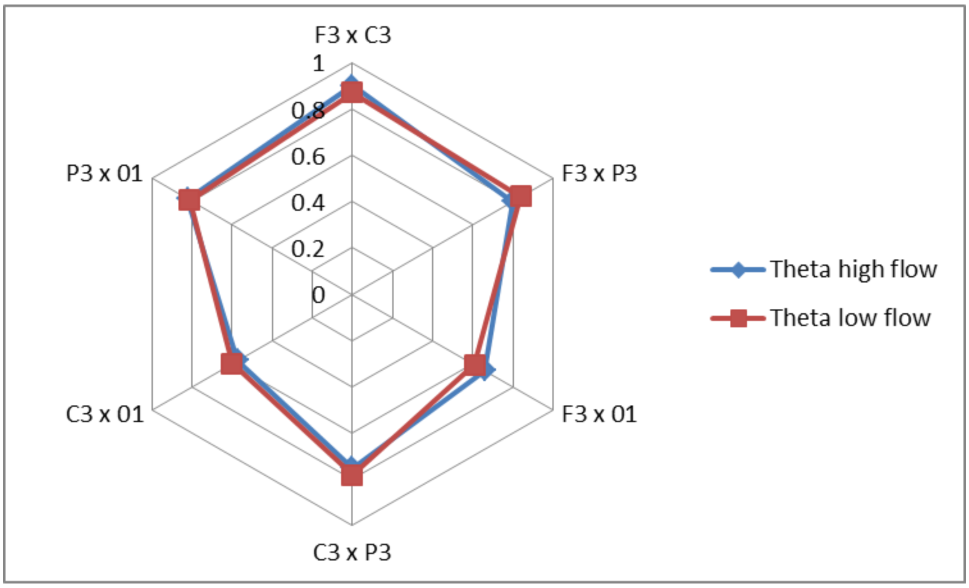


Figure 58. Theta synchrony high vs low flow groups

Theta synchrony was marked by:

(1) Consistency within high- and low flow groups was very strong across all sites and in all conditions. Correlations were significant at the 99% level in all connections.

(2) The strongest theta synchrony seemed to occur in the F3-C3, F3-P3 and P3-O1 connections for both conditions.

(3) The largest difference between the two conditions occured in the prefrontal-occipital (F3-O1) connection with the high flow condition showing the stronger bind.

(4) Horan (2009) postulated that theta is correlated with scanning for visceral pleasure, enhanced artistic creativity, responses to novel situations and various forms of training.

6.5.7.5 Alpha synchrony in high and low flow

Table 37

Alpha synchrony across sites in high and low flow

Freq.	**Group**	**F3 vs C3**	**C3 vs P3**	**F3 vs P3**	**C3 vs 01**	**P3 vs 01**	**F3 vs 01**
Alpha	Group 1 n= 20	0.78***	0.56**	0.74***	0.65**	0.77***	0.79***
	Group 2 n= 20	0.78***	0.58**	0.80***	0.58**	0.71***	0.56**

Note. ***p ≤ 0.001; **p ≤ 0.01; *p ≤ 0.05

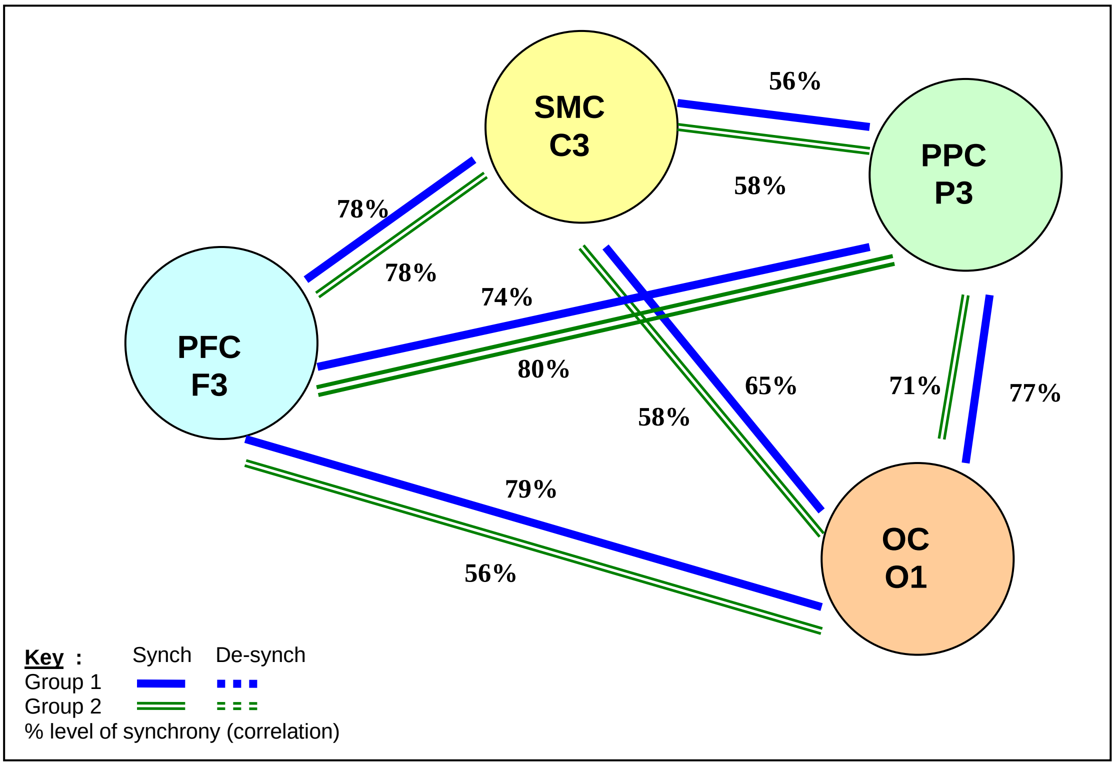


Figure 59. All significant and weakened inter-site neural bindings for Groups 1 and 2 in alpha frequency

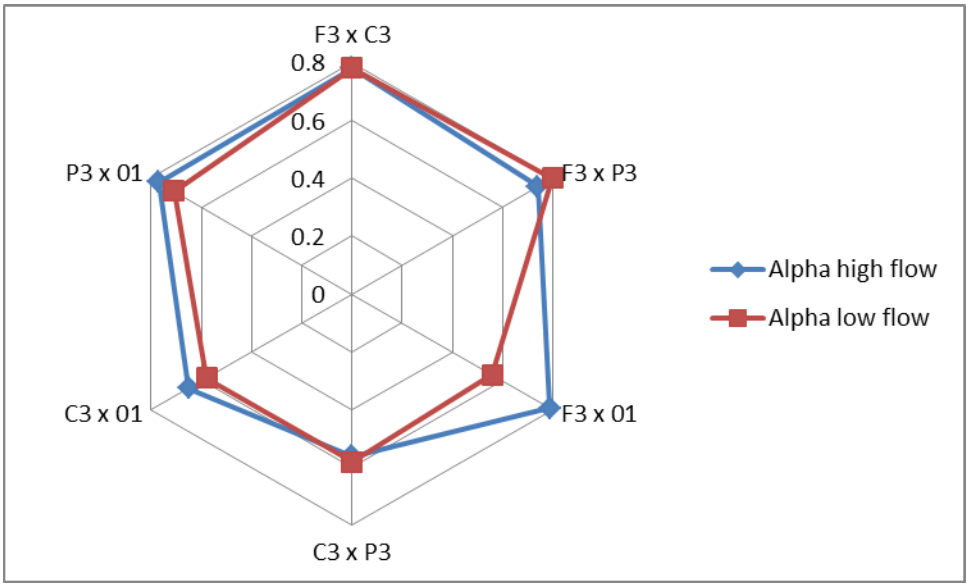


Figure 60. Alpha synchrony across sites in high and low flow

Alpha synchrony was marked by:

(1) Alpha waves were moderately to strongly synchronised for both conditions across all sites.

(2) High consistency of the synchrony scores was evidenced across all frequencies and sites with a 99% level of significance.

(3) The strongest alpha synchrony seemed to occur in the F3-P3 connection for the low flow condition followed by the F3-C3 connection for both conditions.

(4) The largest difference between the two conditions occured in the prefrontal-occipital (F3-O1) connection with the high flow condition showing the stronger bind.

(5) Globally, alpha activity reflects a relaxed wakefulness state, and decreases with concentration, stimulation or visual fixation (Stern & Engel, 2005). Rowe et al. (2007) postulated that the alpha rhythm is a measure of the strength and delay of signal transfer in cortico-thalamocortical loops. Increased alpha activity (synchronisation) may increase the efficiency and accuracy of thalamocortical transfer. Consistent with this, alpha demonstrates positive correlations with information processing speed.

(6) Alpha is also involved in anticipatory attention, which involves top-down interactions between higher-order and primary areas of the visual cortex. These, in turn, have been linked to synchronisation in the alpha frequency band (von Stein & Sarnthein, 2000).

6.5.7.6 Lobeta synchrony in high and low flow

Table 38

Lobeta synchrony across sites in high and low flow

Freq.	**Group**	**F3 vs C3**	**C3 vs P3**	**F3 vs P3**	**C3 vs 01**	**P3 vs 01**	**F3 vs 01**
Lobeta	Group 1 n= 20	0.80***	0.54**	0.52**	0.75***	0.70***	0.78***
	Group 2 n= 20	0.65**	0.18	0.42**	0.27	0.52**	0.43

Note. ***p ≤ 0.001; **p ≤ 0.01; *p ≤ 0.05

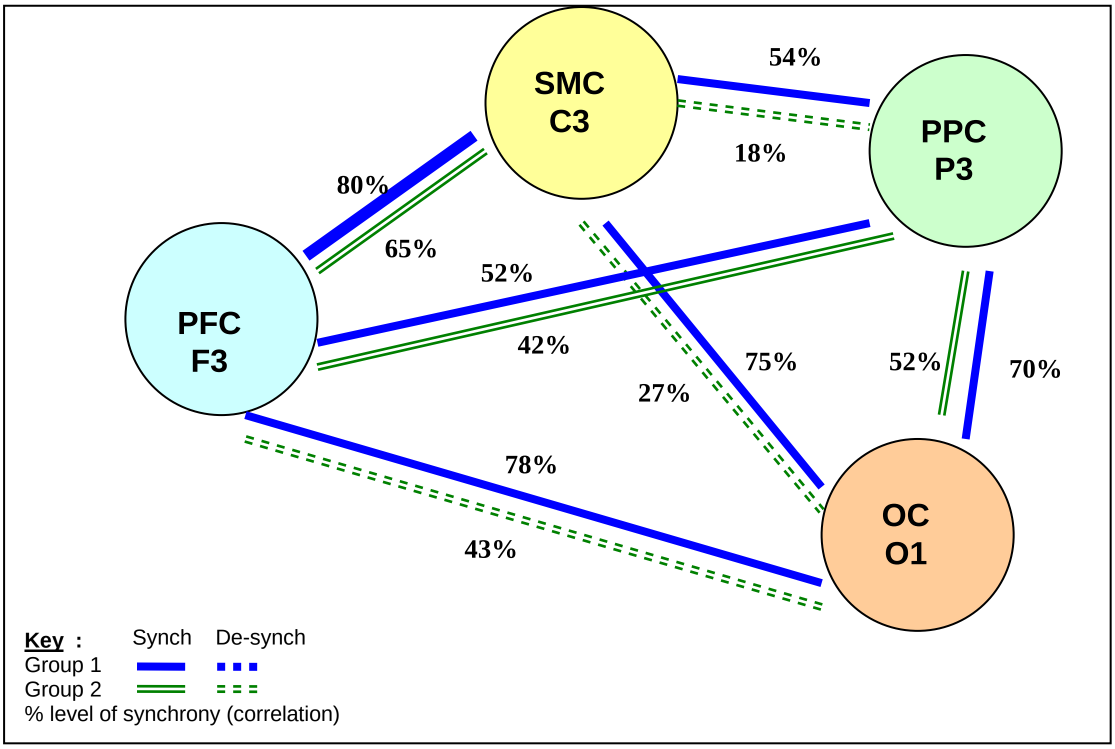


Figure 61. All significant and weakened inter-site neural bindings for Groups 1 and 2 in lobeta frequency

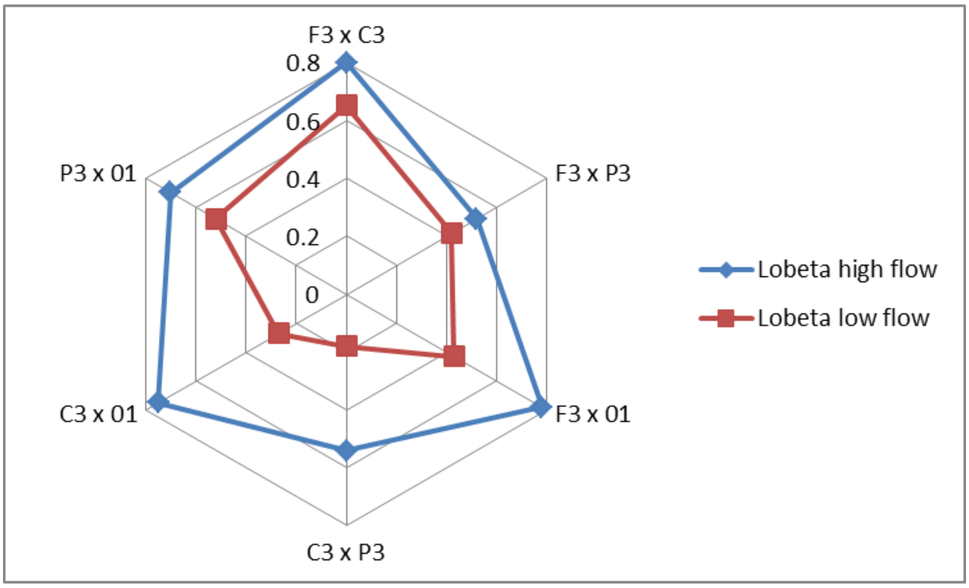


Figure 62. Lobeta synchrony across sites in high and low flow

Lobeta synchrony was marked by:

(1) Moderate to high synchrony levels for the high flow condition at all brain sites.

(2) There was no synchrony (de-synchronised) between C3-P3, F3-O1 and C3-O1 for the low flow condition. For C3 in this condition there was only synchronisation with F3.

(3) There was very strong lobeta synchrony between F3-O1, F3-C3, C3-O1 and P3-O1 for the high flow condition.

(4) The F3-C3 synchrony was the strongest, while O1 had strong bindings with all the other sites

(5) Lobeta predominated only in the sensori-motor cortex (sensori-motor strip). Lobeta amplitude increases with stillness and decreases with movement (Othmer, et al., 1999, p. 267).

(6) Since lobeta is associated with motor functioning, it is suggested that lobeta synchrony is probably associated with enhanced quality (smoothness) in terms of motor functioning. Synchronised lobeta connections between all cortical areas, such as displayed in the high flow condition, was probably an indication of balanced (harmonious) flow of neural information through-out the network ensuring smooth and accurate motor execution. De-synchronisation between C3-P3, C3-O1 and F3-O1 for the low flow condition may have indicated that the sensori-motor cortex was still highly dependent on the pre-frontal cortex for motor input due to un-established skills and a high error rate.

6.5.7.7 Beta synchrony in high and low flow

Table 39

Beta synchrony in high and low flow

Freq.	**Group**	**F3 vs C3**	**C3 vs P3**	**F3 vs P3**	**C3 vs 01**	**P3 vs 01**	**F3 vs 01**
Beta	Group 1 n= 20	0.84***	-0.09	0.16	0.17	0.40	0.29
	Group 2 n= 20	0.73***	0.03	0.10	0.27	0.41	0.18

Note. ***p ≤ 0.001; **p ≤ 0.01; *p ≤ 0.05

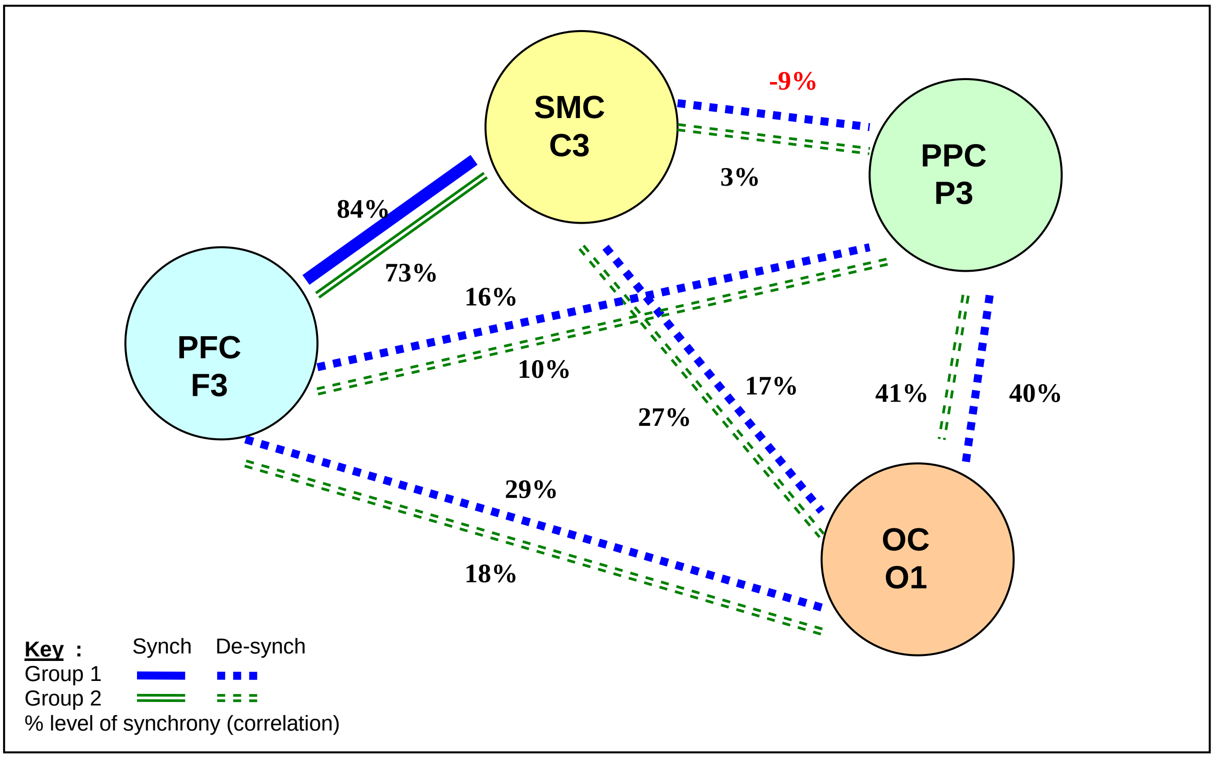


Figure 63. All significant and weakened inter-site neural bindings for Groups 1 and 2 in beta frequency

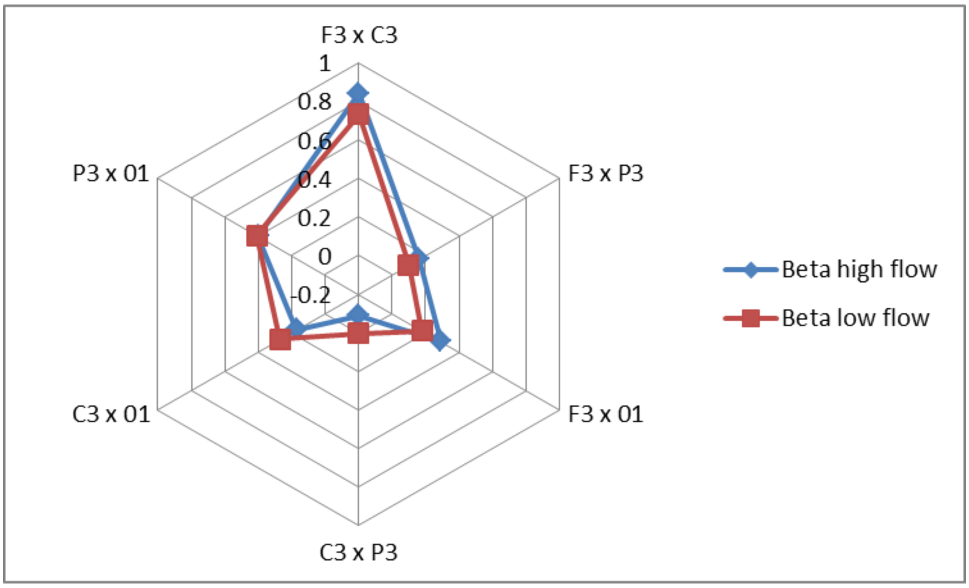


Figure 64. Beta synchrony across sites in high and low flow

Beta synchrony was marked by:

(1) Predominance in the prefrontal-sensori-motor (F3-C3) connection where it was highly consistently represented in both conditions.

(2) Apart from the F3-C3 connection, only weak non-significant correlations were found among all other sites in both conditions, showing evidence of de-synchronisation.

(3) Only one connection, the sensori-motor-parietal connection (C3-P3), displayed a weak negative correlation (de-synchronised), indicating phase switching.

(4) Research by Gross, et al. (2004) indicated that synchronisation/de-synchronisation appears to be a candidate mechanism for enhancing target processing while at the same time avoiding interference by suppressing the processing of non-targets, respectively. Such a mechanism may define an important aspect of what is commonly referred to as ‘‘attention’’ or “selective attention”.

(5) Pfurtscheller et al. (2003) suggested that beta synchronisation/de-synchronisation plays an important role in motor control. Research indicated that beta-rhythm oscillations de-synchronise during automotoric movement and again become synchronised over a larger scale when attention to sensori-motor integration is required (Pfurtscheller & Andrew, 1999; Ivanitsky et al., 2001; Fingelkurts et al., 2005; Schnitzler & Gross, 2005).

(6) Van Wijk, et al. (2009) reported that the role of beta synchrony in biasing response competition appears not only related to a biasing role of alpha activity in the selection of visual information, but also to the concept of ‘‘focal de-synchronisation/surround synchronisation’’. Beta oscillatory synchrony operates as a spatiotemporal filter to sharpen action-selection by cortico-basal ganglia networks (Courtemanche et al., 2003).

6.5.7.8 Hibeta synchrony in high and low flow

Table 40

Hibeta synchrony across sites in high and low flow

Freq.	**Group**	**F3 vs C3**	**C3 vs P3**	**F3 vs P3**	**C3 vs 01**	**P3 vs 01**	**F3 vs 01**
Hibeta	Group 1 n= 20	0.85***	0.77***	0.60**	0.53*	0.86***	0.46*
	Group 2 n= 20	0.85***	0.79***	0.62**	0.56**	0.84***	0.47*

Note. ***p ≤ 0.001; **p ≤ 0.01; *p ≤ 0.05

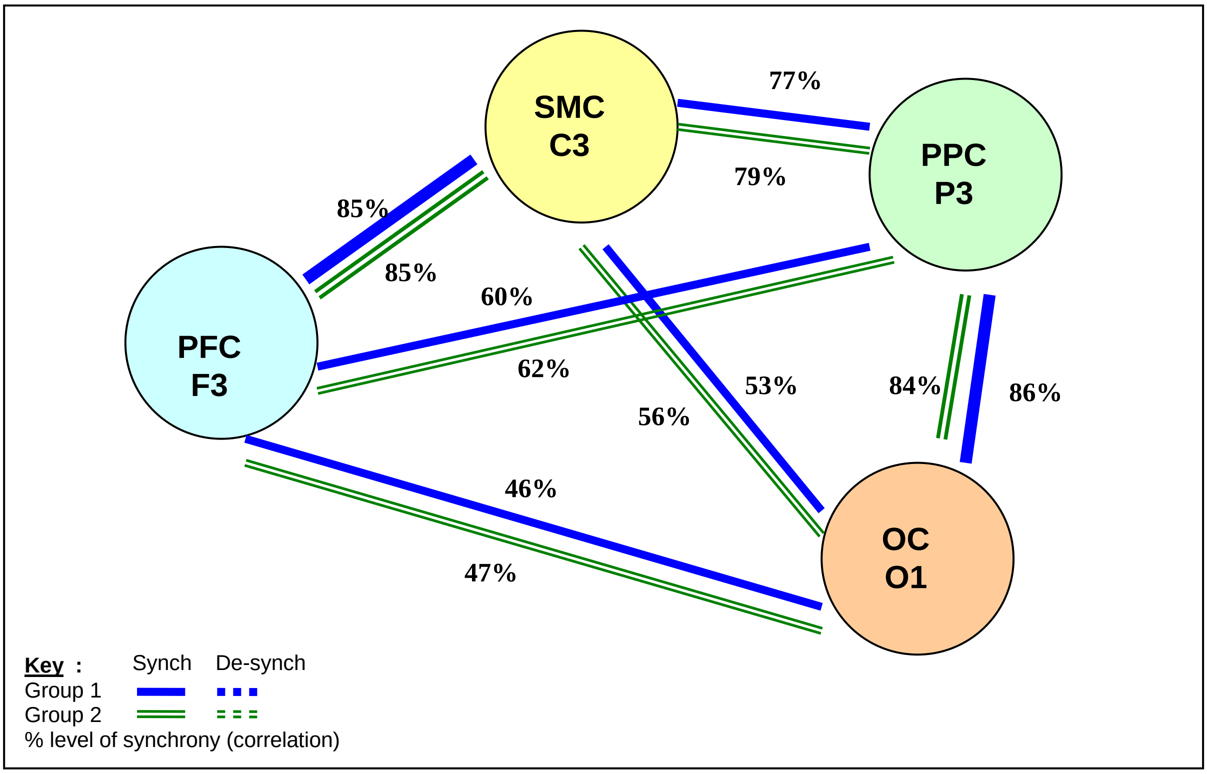


Figure 65. All significant and weakened inter-site neural bindings for Groups 1 and 2 in hibeta frequency

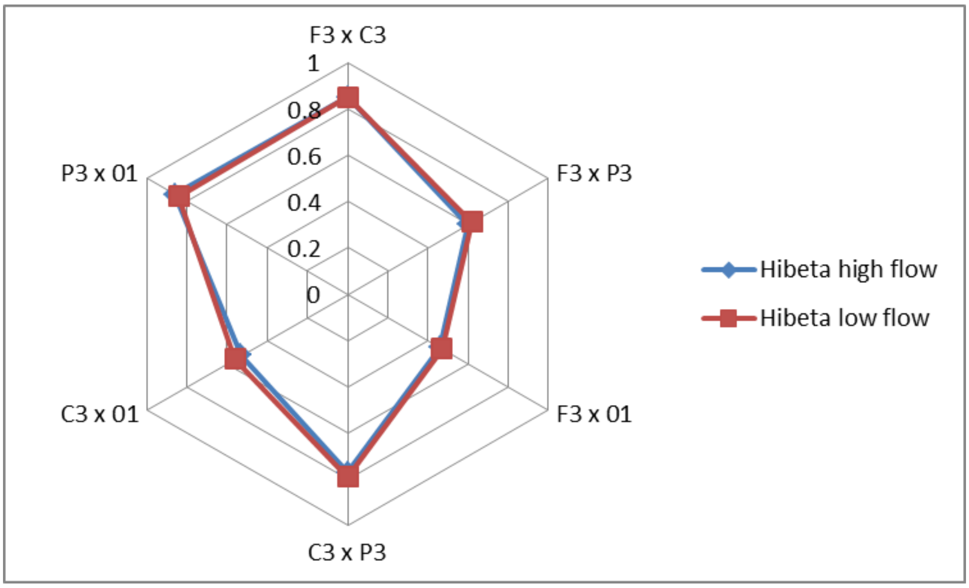


Figure 66. Hibeta synchrony across sites in high and low flow

Hibeta synchrony was marked by:

(1) Synchronous connections between all sites for both conditions.
(2) Strong synchrony in the F3-C3, C3-P3 and P3-O1 connections for both conditions.
(3) A similar synchrony pattern for both conditions.
(4) Consistency within high- and low flow groups that was strong across all sites and in all conditions.
(5) High beta is associated with peak performance, cognitive processing, worry, anxiety, over-thinking, and ruminating (Demos, 2005).

6.5.7.9 Gamma synchrony in high and low flow

Table 41

Gamma synchrony across sites in high and low flow

Freq.	**Group**	**F3 vs C3**	**C3 vs P3**	**F3 vs P3**	**C3 vs 01**	**P3 vs 01**	**F3 vs 01**
Gamma	Group 1 n= 20	0.92***	0.99***	0.92***	0.92***	0.94***	0.98***
	Group 2 n= 20	0.94***	0.97***	0.93***	0.92***	0.97***	0.96***

Note. ***p ≤ 0.001; **p ≤ 0.01; *p ≤ 0.05

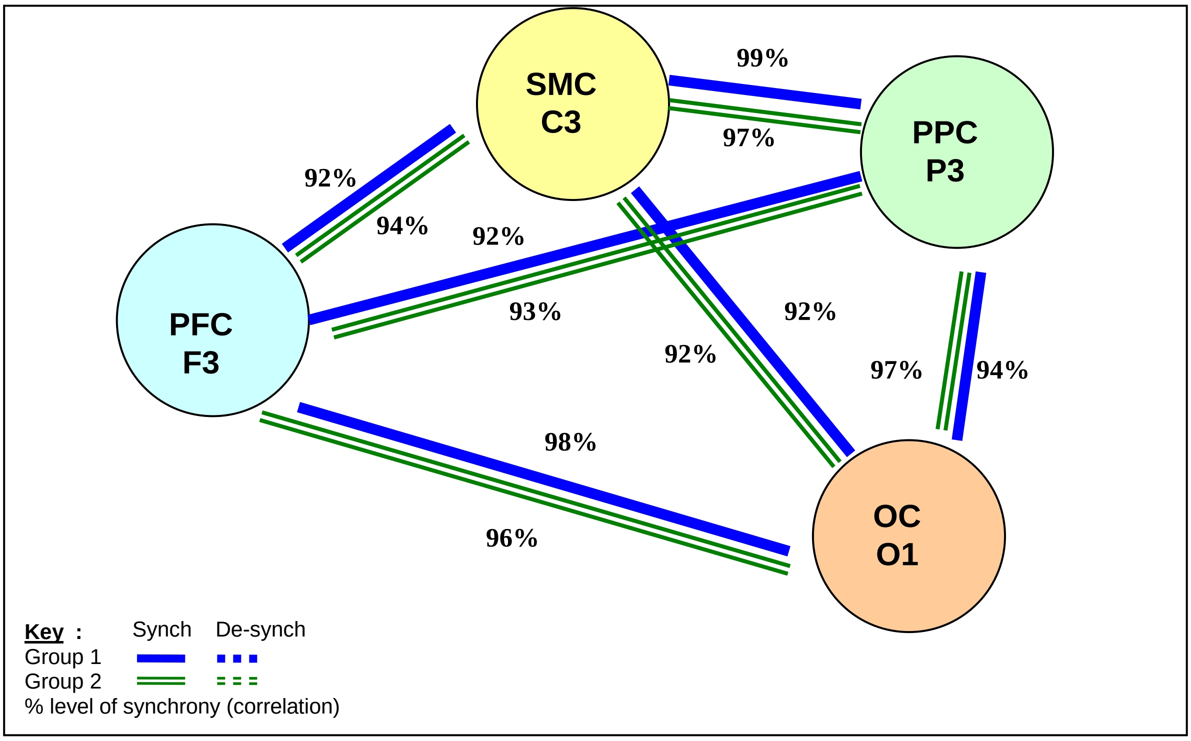


Figure 67. All significant and weakened inter-site neural bindings for Groups 1 and 2 in gamma frequency

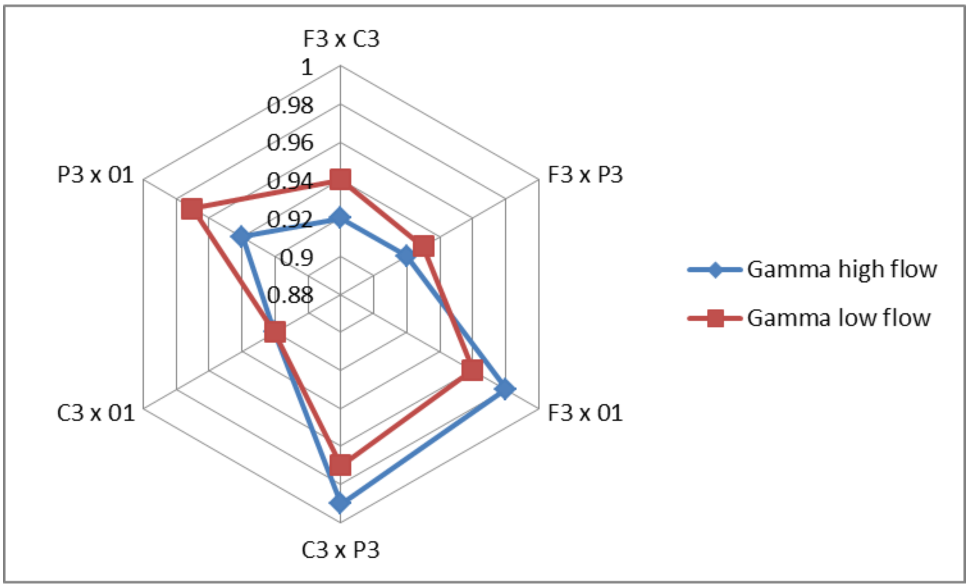


Figure 68. Gamma synchrony across sites in high and low flow

Gamma synchrony was marked by:

(1) Highly synchronous connections between all sites for both conditions.

(2) Consistency within high and low flow groups that was very strong across all sites and in all conditions. Correlations were significant at the 99.9% level in all connections.
(3) Gamma seems to help organise the brain, promote learning and allow for mental sharpness. It is activated when the brain needs to be active and idle when no specialised task is at hand (Hammond, 2000).
(4) Gamma is prominent especially during high alertness and after sensory stimulation, likely contributing to the ‘‘binding” of diverse information into a single coherent percept. Gamma, high beta and beta waves seem to be associated with selective attention, transient binding of cognitive features, and conscious perception of visual objects (Hughes, 2008).

6.6 ASSESSMENT OF THE HYPOTHESES

The first hypothesis dealt with the relationship between peak performance and flow. This relationship was key to investigating the EEG data accompanying flow.

Peak performance on a task is a necessary pre-condition for flow to occur. In this study it was expected that the faster the time taken to complete the task the higher the likelihood of the performer to have indicated the experience of flow.

<u>Hypothesis 1</u>

$H1_0$: There is no relationship between peak performance and psychological flow.
($p \leq 0.05$).
$H1_A$: There is a relationship between peak performance and psychological flow.
($p \leq 0.05$).

Perceived flow and peak performance were significantly correlated in the case of Group 1 ($r = -0.58$; $p = 0.01$). The negative sign follows from an inverse relationship (shorter time = higher performance). Therefore the null hypothesis is rejected with $p = 0.01$.

Further analyses of the relationship between performance and flow indicated that the low flow group (Group 2) had a lower overall negative correlation ($r = -0.47$; $p = 0.04$), still significant at the 95% level, indicating that as performance time increases so also flow increases and vice versa, but it is more variable than when flow is higher.

A correlation of -0.82 (p = 0.00) between Group 1 and Group 2 showed that the less time taken to complete the race, the higher the flow. This is a strong correlation, in the predicted direction, and it is highly significant at the 0.001 level.

A Mulitvariate Analysis of Variance (MANOVA) indicated that the performance and flow levels of the two groups differed significantly with an F-ratio of 150.06 (p = 0.00) for performance and F-ratio of 71.99 (p = 0.00) for flow. The critical value for F was 4.098.

From the above analyses it is evident that there was a positive relationship between performance and flow and that the relationship strengthened and became more consistent with increasing performance.

The following hypotheses dealt with the neurophysiological (EEG) correlates of flow.

The theoretical model postulated that when flow occurs under conditions of peak performance, the following relationships and inter-relationships in EEG were likely to manifest in the areas of the brain indicated:

Table 42

Expected changes in EEG at high flow and peak performance

Brain Site (s)	**Expected brain activity.**
Pre-frontal cortex (F3)	Decreased beta and gamma and increased theta power
Parietal cortex (P3)	Increased theta and alpha power.
Sensori-motor (C3)	Increased alpha.
Between the sensori-motor (C3) and parietal (P3) areas	Increased alpha synchrony
Between the pre-frontal and sensori-motor cortex (F3-C3), the pre-frontal and parietal (F3-P3) and the sensori-motor and parietal (C3 –P3).	De-synchronisation in beta.

MANOVA was used to test for differences (hypotheses 2 to 7). In this study the sample size was 20 and the critical value for F was 4.098 at the 0.05 level of significance.

Formally stated the expectations were hypothesised as follows:

Hypothesis 2

Research question : Is there an increase in Theta power in the PFC (F3) when flow occurs?

$H2_0$: There is no difference in PFC (F3) EEG Theta power between high- and low flow.

$\mu 1 = \mu 2$ ($p \leq 0.05$)

$H2_A$: There is an increase in PFC (F3) EEG Theta power in high flow.

$\mu 1 > \mu 2$ ($p \leq 0.05$)

An F-ratio of 0.20 (p = 0.657) was calculated for F3 Theta, which is lower than the critical value of 4.098 (p = 0.05), thus the null hypothesis is accepted. A small effect size (Eta^2) of 0.02 was calculated which supports the non-rejection of the null hypothesis.

Hypothesis 3

Research question : Is there an increase in Theta power in the PPC (P3) when flow occurs?

$H3_0$: There is no difference in PPC (P3) EEG Theta power between high- and low flow.

$\mu 1 = \mu 2$ ($p \leq 0.05$)

$H3_A$: There is an increase in PPC (P3) EEG Theta power in high flow.

$\mu 1 > \mu 2$ ($p \leq 0.05$)

An F-ratio of 0.47 (p = 0.496) was calculated for P3 Theta, which is lower than the critical value of 4.098 (p = 0.05), thus the null hypothesis is accepted. A small effect size (Eta^2) of 0.05 was calculated which supports the non-rejection of the null hypothesis.

Hypotheses 4

Research question : Is there an increase in Alpha power in the PPC (P3) when flow occurs?

$H4_0$: There is no difference in PPC (P3) EEG Alpha power between high- and low flow.
$\mu1 = \mu2$ ($p \leq 0.05$)

$H4_A$: There is an increase in PPC (P3) EEG Alpha power in high flow.
$\mu1 > \mu2$ ($p \leq 0.05$)

An F-ratio of 0.35 (p = 0.555) was calculated for P3 Alpha, which is lower than the critical value of 4.098 (p = 0.05), thus the null hypothesis is accepted. A small effect size (Eta^2) of 0.04 was calculated which supports the non-rejection of the null hypothesis.

Hypotheses 5

Research question : Is there an increase in Alpha power in the SMC (C3) when flow occurs?

$H5_0$: There is no difference in SMC (C3) EEG Alpha power between high- and low flow.
$\mu1 = \mu2$ ($p \leq 0.05$)

$H5_A$: There is an increase in SMC (C3) EEG Alpha power in high flow.
$\mu1 > \mu2$ ($p \leq 0.05$)

An F-ratio of 2.8 (p = 0.103) was calculated for C3 Alpha, which is lower than the critical value of 4.098 (p = 0.05), thus the null hypothesis is accepted. However, a large effect size (Eta^2) of 0.24 was calculated which indicates a trend in high flow not present in low flow and that may become significant on re-testing.

Hypotheses 6

Research question : Is there a decrease in Beta power in the PFC (F3) when flow occurs?

$H6_0$: There is no difference in PFC (F3) EEG Beta power between high- and low flow.
$\mu1 = \mu2$ ($p \leq 0.05$)

$H6_A$: There is a decrease in PFC (F3) EEG Beta power in high flow.

$\mu 1 < \mu 2$ ($p \leq 0.05$)

An F-ratio of 3.65 ($p = 0.064$) was calculated for F3 Beta, which is lower than the critical value of 4.098 ($p = 0.05$), thus the null hypothesis is accepted. However, a large effect size (Eta^2) of 0.29 was calculated which indicates a trend in high flow not present in low flow and that may become significant on re-testing.

Hypotheses 7

Research question : Is there a decrease in Gamma power in the PFC (F3) when flow occurs?

$H7_0$: There is no difference in PFC (F3) EEG Gamma power between high- and low flow.

$\mu 1 = \mu 2$ ($p \leq 0.05$)

$H7_A$: There is a decrease in PFC (F3) EEG Gamma power in high flow.

$\mu 1 < \mu 2$ ($p \leq 0.05$)

An F-ratio of 0.02 ($p = 0.892$) was calculated for F3 Gamma, which is lower than the critical value of 4.098 ($p = 0.05$), thus the null hypothesis is accepted. A small effect size (Eta^2) of 0.00 was calculated which supports the non-rejection of the null hypothesis.

Linear correlations (Pearson Product Moment Correlations) were calculated to test relationships among variables. Correlations (r) were considered significant at probabilities less than 0.05, but were also interpreted in terms of the following power categories: 0.00 to 0.30, weak; 0.30 to 0.70, moderate; and 0.70 to 1.00, high or strong. Correlations of 0.30 to 1.0 or -0.30 to -1.0 were used as sufficient strength for bindings to be considered synchronous.

Hypothesis 8

Research question : Is there Alpha synchrony between C3 and P3 in high flow?

$H8_0$: There is no Alpha synchrony between C3 and P3 in high flow.

$r < 0.30$ ($p \leq 0.05$)

$H8_A$: There is Alpha synchrony between C3 and P3 in high flow.
$r \geq 0.30$ ($p \leq 0.05$)

For Group 1 a correlation of $r = 0.56$ ($p = 0.001$) was calculated between C3 and P3 Alpha, indicating a moderate relationship which is significant ($p \leq 0.05$). This implies that there was Alpha synchrony between C3 and P3 in high flow, thus the null hypothesis is rejected.

<u>Hypothesis 9</u>
Research question : Is there Beta de-synchronisation between C3 and P3 in high flow?

$H9_0$: There is no Beta synchrony between C3 and P3 in high flow.
$r < 0.30$ ($p \leq 0.05$)

$H9_A$: There is Beta synchrony between C3 and P3 in high flow.
$r \geq 0.30$ ($p \leq 0.05$)

For Group 1 a correlation of $r = -0.09$ ($p = 0.704$) was calculated between C3 and P3 Beta, indicating a very weak negative relationship ($r < 0.30$) which is not significant ($p > 0.05$). Although the result is not statistically significant the level of synchrony between C3 and P3 is so low that it is unlikely even in repeated testing to approach the level of synchronicity. Thus the null hypothesis is accepted. Beta thus desynchronised between the SMC and the PPC as expected.

<u>Hypothesis 10</u>
Research question : Is there Beta de-synchronisation between F3 and P3 in high flow?

$H10_0$: There is no Beta synchrony between F3 and P3 in high flow.
$r < 0.30$ ($p \leq 0.05$)

$H10_A$: There is Beta synchrony between F3 and P3 in high flow.
$r \geq 0.30$ ($p \leq 0.05$)

For Group 1 a correlation of $r = 0.16$ ($p = 0.498$) was calculated between F3 and P3 Beta, indicating a weak relationship ($r < 0.30$) which is not significant ($p > 0.05$). Although the result is not statistically significant the level of synchrony between F3 and P3 is so low that it is unlikely even in repeated testing to approach the level of synchronicity. Thus the null hypothesis is accepted. Beta thus desynchronised between the PFC and the PPC as expected.

Hypothesis 11

Research question : Is there Beta de-synchronisation between F3 and C3 in high flow?

$H11_0$: There is no Beta synchrony between F3 and C3 in high flow.
$r < 0.30$ ($p \leq 0.05$)

$H11_A$: There is Beta synchrony between F3 and C3 in high flow.
$r \geq 0.30$ ($p \leq 0.05$)

For Group 1 a correlation of $r = 0.84$ ($p = 0.000$) was calculated between F3 and C3 Beta, indicating a strong ($r > 0.70$) positive relationship which is highly significant ($p < 0.05$), thus the null hypothesis is rejected. Beta thus remained strongly synchronised between the PFC and the SMC.

Interestingly, when the Group 2 data are subjected to the same hypotheses testing regarding synchrony (indicating neural binding), the outcome is similar.

6.7 CONCLUSION

The above results indicate that the assumptions formulated from the literature regarding the neural activity expected during flow under peak performance conditions largely did not manifested as expected. This leads to a more complete discussion of the contrasting neural patterns between the peak and baseline conditions, and to identify those patterns that do indicate differences over the areas tested which may provide a possible marker for flow while executing a visuomotor task.

In summary, Table 43 (below) illustrates the main findings with regard to observed neural connections under conditions of peak performance for Group 1, the high-flow group and Group 2, the low-flow group.

Table 43

Matrix of EEG correlates for both Groups 1 and 2

Freq.	**Group** (n= 20)	**F3 vs C3**	**C3 vs P3**	**F3 vs P3**	**C3 vs 01**	**P3 vs 01**	**F3 vs 01**
Delta	Group 1	0.92***	0.73***	0.70***	0.65**	0.87***	0.61**
	Group 2	0.95***	0.76***	0.71***	0.67***	0.82***	0.55**
Theta	Group 1	0.90***	0.75***	0.80***	0.57**	0.82***	0.66**
	Group 2	0.87***	0.78***	0.84***	0.60**	0.81***	0.61**
Alpha	Group 1	0.78***	0.56**	0.74***	0.65**	0.77***	0.79***
	Group 2	0.78***	0.58**	0.80***	0.58**	0.71***	0.56**
Lobeta	Group 1	0.80***	0.54**	0.52**	0.75***	0.70***	0.78***
	Group 2	0.65**	0.18	0.42**	0.27	0.52**	0.43
Beta	Group 1	0.84***	-0.09	0.16	0.17	0.40	0.29
	Group 2	0.73***	0.003	0.10	0.27	0.41	0.18
Hibeta	Group 1	0.85***	0.77***	0.60**	0.53*	0.86***	0.46*
	Group 2	0.85***	0.79***	0.62**	0.56**	0.84***	0.47*
Gamma	Group 1	0.92***	0.99***	0.92***	0.92***	0.94***	0.98***
	Group 2	0.94***	0.97***	0.93***	0.92***	0.97***	0.96***

From Table 43 it is evident that the high flow group presents with a distinctly different network of neurological connections than the low flow group. The data indicate that the two groups differ only in the lobeta frequency band. When the neural pathways or bindings are compared for the two groups it seems that the F3 – C3 connection is instrumental to visuomotor performance since all connections remained synchronised across all frequencies for both groups. With regards to the other PFC connections, both groups show identical synchrony patterns, together with beta wave de-synchronisation in the F3 – P3 and F3 – O1 connections. However, in the F3 – O1 connection there is de-synchronisation in the Lobeta frequency for the low-flow group. For this group, in Lobeta, O1 is also desynchronised with C3 and only bound with P3, while C3 is desynchronised with P3 and O1 and only bound with F3. In other words, the only synchronised bindings in Lobeta are between F3 – C3 and F3 – P3 and P3 – O1. Lobeta is associated with stillness and smooth motor function. This may indicate that in the low-flow group motor coordination and execution are still under-developed since the sensori-motor and parietal areas receive frequent input from the pre-frontal cortex (higher order executive input) but lacks feedback loops with each other and the occipital area. Automotoric functioning is likely to occur only when all connections in Lobeta is synchronised.

Figure 69 (below) is an illustrated summary of synchronised and desynchronised connections across all frequencies and locations for the high-flow group. Dotted arrows indicate de-synchronised connections and solid arrows indicate synchronised connections.

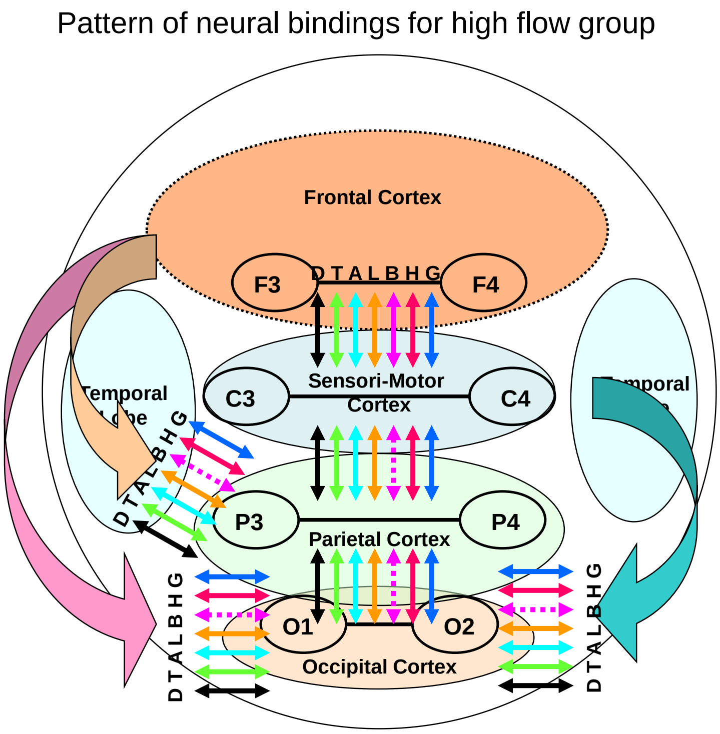

Pattern of neural bindings for high flow group

Figure 69. Illustrative summary of research findings for the high-flow group in terms of frequency and location. Delta (D), Theta (T), Alpha (A), Lobeta (L) and Gamma (G) are significantly synchronised across all localities. Beta (B) is synchronised only in the PFC – SMC connection and has de-synchronised in all other connections.

Figure 69 indicates that for the high-flow group all frequencies, but Beta, are significantly synchronised across all localities. Beta is synchronised only in the PFC – SMC connection and has de-synchronised in all other connections.

In the following chapter the above research results will be discussed fully and integrated into existing literature, research questions will be addressed, insights offered, limitations of the current study outlined, and recommendations offered. Lastly, suggestions for future research are offered.

CHAPTER 7

CONCLUSIONS, LIMITATIONS, AND RECOMMENDATIONS

7.1 INTRODUCTION

The purpose of this chapter is to discuss and integrate the findings of this study with existing literature, explore insights offered by the research process, outline the limitations of the current study, and make recommendations for possible future use. Lastly, suggestions for future research are offered.

The aim of the study was to determine the EEG correlates of flow (a particular state of consciousness) under conditions of peak performance. The justification for doing this is to establish an objective measure of flow. An objective measure of flow is deemed to be valuable in coaching, training, and self-development because flow is associated with peak performance and flow induction may increase performance in the workplace, sports field and leisure activities. An objective measure of flow, such as EEG, can be used to monitor flow during performance since it provides more accurate information than subjective behavioural measures.

7.2 CRITICAL DISCUSSION OF THE FINDINGS OF THE STUDY

In this section the findings of the study will be discussed and linked to existing literature, where after the implications of the findings will be integrated into the earlier proposed neurophysiological model for flow.

7.2.1 Flow and performance

The first research question centred on the relationship between performance and flow. This relationship was key to investigating the EEG data accompanying flow in order to arrive at a probable marker for flow.

Pates and Maynard (2000) postulated that the subjective experience when achieving the desired performance is the primary reward in flow. Once flow is experienced, the standard has to be raised (Jackson & Csikszentmihalyi, 1999). Therefore, in order to re-experience flow one has to improve or expand one's skill level(s). It was inferred that flow was likely to occur when skill reaches a certain level of competency, which was most probable when the autonomous phase (Fitts & Posner, 1967) in learning or skill execution was reached. This phase is characterised by continuous errorless and seemingly effortless performance, which is also a characteristic of flow.

From the above literature peak performance was deemed a necessary pre-condition for flow to occur. In this study, 20 experienced video gamers were subjected to a continuous visuomotor task which they had to repeat 10 times in order to produce a best performance. It was expected that the faster the time taken to complete the task the higher the likelihood of the performer to experience flow.

The sample was segmented into two sub-samples reflecting two levels of the flow variable. The first race completed by each participant was used as a "baseline" (and indicative of a low flow state – Group 2) for comparison with their own personal fastest race/highest flow score combination, indicative of the high flow state (Group 1).

Results indicated that the high performance / high flow level (Group 1) presented with a significant negative correlation ($r = -0.58$; $p = 0.01$) between perceived flow and peak performance. Since a decreasing value for performance (time) constituted improved performance, the negative r value indicated that the level of perceived flow increased with increasing performance. Further analyses of the performance – flow relationship indicated that the low performance / low flow level (Group 2) had a lower overall negative correlation ($r = -0.47$; $p = 0.04$), but was still significant at the 95% level, indicating that as performance time increased so also flow increased and vice versa, but it was more variable than when flow was higher.

Therefore the null hypothesis that there was no relationship between peak performance and psychological flow was rejected.

A correlation of -0.82 ($p = 0.00$) between the two flow levels showed that the less time taken to complete the race, the higher the flow. This is a strong correlation, in the predicted direction, and highly significant at the 99% level.

From the above analyses it was evident that there was a positive relationship between performance and flow and that the relationship strengthened and became more consistent with increasing performance.

A Mulitvariate Analysis of Variance (MANOVA) indicated that the performance and flow levels of the two groups differed significantly with an F-ratio of 150.06 ($p = 0.00$) for performance and F-ratio of 71.99 ($p = 0.00$) for flow. A very large effect size ($Eta^2 = 0.94$), for performance confirmed that the two levels differ by 94%. Similarly, a very large effect size ($Eta^2 = 0.89$) for flow confirmed that the two levels differ by 89%. The above results justified the segmentation of the data into the high- and low flow groups on the basis of them being representative of significantly different levels of flow and performance. This allowed the comparison of EEG data between the two levels.

The accompanying EEG data for Group 1 and Group 2 were used to examine and interpret the neurophysiological findings of the study and in the final analysis to identify a probable EEG marker for flow.

7.2.2 The EEG findings accompanying flow

The findings will be covered by discussing the power indicators, synchronisation and de-synchronisation patterns, linking the results to the proposed neurophysiological model for flow, re-configuration in brain processes and flow, a possible EEG marker for flow, integration of the findings with existing knowledge, and validity of findings emanating from the study.

7.2.2.1 Power indicators

With reference to the proposed neurophysiological model for flow, it was expected that theta power would increase and beta and gamma power decrease in the frontal (F3) region as the state of flow is assumed. Also theta and alpha power were expected to increase in the parietal (P3) region while alpha power was expected to also increase in the sensori-motor (C3) area.

MANOVA results indicated that there were no significant differences between the means of the two groups in any frequency but for lobeta in the sensori-motor cortex (C3). Lobeta increased significantly ($p = 0.0432$) at C3 in the high flow condition. The differences for F3 and P3 in the beta frequency were at the 0.06 level of probability and fell just outside the significant range. In both areas beta power increased as flow increased.

Although the research results revealed only significant change in lobeta in the sensori-motor area, it was still useful to look at the movement (change size and directions) trends by frequency band for the measured scalp positions as flow was assumed. It was evident that performance and the flow (AFQ4) accounted for the greatest amount of variability from low to high flow states. C3 lobeta was next, and as mentioned earlier, the only significantly different EEG variable, followed by other (statistically non-significant) changes. It was observed that the beta frequency produced large effects ($\text{Eta}^2 \geq 0.14$) across three of the four cortices while the effect in O1 was only medium ($\text{Eta}^2 \geq 0.06$). In the pre-frontal cortex, large effect sizes were also observed in delta and lobeta. In the sensori-motor cortex large effect sizes were evident in alpha, lobeta, and beta, while in the parietal cortex it was in delta and beta. Alpha displayed a large effect size in the occipital cortex.

In this study, delta power reduced in all cortical areas in the high flow group. Delta was most dominant in the sensori-motor area. However, large effect sizes were displayed in F3 (Eta^2 = 0.-17) and P3 (Eta^2 = 0.-23), and medium size in C3 ($\text{Eta}^2 = -0.09$) and O1 (Eta^2 = 0.-11). With regards to the role of delta, Vogel, et al. (1968) postulated that two kinds of behavioural inhibitions are characterised by delta. Class I inhibition refers to the gross inactivation of an entire excitatory process resulting in a relaxed, less active state, such as sleep, while Class II inhibition refers to the selective suppression of inappropriate, or non-relevant, neural activity during mental task performance. The fact that delta power decreased in all areas as flow increased may be a result of deactivation of Class 1 inhibition, thus enhancing general alertness and action orientation. Also as concentration increased with increased performance and flow levels, Class II Delta inhibition was likely to reduce.

It was hypothesised that theta power would increase in F3 (H_2) and P3 (H_3) in the high flow condition. However, theta power remained fairly constant in all cortical areas, but reduced somewhat in the parietal area in the high flow condition. In addition, all effect sizes in theta were small ($Eta^2 < 0.06$), indicating that theta played a similar role in both flow conditions. Increased frontal (F3) theta is reported in error detection (Luu et al., 2003; Luu et al., 2004), working memory tasks (Gevins et al.,1997; Jensen & Tesche, 2002; Krause et al., 2000; Onton et al., 2005), task complexity and focussed attention. Increased theta power in posterior (P3) brain areas are linked to increased task complexity during complex visuomotor tasks (Fournier et al., 1999).

It was hypothesised that alpha power would increase in P3 (H_4) and C3 (H_5) in the high flow condition. However, alpha power increased in all cortical areas in the high flow condition, especially in the sensori-motor (C3) and occipital (O1) areas, but the increases were not significantly different from the low flow condition. Alpha showed large effect sizes in C3 ($Eta^2 = 0.24$) and O1 ($Eta^2 = 0.14$). The effect size in P3 was small ($Eta^2 = 0.04$). Rowe et al. (2007) postulated that alpha demonstrates positive correlations with information processing speed. Alpha is also involved in anticipatory attention, which involves top-down interactions between higher-order and primary areas of the visual cortex. Alpha power increases have been linked to active inhibition of neuronal activity that could otherwise disturb the working memory (WM) process (Jokisch & Jensen, 2007; Klimesch et al., 2007). Babiloni et al. (2008) postulated that alpha rhythms might represent a major physiological mechanism at the basis of “neural efficiency” during the judgment of observed actions. Working memory, information processing speed, anticipatory attention, and neural efficiency are all essential to successful visuomotor performance.

No hypothesis was set for lobeta. Lobeta power increased in all cortical areas in the high flow group. The least increase was in the parietal area while the increase in the sensori-motor area was at a statistically significant level (C3 : $p = 0.0432$). The largest effect was also at C3 ($Eta^2 = 0.33$). However, a large effect was also observed at F3 ($Eta^2 = 0.22$) and a medium effect at O1 ($Eta^2 = 0.12$). SMR or lobeta predominates only in the sensori-motor cortex (sensori-motor strip). Lobeta increases with stillness and decreases with movement (Othmer, Othmer & Kaiser, 1999, p. 267). The significant shift in power in the sensori-motor area may be an indication that motor movement have smoothed out into fluent and synchronised motion as flow increased. Sterman et al. (1994) indicated that the sensori-motor system involves the ascending touch and proprioceptive pathways and their projections to the thalamus and on to the sensori-motor cortex and the efferents from this cortical area. This system generates the sensori-motor rhythm (SMR), the 12 - 14 Hz rhythm (lobeta) over the sensori-motor strip. Lobeta is seldom isolated (mostly included in a broader beta range) in neurophysiological research, thus little information is available regarding its role in behaviour. However, lobeta or SMR is extensively used in neurofeedback training across the sensori-motor strip.

Beta power was hypothesised (H_6) to decrease in the frontal (F3) area in the high flow condition. However, beta power <u>increased</u> substantially in all cortical areas in the high flow condition, especially for F3 ($p = 0.0637$) and P3 ($p = 0.0608$). Also large effect sizes (F3 : $Eta^2 = 0.29$; P3 : $Eta^2 = 0.29$) were demonstrated at these two locations. A large effect size was also indicated at C3 ($Eta^2 = 0.22$), while the effect was only medium size at O1 ($Eta^2 = 0.08$). Beta frequency is associated with concentration, analytical thinking, being externally oriented, or being in a state of relaxed thinking (Demos, 2005). According to Eoh, et al. (2005), increased beta activity has been related to heightened alertness. Beta also plays an important role in the fronto-parieto-temporal attentional network and is known to be involved in target detection, visual attention, and working memory; processes that are required for the successful execution of any visually based task (Gross, et al., 2004). In this study, although not significant at the 0.05 level, but with large effect, increased frontal and parietal beta power was probably related to the heightened level of alertness and concentration involved in high speed motor racing, requiring target detection (other cars, obstacles, and track conditions), visual attention, and working memory in order to set up peak performance and assuming the flow state.

No hypothesis was set for hibeta. Hibeta power increased substantially in all cortical areas in the high flow group, with the least in the sensori-motor area. However none was at a statistically significant level. Medium effect sizes were demonstrated at F3 ($Eta^2 = 0.08$) and O1 ($Eta^2 = 0.07$). High beta is associated with peak performance, cognitive processing, worry, anxiety, over-thinking, and ruminating (Demos, 2005). The increase in hibeta power may be an indication of improved cognitive processing in lieu of peak performance.

Gamma power was hypothesised (H_7) to decrease in the frontal (F3) area in the high flow condition. However, gamma power increased in all cortical areas in the high flow group, especially in the parietal- and occipital areas. However none was at a statistically significant level. Effect sizes were also small at all locations. This indicated that gamma played an equal role in both flow conditions. Gamma is prominent especially during high alertness and after sensory stimulation, likely contributing to the ‘‘binding” of diverse information into a single coherent percept. Gamma, high beta and beta waves seem to be associated with selective attention, transient binding of cognitive features, and conscious perception of visual objects (Hughes, 2008). Increased gamma power has also been linked to working memory maintenance (Tallon-Baudry et al., 1998; Lutzenberger et al., 2002; Kaiser et al., 2003; Jokisch & Jensen, 2007). Selective attention, transient binding of cognitive features, conscious perception of visual objects and working memory maintenance are important aspects in performance improvement while performing a visuomotor task such as video gaming.

From the above the main findings (large changes) are summarised in Table 44 (below).

Table 44

Large changes in EEG power at high flow and peak performance

Brain Site (s)	**EEG changes from low to high flow**
Pre-frontal cortex (F3)	Decreased delta and increased lobeta and beta power
Sensori-motor cortex (C3)	Increased alpha, lobeta and beta power
Parietal cortex (P3)	Increased beta power
Occipital cortex (O1)	Increased alpha power

In contrast with the predicted model, the fact that none of the null hypotheses regarding a shift in EEG power were rejected is probably due to the different nature of the activities upon which the previous research was based. These activities included shooting, archery, golf putting, etc., which require stillness of movement, visualisation of outcome, and have a stationary target, compared to a video game where there is a moving target, continuously changing visual stimuli, dynamic decision making and complex dynamic bilateral (left and right hands executing different functions simultaneously) hand-eye coordination. Furthermore, due to most subjects in the study being experienced video gamers they already have a certain level of pre-existing video game stimulus - response mappings and mental “circuitry” which caused an “elevated” EEG baseline that is not so different from their performance EEG profile. In this study there was no expert versus novice group comparisons; the subjects’ first attempts were compared to their own best attempts/highest flow scores.

7.2.2.2 Synchronisation and de-synchronisation patterns

The proposed neurophysiological model for flow hypothesised that individuals performing at peak levels, and thus experiencing flow, exhibit increased alpha synchrony between the sensori-motor (C3) and parietal (P3) regions along with beta rhythm de-synchronisation and phase lags between the various cortical areas.

In terms of alpha synchrony, the two groups were no different. All connections were synchronised. However, there was a large difference in binding strength between the two conditions in the prefrontal-occipital (F3-O1) connection with the high flow condition showing a much stronger bind (79% versus 56%), albeit both bindings constituted synchrony. The null hypothesis (H_8) that there was no alpha synchrony between C3 and P3 in high flow was rejected. Rowe et al. (2007) postulated that the alpha rhythm is a measure of the strength and delay of signal transfer in cortico-thalamocortical loops. Increased alpha activity (synchronisation) may increase the efficiency and accuracy of thalamocortical transfer. Consistent with this, alpha demonstrates positive correlations with information processing speed. Alpha is also involved in anticipatory attention, which involves top-down interactions between higher-order and primary areas of the visual cortex. These, in turn, have been linked to synchronisation in the alpha frequency band (von Stein & Sarnthein, 2000). In this study the higher level of F3-O1synchrony in the high flow condition probably indicated higher efficiency in information processing speed and anticipatory attention between the frontal (F3) and visual (O1) cortices.

The only differences in synchronisation/de-synchronisation patterns between the two flow conditions were in lobeta where, for the low flow group only, the C3 – P3, C3 – O1 and F3 – O1 connections were de-synchronised compared to the high flow condition where these connections were synchronised. There were no hypotheses set for lobeta synchronisation/de-synchronisation. See table 45 below for detail.

Table 45

Lobeta synchrony across sites in high and low flow

Freq.	**Group**	**F3 vs C3**	**C3 vs P3**	**F3 vs P3**	**C3 vs 01**	**P3 vs 01**	**F3 vs 01**
Lobeta	Group 1 High flow	0.80***	0.54**	0.52**	0.75***	0.70***	0.78***
	Group 2 Low flow	0.65**	0.18	0.42**	0.27	0.52**	0.43

Note. ***p ≤ 0.001; **p ≤ 0.01; *p ≤ 0.05

The figure below illustrates the differences in strength of "binding" (correlation) between the various brain areas for the two conditions.

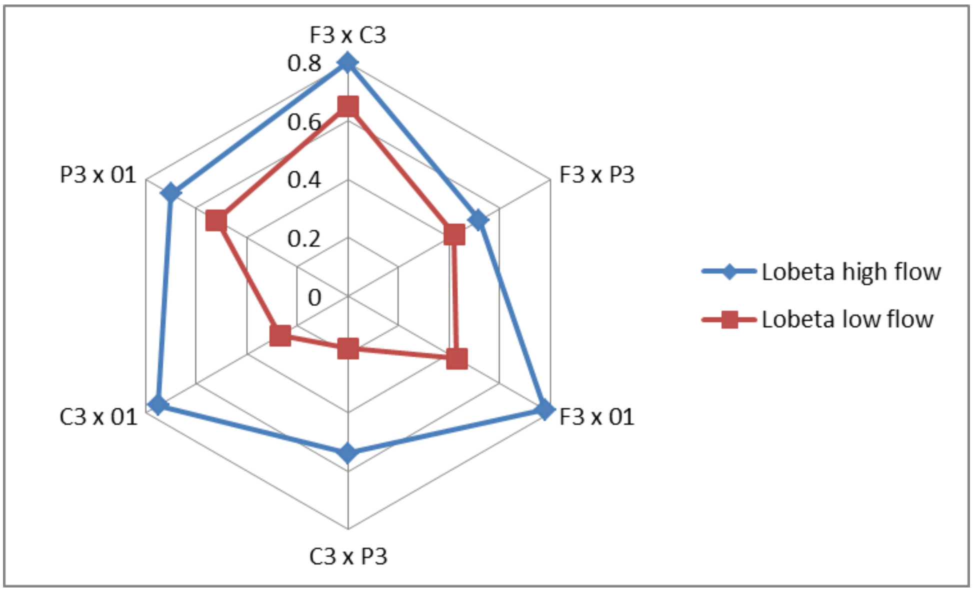


Figure 70. Lobeta synchrony across sites in high and low flow

The above table and figure indicate moderate to high synchrony levels for the high flow condition at all brain sites. There was no synchrony (de-synchronised) between C3-P3, F3-O1 and C3-O1 for the low flow condition. For C3 in this condition there was only synchronisation with F3. There was very strong synchrony between F3-O1, F3-C3, C3-O1 and P3-O1 for the high flow condition. The F3-C3 synchrony was the strongest, while O1 had strong bindings with all the other sites.

Since lobeta is associated with motor functioning, it is suggested that in this study lobeta synchrony was probably associated with enhanced quality (smoothness and calmness) in motor functioning. Synchronised lobeta connections between all cortical areas, as displayed in the high flow condition, was probably an indication of optimised flow of neural information through-out the network ensuring smooth, relaxed and accurate motor execution, which can probably be associated with the “effortless” and super-efficient characteristics of “zoning” in sport and flow. De-synchronisation between C3-P3, C3-O1 and F3-O1 for the low flow condition may have indicated that the sensori-motor cortex was still highly dependent on the pre-frontal cortex for motor input due to un-established skills and a high error rate. Automotoric functioning was likely to occur only when all connections in Lobeta were synchronised.

For the high flow group all frequencies but beta were synchronised across all scalp locations. Beta remained synchronised only in the F3-C3 connection. It was hypothesised that beta will de-synchronise between the frontal (F3), sensori-motor (C3) and parietal (P3) areas. This implied that the null hypotheses, indicating a synchronised connection, for hypotheses 9 (C3-P3) and 10 (F3-P3) were rejected, but not for hypothesis 11 (F3-C3). However, the beta pattern was the same for both conditions.

Figure 71 below illustrated the peculiar beta band synchronisation / de-synchronisation pattern for both groups.

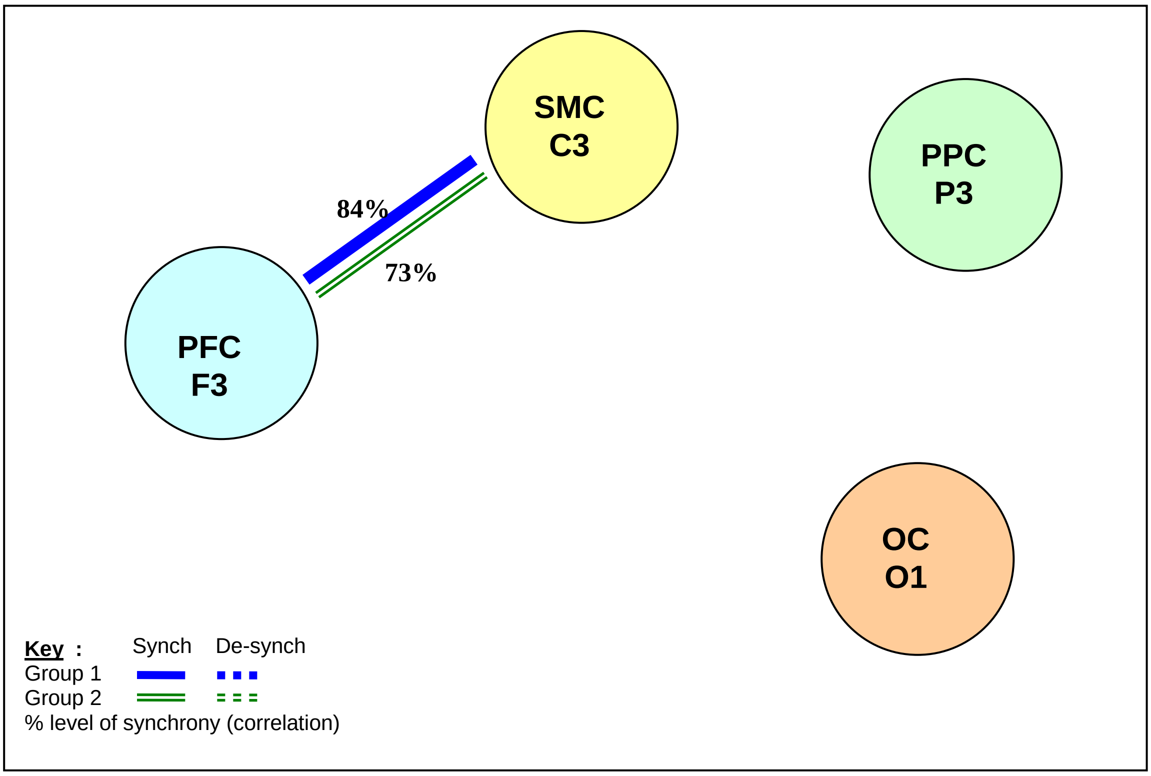


Figure 71. Pattern of synchronised connections in Beta for high flow group (de-synchronised connections are not displayed)

The above phenomenon of beta synchronisation/de-synchronisation is congruent with research by Gross, et al. (2004) who reported that changes in beta synchronisation reflect changes in the attentional demands of the task and are directly related to behavioural performance. They concluded that synchronisation / de-synchronisation appears to be a candidate mechanism for enhancing target processing while at the same time avoiding interference by suppressing the processing of non-targets, respectively. Pfurtscheller et al. (2003) suggested that beta synchronisation/de-synchronisation plays an important role in motor control. Beta oscillatory synchrony operates as a spatiotemporal filter to sharpen action-selection by cortico-basal ganglia networks (Courtemanche et al., 2003). Research indicated that beta-rhythm oscillations de-synchronise during automotoric movement and again become synchronised over a larger scale when attention to sensori-motor integration is required (Pfurtscheller & Andrew, 1999; Ivanitsky et al., 2001; Fingelkurts et al., 2005; Schnitzler & Gross, 2005). Van Wijk, et al. (2009) reported that the role of beta synchrony in biasing response competition appears not only related to a biasing role of alpha activity in the selection of visual information, but also to the concept of ‘‘focal de-synchronisation/surround synchronisation’’.

The above pattern of lobeta synchronisation and beta synchronisation/de-synchronisation during flow under conditions of peak performance seemed to have coincided with the notion of automaticity (automotoric movement) during which task execution was mainly controlled by posterior implicit processes whilst monitored by explicit frontal processes. The above lobeta/beta pattern seemed to have indicated that automotoric movement was in progress and that the frontal region was only partially involved the motor control loop. The synchronised frontal – sensori-motor connection in beta was probably an indication that the frontal lobes were still engaged with target (the moving car) tracking, cognitive processing and feedback monitoring by maintaining communication with the sensori-motor area. The beta de-synchronisation of the frontal cortex with the parietal and occipital cortices was probably an indication that the frontal region was externally focussed while the other cortices were internally oriented, i.e. the motor function was controlled by implicit processing. The beta de-synchronisation between the sensori-motor, parietal and occipital areas was probably an indication that no explicit processes were operative and no external awareness was present. This is probably associated with the "action-awareness merging" or "loss of self-awareness" characteristic of the flow condition. Beta seems to be the pivotal frequency associated with the shift in conscious (explicit) attentional resources by means of inhibition / non-inhibition through the process of synchronisation / de-synchronisation between cortical areas.

No hypotheses were set for hibeta and gamma synchronisation / de-synchronisation. Both frequencies remained synchronised for all scalp positions for both conditions.

7.2.2.3 Linking the results to the proposed neurophysiological model for flow

With regard to the proposed neurophysiological model for flow, synchronous gamma activity was expected across all cortical areas. In this study, synchronised gamma occurred across all cortical areas in both high and low flow conditions. Research suggests that functionally gamma contribute to the coordination between sensory and motor activity. It is activated when the brain needs to be active and idle when no specialised task is at hand (Hammond, 2000). Gamma functions to bind the brain into a single coordinated unit (Hughes, 2008). Synchronised delta occurred across all cortical areas suggesting involvement in inhibition of irrelevant external stimuli (Harmony et al., 2009). Theta, alpha and lobeta were all synchronised across all cortical areas. Research suggests that theta is involved in mediating information flow between the cortical- and sub-cortical structures, probably associated with increased selective attention, working memory maintenance, and error detection (Engel & Singer, 2001). Alpha synchronisation seems to be associated with inhibition of local irrelevant neuronal processing interference, i.e. blocking "noise" from surrounding neural processing unrelated to the task under attention (Babiloni et al.; 2008), probably associated with control of visual attention (concentration). Synchronised lobeta is probably involved in smoothing information flow to the sensori-motor area to assure smooth, relaxed and accurate motor execution, which can probably be associated with the "effortless" and super-efficient characteristics of "zoning" in sport and flow. As discussed above, synchronised beta between the pre-frontal and sensori-motor cortices seems to indicate that conscious attention (executive/explicit processing) to sensori-motor integration is maintained, while the de-synchronisation between all other areas probably indicate a break in top-down (executive) processing and reliance on bottom-up functioning, which signifies automotoric functioning and a perception of automaticity (being in "auto-pilot" mode). Beta de-synchronisation in the parietal and occipital circuits indicates that motor skill is internalised and unconsciously controlled by the basal ganglia circuit. Synchronised hibeta in all areas is probably related to maintenance of long range cognitive information processing between regions.

7.2.2.4 Re-configuration in brain processes and flow

The critical question was whether the system (neural network) underwent a significant reconfiguration when flow was assumed. Even more critical was whether there was evidence of a neurological pattern suggesting a shift between the "explicit and implicit" systems, or a shift from the frontal networks to the posterior networks during flow under condition of peak performance. The above results did not answer this question clearly. There was a clear shift in neurological pattern represented by the high flow group and not the low flow group, indicating a refinement in sensori-motor integration (lobeta synchronisation of all cortical areas), but the shift in motor control away from the frontal networks (beta de-synchronisation of the pre-frontal cortex with the parietal and occipital areas) and away from explicit processing (beta de-synchronisation between sensori-motor, parietal and occipital areas) towards automotoric or implicit processing was evident for both high and low flow conditions.

As mentioned earlier, a possible explanation for the lack of discrimination between the two conditions in beta may be due to most subjects in the study being experienced video gamers which already have a certain level of re-existing video game stimulus - response mappings and mental "circuitry" which causes an "elevated" EEG baseline that is not so different from their performance EEG profile. In this study there was no expert versus novice group comparisons; the subjects' first attempts were compared to their own best attempts/highest flow scores.

7.2.2.5 A possible EEG marker for flow

The above arguments and supporting data provide a basis for establishing an identifiable marker in EEG that represents flow. When the various connections (neural pathways) were plotted over the frequency bands a unique EEG pattern or "signature" was created that can serve as marker for flow under conditions of peak performance. This EEG pattern is illustrated in Figure 72 (below).

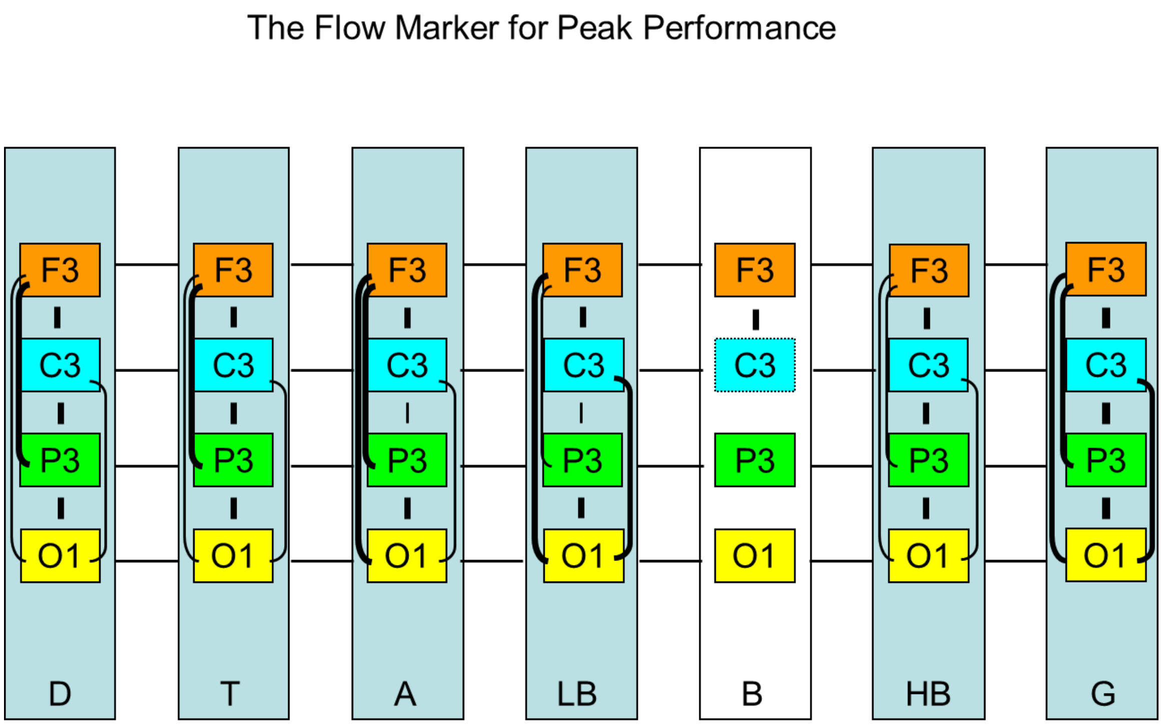


Figure 72. Illustration of marker for flow. Inter-connecting lines indicate synchronised connections. Thick lines indicate highly correlated connections.

It is proposed that the above correlates be considered an EEG marker for flow under conditions of peak performance during the execution of a visuomotor task, especially in a video/simulation based driving context.

The neurophysiological model for flow proposes that flow is a product of neurological productivity during which the brain attempts to optimise processing efficiency by using the least amount of resources necessary to achieve maximum task performance.

7.2.3 Integration of the findings with existing knowledge

Although the flow phenomenon has been extensively researched as a subjective perception of experienced happiness, total engagement and self-reward during the performance of a large variety of activities, it has not been much researched in terms of its physiological properties or -origin.

According to Chalmers (1995), ‘the hard problem' is ‘the question of how physical processes in the brain give rise to subjective experience' - that is, how physical and mental interact. He argues that there is an explanatory gap between matter and sensation that has not yet been satisfactorily bridged.

According to Wilber (1997), an attempt to solve this dilemma of an explanatory gap by any sort of reductionism, is doomed to failure. He argued that consciousness is not located merely in the physical brain, nor in the physical organism, nor in the ecological system, nor in the cultural context, nor does it emerge from any one of those domains. Rather, it is anchored in, and distributed across, all of those domains with all of their available levels. According to his Four Quadrants Model of existence, based on the premise that holons evolve along four dimensions (the four quadrants, i.e. intentional, behavioural, cultural and social) to increasing levels of development or complexity, the most important aspect is that these four dimensions have a very specific correlation with all the others. Each quadrant causes, and is caused by, the others, in a circular and non-reducible fashion.

With reference to the above model, peak performance, as high quality outcome of a particular activity, can be regarded as a social requirement of a larger collective (society, organisation, structure, etc.). Peak performance is easily measurable and recognisable and can be classified according to a socially determined standard of usefulness or competence. At the same time, peak performance is associated with an optimal state of mind which in sporting terms is better known as the "zone" or the "groove"; or "magical" period during performance where body and mind work together in a super-efficient manner. This phenomenon is called flow. It is for this reason that flow is an important aspect of coaching, training, self-development, and consulting.

From a flow point of view, the learning point from Wilber's line of argument is that the flow phenomenon as a state of consciousness should be researched covering all four domains (intentional, behavioural, cultural, and social), using all four validity claims and following the three strands of valid knowledge acquisition: injunction, apprehension, confirmation/rejection (or exemplar, evidence, falsifiability) relevant to each facet. This study has made some contribution towards "reconciling" the intentional and behavioural dimensions. However, there is truth in Chalmer's argument that an explanatory gap exists between the physical and behavioural aspects of experience. It is evident that both neuro-anatomy and behaviour is much too complex to be able to account for all variables (electrical, chemical, cognitive, emotive, conative, etc.) using only a few measuring instruments and at the same time accurately isolate specific neurological processes and behaviours in order to bridge the "gap" at a satisfactory level of confidence. This study made some attempt to provide "hard problem" answers to the question of how physical processes in the brain give rise to a subjective experience such as flow.

Flow theory, as reported by Csikszentmihalyi and associated researchers, mainly focus on the left hand (subjective, individual and collective) dimensions of the Wilber model. Csikszentmihalyi (1990) formulated a flow model (exemplar) that interprets people's subjective experiences as a mental state where there is order in consciousness, a match between challenge and skill, concentration on the task at hand, action-awareness merging, sense of control, loss of self-consciousness, transformation of time and autotelic experience, during which they experienced happiness, total engagement and self-reward. As far as research on the right hand dimensions (objective, individual and collective) of the flow state is concerned, many questions are still unanswered. One of those questions, i.e. whether there is an identifiable neurological pattern in the brain that is representative of the flow state and which can be used as objective evidence of being in flow, was targeted by this study, using EEG.

Linking the research findings of this study to Csikszentmihalyi’s (1997) nine dimensions or general conditions that purportedly facilitate flow experiences, the following explanations, from a neuropsychological viewpoint, are put forward:

(1) *Clear goal.* A clear goal of achieving a fastest time in ten attempts at the same task was set. From an observational perspective it was evident that the goal was an important intrinsic motivator, which inspired the subjects to improve their performance. Goal achievement is conscious confirmation of the quality of skill execution (skill/challenge match) with consequent unconscious elevation in confidence level regarding the task and feelings of enjoyment and satisfaction. Goals serve as a conscious and unconscious threshold or baseline for flow to occur. Flow will only re-occur once the threshold has been upwardly adjusted following the superseding of the threshold during a prior flow experience.

(2) *Concentrating and focusing* requires attention to the task at hand, which is predominantly a function of the prefrontal cortex (PFC) and anterior cingulated cortex (ACC). According to Luu et al. (2009), the prefrontal lobes and anterior cingulate have been observed to be strongly engaged early in the learning cycle when stimulus-response mappings are actively being established (Chein & Schneider, 2005; Luu et al., 2007; Toni et al, 1998). When contingency mappings are internalised by the implicit information system with little or no error correction required, it triggers the beta rhythm to de-synchronise; switching off conscious attention to the implicit system and shifting conscious attention to the explicit system focussing on executive functioning involving skill application. Concentration (selective attention) on the task is enhanced by synchronised delta blocking task irrelevant external information from distracting attention, while synchronised alpha blocking local unrelated neural activity from interfering, allowing the frontal structures to focus attention on conscious executive functions and posterior structures to focus attention on unconscious implicit information processing.

(3) *A loss of the feeling of self-consciousness*, the merging of action and awareness. This will appear as the performance is nearing its peak and the posterior driven "automatisation" state is entered by virtue of beta rhythm de-synchronisation and lobeta synchronisation. Skill execution then becomes unconscious, since conscious attention is externally focussed by executive functions in the PFC. Synchronised gamma probably also plays a role in that it serves to coordinate sensory and motor activity and binds the brain into one functional unit.

(4) *Distorted sense of time*. This is a by-product of the "automatisation" state, probably because of beta rhythm "disengagement" of the PFC from posterior regions, separating conscious and unconscious attention.

(5) *Direct and immediate feedback*. This is necessary for error detection and correction in order to progress up the learning-curve and entering the "automatisation" state. Beta de-synchronisation and phase switching is involved in error correction and motor control during the latter state. When no error correction is required "consistently", it paves the way for automotoric functioning (synchronous bindings in all areas and frequencies except beta) and frontal attentional shift to proceed, allowing flow to occur. Synchronised oscillations have been found to be a neural correlate of integration processes during conscious perception (Engel & Singer, 2001), attention (Niebur, 2002), working memory (Sarnthein et al., 1998) and recollection of episodic information (Klimesch et al., 2001).

(6) *Balance between ability level and challenge*. This is necessary to produce calmness and confidence and prevent the brain from engaging a stress (fight-or-flight) reaction, which will cause heightened activation of the limbic system. Rather, skill acquisition or motor performance occur as a function of practice so that the details of a motor task become gradually controlled by the basal ganglia circuit (Mishkin et al., 1984) until little or no pre-frontal top-down activity is required, freeing up working memory and allowing executive attention to fill its premium computational space with content that requires higher order processing.

(7) *A sense of personal control* over the situation or activity. In the "automatisation" state the PFC receives unconscious feedback (especially through theta and alpha) from the occipital- and parietal cortices that no errors are made and peak performance is in

progress. In the absence of error, stress reactions and therefore anxiety is eliminated and confidence levels increase. Attention is consciously allocated to executive functioning (beta synchronisation F3-C3), which through direct feedback confirms that no errors are made and that skill execution is successfully managed by the posterior networks.

(8) The activity is *intrinsically rewarding*, so there is an effortlessness of action. During flow, both emotional- (such as self-discipline, achievement, self-esteem and confidence) and cognitive information (such as space, time and logic) converge back on the dorsolateral pre-frontal cortex, confirming that plans and strategies are efficient and leading to goal achievement, causing joy and satisfaction to follow (LeDoux, 1996; Fuster, 2000).

(9) When in the flow state, people become absorbed in their activity, and focus of awareness is narrowed down to the activity itself, *action awareness merging*. This is the "proof" of being in "automatisation" state, i.e., being in flow and driven by the same processes as loss of the feeling of self-consciousness.

In this study, an EEG marker for flow under conditions of peak performance during the execution of a visuomotor task was established, especially in a video/simulation based driving context.

Figure 73 (below) is an illustrated summary of synchronised and desynchronised connections across all frequencies and locations during flow under conditions of peak performance**.** Dotted arrows indicate de-synchronised connections and solid arrows indicate synchronised connections.

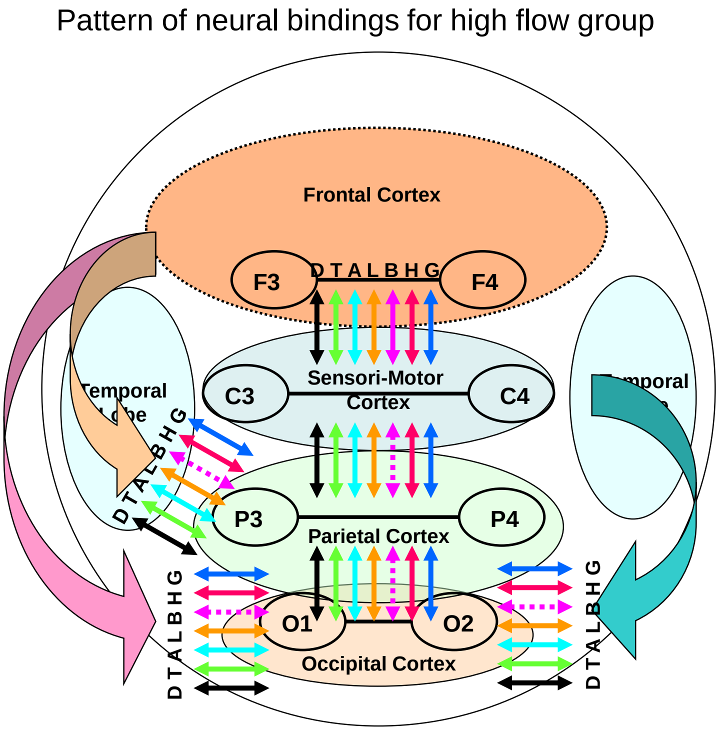


Figure 73. Illustrative summary of research findings for the high-flow group in terms of frequency and location. Delta (D), Theta (T), Alpha (A), Lobeta (L) and Gamma (G) are significantly synchronised across all localities. Beta (B) is synchronised only in the PFC – SMC connection and has de-synchronised in all other connections.

Figure 73 indicates that when in flow all frequencies, but Beta, are significantly synchronised across all localities. Beta is synchronised only in the PFC – SMC connection and has de-synchronised in all other connections.

In summary, the current study, within the context of its limitations, has succeeded in suggesting a recognisable set of neural correlates for flow under conditions of peak performance, as well as a crude neuropsychological model to explain flow.

7.3 VALIDITY OF FINDINGS EMANATING FROM THE STUDY

With regards to internal validity, threats such as maturation, regression to the mean and experimental mortality were not applicable in this research.

Relevant measures to enhance internal validity in the study are discussed below.

7.3.1 Sample characteristics

Bias due to factors such as age, gender and brain laterality that could moderate responses and prove to be contaminating variables were controlled. Twenty subjects were selected from a volunteer group and only right handed males over the age of 16 years who are familiar with computer gaming were chosen. Of the 20 participants, 10 rated their computer gaming skills as “good”, while 8 rated themselves as “moderate” and only 2 rated themselves as “basic”. Although the sample was skewed in terms of age, with 75% of the subjects being between the ages of 16 and 24 years, there was no correlation between performance and age ($r = 0.023$; $p= 0.53956$). The correlation between their fastest race times and their reported gaming skill levels was $r = -0.62$ and highly significant at the 0.01 level. Variation in the results that could be caused by age, handedness, gender and widely varying levels of experience at the experimental task was, therefore, limited.

7.3.2 Standardising the data

Subjects were given ten trials each to produce a best performance. Along with each performance (recorded in seconds) a flow score (a score out of twenty) was obtained and a set of EEG data (in microvolts) were recorded. Because of the different skill levels amongst subjects, some subjects’ peak performances were slower than the poorest performances of other subjects. It was, therefore, necessary to standardise the data so that, for every individual subject, each score is represented in terms of standard deviations from their individual means. Another reason for standardising the data was to transform all the data to a common scale and to bring all of the variables into proportion with one another in order to eliminate unequal weights. Additionally, although not a normalising technique, by standardising the data it became more normally distributed with the added advantage that it allowed using a MANOVA that is based on the assumption that the data is normally distributed.

7.3.3 Instrument validity

The EEG data collected from the BrainMaster instrumentation has high validity as the equipment is specifically designed for the purpose of collecting the electrical output of the brain for clinical purposes. Impedance for each electrode placement was kept under 5000 ohms (Ω) in order to conform to the accepted standard for scientific research.

With regards to the behavioural questionnaires, the GFI (Game Flow Inventory) was considered a validated questionnaire since it was an adapted form of the WOrk-reLated Flow inventory (WOLF) developed by Bakker (2008), that measures employees' flow in the workplace. Bakker (2008) reported that "the internal consistency or reliability of the scales for absorption, work enjoyment and intrinsic work motivation have been proved to be acceptable. In seven samples, the coefficients ranged between 0.75 and 0.85 for absorption, 0.88 and 0.95 for work enjoyment, and 0.53 and 0.82 for intrinsic work motivation. Only the scale for the assessment of intrinsic work motivation performed somewhat unsatisfactorily in one of the seven samples (the agency for temporary work), with a coefficient of 0.53. Nevertheless, the test–retest reliability in this sample was very good for each of the scales, with stability coefficients of about 0.75. This means that flow can be measured reliably and that the answers of employees to questions about flow correlate strongly with their responses six weeks later". Construct validity and predictive validity of the WOLF were also satisfactory, however, in terms of the latter, absorption proved to be an unreliable predictor of performance during flow (Bakker, 2008).

In this study, the GFI as instrument presented with a Standardised Cronbach's Alpha of 0.91, showing very high internal consistency. The GFI factors were all highly significantly inter-correlated. Enjoyment and Motivation and Enjoyment and Absorption were strongly correlated, both at $r = 0.73$ and both highly significant at the 0.001 level. Absorption and Motivation was also highly significant but slightly lower as a correlation ($r = 0.64$; $p = 0.002$).

The AFQ (Abbreviated Flow Questionnaire) is not a validated questionnaire. The items have not been formally tested on a larger sample and validated statistically against relevant criteria but it was constructed specifically to serve the needs of this research after a thorough research of the literature. The questionnaire is based on the dimensions that are labelled by Csikszentmihalyi as flow characteristics. The five test items were selected to provide immediate feedback after each race to indicate if, and how strongly, attributes of flow were experienced according to a 5-point rating scale. Because of the once-off nature and duration of the test sessions it was impractical to pre-validate the test. Therefore the validation was done afterwards.

The questionnaire was administered 200 times. Initially there were five items, but one was discarded during the analysis, hence the reference to AFQ4. The AFQ4 presented with a Standardised Cronbach's Alpha = 0.756059 when all 4 questions were inter-correlated showing adequate internal consistency, and therefore reliability, amongst the separate items. Bear in mind that there are only four questions since the Cronbach's Alpha is sensitive to the number of items and tends to increase with larger number of test items. All four test items were moderately correlated and highly significant. Engagement was correlated with Challenge (r = 0.42), Control (r = 0.41) and Accomplishment (r = 0.39), all at the 0.001 level of significance. Challenge was correlated with Control (r = 0.42) and Accomplishment (r = 0.37), both at the 0.001 level of significance, while Control and Accomplishment was correlated at r = 0.61 at 0.001 level of significance.

The relationship between the GFI and AFQ for the total sample of 20 subjects was very low (r = 0.03) and insignificant (p = 0.88) and suggested that they each measure different interpretations of flow. The GFI presented with strong within-item inter-correlations, as already noted, but the AFQ items were relatively independent items. None of the GFI and AFQ4 individual items inter-correlated, yet highly significant inter-item agreement was found within both the GFI and AFQ4, except for Time, which was discarded in any event as mentioned earlier. The low correlation of Time with the other four AFQ items was another reason to justify its exclusion. These high levels of internal consistency suggest that both instruments are reliable measures of flow and valid for the different purposes they served. A factor analysis of the results from the total sample showed even more precisely that the two instruments were measuring different aspects of flow. The GFI loaded more heavily on factor 1 and the AFQ on factor 2. The reliability of the measures over time could not be assessed since no repeat testing were conducted but it is clear from the information presented that, on the whole, the two questionnaires measured different aspects of flow. The GFI seemed more behaviourally orientated (flow experience) while the AFQ seemed more performance oriented (flow characteristics).

The GFI and AFQ results were used separately and for different analytical purposes. The AFQ provided feedback as a measure of flow per race, specifically for identifying those races where stronger versus weaker flow was experienced. The GFI provided further insight into the total but less directly related experience of flow after all races were completed.

7.3.4 External validity

Controls used to enhance internal validity often restrict the generalisability of the research results. In the present study, the sample was restricted to a group of right-handed, male computer gamers over the age of 16 years. As this was pioneering research and the intention was to determine an EEG marker for flow under conditions of peak performance, it was important to trade higher internal validity for a lesser degree of external validity. Once the EEG marker was established, future research can expand the generalisability and external validity of this initial research to a larger variety of tasks and populations.

Sample size is also a factor that influences generalisability of the research results. An adequate sample size reduces potential sources of random error and enhances generalisability. In this study both qualitative and quantitative methods were used to determine an EEG marker for flow. In quantitative studies a sample of at least 30 subjects is required to reduce random error. Qualitative studies require smaller samples (around 10) and are based on the principle of level of saturation. It was decided to settle on a sample of 20 subjects in order to strike a balance between practical limitations (logistical issues relating to EEG recordings and time taken to conclude one assessment) and satisfying minimum requirements for inferential statistical tests which were required in order to arrive at the qualities to be analysed. Also the composition of the sample reduced variance.

The bias of individual differences was limited by a repeated measures design. In this research the 20 gamers were required to complete 10 races, each one under instruction to produce a best performance. The nature of flow is that it occurs when a peak performance is reached. Once this occurs the standard has raised and flow will only re-occur when a new peak performance is achieved. The way in which the gamers managed their own behaviour included individual differences which cannot all be controlled. Likewise, their exposure to other sources of random error is unknown. The single sample repeated measures design reduced the influence of individual differences since the bias of inter-participant correspondence was limited.

Ecological validity was reduced by the laboratory type setting in which the assessment was performed, however it was enhanced by the selection of established video gamers and the repeated measures design allowing the subjects to acclimatise to the testing condition. The design also allowed learning to take place and reduced test anxiety. From an observational point of view the subjects were visibly at ease and exited by the time they produced their best performances. Therefore the ecological validity of the study is considered satisfactory and adequate.

7.3.5 Measures taken to enhance reliability of the data

In order to ensure that the findings (results) of the study were replicable, the following research protocols were applied:

(1) Careful sample selection to limit mediating and confounding variables.

(2) Strict protocols were followed so that the test conditions may be repeated in future studies.

(3) Standardised test conditions applied. The experimental task was administered in the same consistent way for all subjects, in the same physical conditions, with the same instructions, using the same EEG equipment (with known reliability) and performing the same task.

(4) Potential bias caused by electrical interference with the BrainMaster equipment was controlled by removing all possible sources of interference from the test environment.

(5) EEG sampling consistency was obtained by using the same equipment. Fast Fourier Transform (FFT) separated the raw data into individual frequency bands.

Importantly, impedance for each electrode placement was kept under 5000 ohms (Ω) in order to eliminate interference and optimise sensor sensitivity.

(6) Standardised instructions, instruments and procedures were followed and rapport established with the subjects prior to the commencement of the tasks.

(7) Experimenter bias was reduced by having a suitably skilled and experienced psychologist (the author of this thesis) administer the test sessions.

(8) All data records were checked for accuracy and completeness before and after being transferred to excel spreadsheets.

(9) Analyses were conducted using recognised data processing packages, in this case Excel and NCSS.

(10) The choice of statistical analyses was appropriate for the types of data being analysed.

(11) Standardising the data within each subject's own personal repertoire of results was required to compare data collected from each subject's personal best and first race.

7.4 VALUE OF THE STUDY

The study was undertaken to establish an objective measure to monitor flow under conditions of peak performance. This was done in order to expand the use of flow into the domains of coaching, training, and self-development for application in the workplace, sports field and leisure activities. Non-invasive technology, such as EEG, is regarded as suitable technology to measure flow since it produces reliable and credible feedback. It was therefore decided to use EEG equipment that was available to the researcher, which was *BrainMaster* 3.0 software using *Atlantis* I "4+4" (4 EEG and 4 Bio-potential channels) link to laptop computer.

The results obtained in the study were produced by a purposive sample consisting of experienced computer gamers. A PC video game was chosen as conduit to induce flow since computers are common and critical working instruments in a very large portion of the semi-skilled and skilled working environment. Although computyping as skill in a generalised work setting is different from using a game controller in a video game, it is still similar in that both activities require visuomotor coordination while performing a cognitive task in which the manual manipulation of the device is contributing to task efficiency. Since computer gaming is known for inducing flow (by design), it is considered a comparable medium for producing a neurological pattern for flow that is generic to most computer based tasks involving manual dexterity. Although the visuo-motor activities required for the experimental task share a number of visuo-motor activities in using computers in the work environment this cannot be assumed. Therefore the study should be replicated using different visuo-motor tasks. Also the sample was limited to age (above 16), handedness (right-handed), and gender (males), which will limit the generalisability of the protocol.

This study has identified neurological correlates of flow under conditions of peak performance on a continuous visuomotor response task which can be used as input to the development of a EEG measuring and monitoring device for application during training, coaching, self-development or other performance feedback situations.

The EEG correlates can be programmed into computer software that provides various forms of neurofeedback of being in the flow state. It is important that output should not be perceived consciously since it will act as detractor and thus cause the operator to disengage the flow state. Personal flow feedback has to be "disguised" as subtle background output only to be recognised unconsciously as reward for being in flow and further deepening the flow state. Subtle changing of light or colours or music may be suitable forms of feedback. The latter topic may require further research. Ethical considerations need being applied when used in the work place. Inducing flow under normal working conditions should lead to improved work performance, work enjoyment and work motivation.

Using the EEG correlates of flow as a flow monitoring (no feedback training) device is less complex since there is no feedback to the operator, only to the coach or "monitor". As monitoring device it has the potential to act as input to research, i.e. how often does the operator enters the flow state, how long does he/she remains in flow, how does it correlate with level of performance, what caused the person to "fall" out of flow. This research can be valuable input to the coach or consultant during performance reviews or for suggesting changes to the environment (work or otherwise) to facilitate more flow opportunities. In terms of future work environment designs it could result in doing away with open plan offices and serve as impetus to buffering/parking/batching of telephone calls. In some work environments, such as flying an aircraft, performing surgery, monitoring CCTV, etc., duration of being in flow for a prolonged time period may become a future key performance indicator in terms of performance management. However, there may be ethical considerations which will limit the use of such devices based on the premise of invasion of privacy or being inhuman.

In summary, the value of this study is deemed the following :

(1) Confirms that flow is an identifiable mind state under conditions of peak performance.
(2) Provides crude neuropsychological- and neurophysiological models for flow.
(3) Provides a set of correlates for marking flow during a visuomotor task.
(4) Serves as a platform for further research.
(5) Serves as input for future technological development, especially in the consulting environment.
(6) Data can be used by neurofeedback practitioners.

7.5 LIMITATIONS OF THE CURRENT STUDY

A major limitation of the current study was the limited number of channels that were used due to the constraints of the technology available to the researcher. Since only four channels (eight scalp positions) were used, no temporal data were collected, and because of the montage used, no lateralisation of data was possible. The findings are thus limited to just four major source localisations, i.e. the Pre-frontal Cortex, the Sensori-motor area, the Parietal Cortex, and the Occipital area.

More advanced EEG technology would have shed more light on specific localities, modalities, inter-site connectivity, functional networks, brain lateralisation, etc. related to flow under conditions of peak performance. Because of the limitations of the 4-channel system used in this study, no temporal or lateralisation effects were explored. Kramer (2007), studying the predictive power of lateralised cortico-electrical patterns on performance during a visuo-spatial motor-response task (a video game specifically designed to induce flow), found that greater left temporal alpha activity, compared to that of the right temporal lobe, was a positive predictor of performance. Performance was also aided by higher mid-range beta in the left hemisphere. Haufler et al. (2000, 2002), contrasting EEG activity in novice and expert marksmen, reported that the experts exhibited higher levels of alpha power and lower levels of beta and gamma power at site T3. Crews and Landers (1993) reported an inhibitory increase in alpha power over the right hemisphere during skilled golf performance. None of the above research results could be tested' as a result of the mentioned limitations and were thus excluded in terms of the neurophysiological model for flow. The above research findings should be expanded by including EEG power and synchrony results related to inter- and intra-hemispheric and temporal differences.

Another limitation to the current study was the generalisability of the sample. The study was designed to minimise additional variance in an attempt to establish whether an EEG marker could be observed, therefore inter-subject variance was limited as far as possible. However, this feature has limited the generalisability of the results to over 16 year-old right-handed males.

The findings of this study have to be interpreted within the context of these limitations.

7.6 RECOMMENDATIONS

In order to address the limitations of the current study it is recommended that this study be expanded to include more EEG channels. It is proposed that a 19-channel system should provide the necessary coverage and data types since it is still based on the international 10/20 electrode placement system and the associated software is able to provide all the required statistical and topographic information necessary to fill the gaps left by this study. Dense array systems use a different referencing system which is not directly translatable to the 10/20 system used in this study. It is equally important that the study be expanded in to include children, females and lefthanders into the sample.

In order to establish how universal the above set of correlates is, it is recommended that the study be repeated using other visuomotor tasks, such as typing, active video tracking/monitoring, flight simulation, or air traffic control.

It is further recommended that other technologies such as fMRI, MEG, BOLD, etc. be included to provide additional information on flow and further enhance the neuropsychological model for flow. Biofeedback measures such as heart rate monitoring, body temperature, etc. can also be included in conjunction with EEG as a broader basis for flow measurement.

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APPENDIX A

Participant consent form

Participant

I have been asked to take part in a research study which also includes the use of EEG recordings. I hereby confirm that the researcher has informed me to my satisfaction about the nature, purpose, and benefits of the research study, including the use of EEG recordings. The researcher has also informed me that I can terminate my participation at any time. I was also made aware that my responses will be treated as completely confidential. Responses will be summarised so that individuals cannot be identified. Only summaries of findings will be reported. I therefore participate in this research study willingly.

Name and Surname of participant: ____

Signature of participant: ____

Date: _______________________

Researcher

I hereby confirm that I have informed the above participant about the nature, purpose and benefits of the research study. I also acknowledge that the participant is free to terminate his participation at any time.

Name and Surname of researcher: ____

Signature of researcher: ____

Date: _______________________

APPENDIX B

Permission to Participation consent form

Parent/Guardian

I confirm that my child has been asked to take part in a research study which also includes the use of EEG recordings. I acknowledge that my child's participation in this study is voluntary and I can stop his participation at any time. I hereby confirm that the researcher has informed me to my satisfaction about the nature, purpose, and benefits of the research study, including the use of EEG recordings. I was also made aware that my child's responses will be treated as completely confidential. I hereby agree to allow my child to participate in this research study.

Name and Surname of Parent/Guardian: ______________________________________

Signature of participant: ____

Date: ______________________

Researcher

I hereby confirm that I have informed the above parent/guardian about the nature, purpose and benefits of the research study. I also acknowledge that the participant is free to terminate his participation at any time.

Name and Surname of researcher: ____

Signature of researcher: ____

Date: ______________________

APPENDIX C

Biographical Data

Name : ________________________ Date : ____________________

A. Age :

16 -19	20 - 24	25 - 29	30 - 34	35 - 39	40 - 44	45 - 49	50+
1	2	3	4	5	6	7	8

B. Gender

Male	1
Female	2

C. Population Group

White	Coloured	Black	Indian	Other
1	2	3	4	5

D. Dominant Hand

Right	1
Left	2

E. Gaming Skill Level

Poor	Basic	Moderate	Good	Excellent
1	2	3	4	5

APPENDIX D

Game Flow Inventory (GFI)

The following 13 statements are about how you felt during the last activity.

Please read each statement carefully and decide how you felt.

Use the accompanied answer sheet and rating scale.

1. When I was racing, I thought about nothing else
2. I got carried away by the race
3. When I was racing, I forgot everything else around me
4. I was totally immersed in the race
5. The race gave me a good feeling
6. I was racing with a lot of enjoyment
7. I felt happy during the race
8. I felt cheerful during the race
9. I would still do this activity, even if I received less reward
10. I would like to continue racing, just for the fun of it
11. I raced because I enjoyed it
12. When I was racing, I was doing it for myself
13. I got my motivation from the race / activity itself, and not from the reward for it.

GFI Answer Sheet

Mark your response by placing a cross (X) in the appropriate box.

Quest. No.	Answers						
	Never	Almost Never	Sometimes	Regularly	Often	Very Often	Always
1	1	2	3	4	5	6	7
2	1	2	3	4	5	6	7
3	1	2	3	4	5	6	7
4	1	2	3	4	5	6	7
5	1	2	3	4	5	6	7
6	1	2	3	4	5	6	7
7	1	2	3	4	5	6	7
8	1	2	3	4	5	6	7
9	1	2	3	4	5	6	7
10	1	2	3	4	5	6	7
11	1	2	3	4	5	6	7
12	1	2	3	4	5	6	7
13	1	2	3	4	5	6	7
	Never	Almost Never	Sometimes	Regularly	Often	Very Often	Always

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APPENDIX E

Abbreviated Flow Questionnaire (AFQ)

Introduction

This questionnaire will serve as a quick, inter-activity survey regarding your experience during the preceding activity. You will be required to complete this short questionnaire, only five questions, every time you have completed an activity. When responding to the questions think about your experience during the just completed activity.

Instructions

- Answer each question by rating it according to the scale provided. Mark your response with a cross (X) on the provided answer sheet.
- This is a survey about your experience during and after the activity.
- There are no right or wrong answers.
- Do not make any marks on the questionnaire.
- There is no time limit.
- If you have any questions, please ask the administrator.

Abbreviated Flow Questionnaire : Racing *(Need for Speed)*

Question 1

During the race my perception of time was :

1	2	3	4	5
It was a drag	It felt longer than what it really was	I kept track of time	It felt shorter than what it really was	I lost track of time

Question 2

During the race my level of engagement was :

1	2	3	4	5
I felt totally disengaged	I felt distracted and not fully engaged	I felt engaged but not immersed	I felt immersed but distracted at times	I felt totally immersed

Question 3

During the race my level of skill-challenge was :

1	2	3	4	5
My skill is good, I am just not motivated	The challenge is OK, I am still learning	The challenge exceeded my skill level	My skill far exceeded the challenge	A perfect match

Question 4

During the race my perception of control was :

1	2	3	4	5
I never felt in control	I seldom felt in control	Occasionally I felt in control	I felt in control most of the time	I felt in control the whole time

Question 5

After the race my level of accomplishment (intrinsic reward) was :

1	2	3	4	5
I felt unsuccessful and disappointed	I felt unsuccessful but not disappointed	I felt that I had not entirely succeeded	I felt somewhat accomplished but not satisfied	I felt highly accomplished and satisfied

ANSWER SHEET : Abbreviated Flow Questionnaire

NAME : ________________________________ DATE : _______________

AGE : _____________ MALE / FEMALE

Mark your responses with a cross (**X**) using the sheet below.

Run 1	**Quest**	**Responses**							
Time	**1**	1	2	3	4	5			
Engagement	**2**	1	2	3	4	5			
Challenge	**3**	1	2	3	4	5			
Control	**4**	1	2	3	4	5	**Total**	**%**	**Run Time**
Accomplish	**5**	1	2	3	4	5			

Run 2	**Quest**	**Responses**							
Time	**1**	1	2	3	4	5			
Engagement	**2**	1	2	3	4	5			
Challenge	**3**	1	2	3	4	5			
Control	**4**	1	2	3	4	5	**Total**	**%**	**Run Time**
Accomplish	**5**	1	2	3	4	5			

Run 3	**Quest**	**Responses**							
Time	**1**	1	2	3	4	5			
Engagement	**2**	1	2	3	4	5			
Challenge	**3**	1	2	3	4	5			
Control	**4**	1	2	3	4	5	**Total**	**%**	**Run Time**
Accomplish	**5**	1	2	3	4	5			

Run 4	**Quest**	**Responses**							
Time	**1**	1	2	3	4	5			
Engagement	**2**	1	2	3	4	5			
Challenge	**3**	1	2	3	4	5			
Control	**4**	1	2	3	4	5	**Total**	**%**	**Run Time**
Accomplish	**5**	1	2	3	4	5			

Run 5	**Quest**	**Responses**							
Time	**1**	1	2	3	4	5			
Engagement	**2**	1	2	3	4	5			
Challenge	**3**	1	2	3	4	5			
Control	**4**	1	2	3	4	5	**Total**	**%**	**Run Time**
Accomplish	**5**	1	2	3	4	5			

Run 6	**Quest**	**Responses**							
Time	**1**	1	2	3	4	5			
Engagement	**2**	1	2	3	4	5			
Challenge	**3**	1	2	3	4	5			
Control	**4**	1	2	3	4	5	**Total**	**%**	**Run Time**
Accomplish	**5**	1	2	3	4	5			

Run 7	**Quest**	**Responses**							
Time	**1**	1	2	3	4	5			
Engagement	**2**	1	2	3	4	5			
Challenge	**3**	1	2	3	4	5			
Control	**4**	1	2	3	4	5	**Total**	**%**	**Run Time**
Accomplish	**5**	1	2	3	4	5			

Run 8	**Quest**	**Responses**							
Time	**1**	1	2	3	4	5			
Engagement	**2**	1	2	3	4	5			
Challenge	**3**	1	2	3	4	5			
Control	**4**	1	2	3	4	5	**Total**	**%**	**Run Time**
Accomplish	**5**	1	2	3	4	5			

Run 9	**Quest**	**Responses**							
Time	**1**	1	2	3	4	5			
Engagement	**2**	1	2	3	4	5			
Challenge	**3**	1	2	3	4	5			
Control	**4**	1	2	3	4	5	**Total**	**%**	**Run Time**
Accomplish	**5**	1	2	3	4	5			

Run 10	**Quest**	**Responses**							
Time	**1**	1	2	3	4	5			
Engagement	**2**	1	2	3	4	5			
Challenge	**3**	1	2	3	4	5			
Control	**4**	1	2	3	4	5	**Total**	**%**	**Run Time**
Accomplish	**5**	1	2	3	4	5			

Notes

File Numbers :