Goldsmiths
UNIVERSITY OF LONDON

EEG Neurofeedback as a tool to modulate creativity in music performance.

Joseph Leach

Submitted in total fulfilment of the requirements
of the degree of Doctor of Philosophy

April 7, 2014

Department of Psychology

Declaration

I declare that the work presented in this thesis is my own, and that no portion of this work has been submitted in support of an application for another degree of this or any other university, or institute of learning.

Abstract

For millennia, anecdotal reports have described how creative insights have been experienced during the transition from wake to sleep (hypnagogia). In the 1970's, it was reported that the fleeting moments in which hypnagogia and creativity interact are accompanied by characteristic neuroelectric activity, which is disclosed by a specific feature of the Electroencephalogram (EEG): the increase of spectral power in the theta range (5–8 Hz) in relation to alpha (8–11 Hz). Consequently, prior research, and experiments documented in this thesis, have attempted to modulate the relationship between hypnagogia and creativity using EEG biofeedback.

The current thesis charts the historical development of EEG neurofeedback, and evaluates the application of the two neurofeedback methods used most widely by clinicians: the alpha-theta and SMR protocols. Both therapeutic and 'optimal performance' contexts are considered; the latter of which includes the study of creative behaviour in musicians, which in turn constitutes the area of experimental observation studied here.

The first of three experiments found that prior findings relating neurofeedback to improvement in instrumental solo performance were replicable with the caveat that improving participants started from low baseline scores, and also further isolated the effects of neurofeedback on creativity by suggesting differences in the performance of spontaneous music creation following alpha-theta neurofeedback compared to controls. The second argued that short-term effects of neurofeedback are different from the longer-term outcomes, finding that an alpha-theta intervention impairs music performance in the short-term. The final experiment found that inhibitory activity in the frontal and parietal lobes, distinguishes piano improvisation from the rendition of a score.

Overall, this thesis makes the case that creativity, hypnagogia and music improvisation share a common neurophyisology, and that this may be open to regulation by the application of neurofeedback training that regulates alpha and theta EEG.

Acknowledgements

I feel especially indebted to the unnamed participants who volunteered for the studies and gave many hours of their time.

The musical judges also contributed many hours of their time to this research, selecting and evaluating tasks: Linda Hirst, Patricia Holmes and Sophie Grimmer. Together with the participants, they provided the all important data.

I would like to thank my supervisor John Gruzelier for developing me as a researcher, and for providing me with a glimpse into the exciting field of applied neuroscience. I'd also like to thank Graham Welch and Adrian Burgess for helping me to improve an earlier version of this dissertation, and Philomena Kelly and my daughters, who supported me throughout.

I worked closely with Tony Steffert, Felicia Cheng, Kate Bulpin, Shama Rahman and Alexander Rass, who collaborated with me on some of the experiments in this thesis.

Several of my colleagues encouraged me with their enthusiasm for neurofeedback research: Tomas Ros, Max Chen, Boris Kleber and Aisha Cortoos.

There are several researchers I was pleased to meet and correspond with during the course of my study: Arne Dietrich for his challenging and beautiful writing on creativity and consciousness, Tom Perchard for sharing his understanding of the many types of improvisation, and Sam Thompson and Evangelos Himonides for their guidance on music evaluation.

Thanks to the staff at Goldsmiths who helped to keep my studies afloat during difficult times: Pam Heaton, Lesley Hewings, Jo Mackarell, Elaine Thompson, Anne Craven, Lauren Stewart and Frank Bond.

Finally, thanks to NESTA, Goldsmiths and Philomena Kelly for supporting this research.

Contents

List of Figures

List of Tables

1 Introduction

1.1 Summary

This chapter reviews developments in neuroscience, psychology and music performance that led to the experimental studies presented in this dissertation.

Initially the electroencephalograph (EEG) and its use in the application of EEG biofeedback training, also called neurofeedback training (NFT) will be described. The historical origins of NFT methods used today will be briefly summarised, prior to a more detailed analysis of the empirical literature specific to the 'Optimal performance' application of NFT in healthy subjects. The clinical NFT literature is also surveyed in Appendices A and B on page 271). The proposed link between NFT and creativity will be introduced.

Creativity will then be examined, beginning with a review of how scientists have tried to make it experimentally tractable, although after 60+ years of discussions, this remains a problematic issue — for the purposes of this dissertation, creativity is viewed as an interplay between spontaneous emotional neural processes and the social responses that these evoke.

Hypnagogia, a candidate neural correlate of creativity, is then examined as a potential mechanism for regulating spontaneous emotional content processing. This is related to the NFT literature.

Finally, music improvisation is presented as an experimental method for observing both creative processing *and* the evoked social response.

1.2 Electrophysiology in the brain, and neurofeedback applications

1.2.1 The physiological origins of EEG oscillations

Neurofeedback is applied as a means of facilitating the self-regulation of neurophysiology: the feedback itself typically takes the form of information about electrical neuronal activity recorded from the scalp (EEG), with some indication as to whether aspects of synaptic activity are to be encouraged or inhibited in line with the associated brain state that is being trained. A short description of the EEG signal itself is given here as a precursor to describing its uses in NFT.

1.2.1.1 The origins of distinct EEG frequencies

A single electrode on the scalp will detect changes in the field potential of thousands to millions of neurons on the surface of the cortex across a localised area of approximately 10 cm^2 (Klein and Thorne, 2006). The main source of activity detected by a scalp electrode is the synchronous fluctuation in the electrical potential of the membranes of postsynaptic neurons. The term postsynaptic refers to a neuron whose synaptic receptors have just taken up neurotransmitters following their release by a presynaptic neuron, which in turn follows the triggering of an action potential in that cell. As neurotransmitters bind to a neuron, its cell membrane changes in its permeability allowing ions to flow between the cell wall and its surrounding environment, which in turn effects changes to its resting potential of approximately -70 millivolts (mV). Depending on the type of neurotransmitter that is binding to the postsynaptic neuron, the cell membrane either depolarises and its potential moves closer to 0, or it hyperpolarises and its potential falls further. Depolarisation occurs when an excitatory neurotransmitter, principally glutamate (van den Pol et al., 1990), is taken up at several synapses, and the subsequent inflow of positive ions and/or outflow of negative ions through the cell membrane increases its voltage. If the cell membrane voltage depolarises to more than the action potential threshold of -55mV, an action potential is triggered, which then repeats the process of neurotransmission in connected postsynaptic neurons. If however the neurotransmitter being bound to the post-synaptic neuron is inhibitory the cell membrane hyperpolarises, reducing the likelihood that the cell will produce an action potential (Bullock et al., 1977). Although action potentials are integral to neurotransmission they are not thought to contribute greatly to scalp EEG measures, which instead reflect rhythmic changes in ionic currents around dendrites in large numbers of postsynaptic neurons close to the surface electrode (Whittingstall and Logothetis, 2009).

The frequencies Either visual or spectral analysis of the EEG signal indicate that large numbers of neurons oscillate within a range of distinct frequency ranges. The EEG is described as being made up of several 'band' components broadly categorised as:

- Slow wave (0.1 to 1 Hz)
- Delta (1 to 4 Hz),
- Theta (4 to 8 Hz),
- Alpha (8 to 13 Hz),
- Beta (13 to 30 Hz)
- Gamma (greater than 40 Hz).

Each of these specific frequency ranges is entrained by a pacemaking property of neurons, either by intrinsically generating oscillations in electrical voltage, or by interacting with other neurons in an excitatory/inhibitory pattern, or in a combination of the above (Steriade et al., 1990). Nonetheless, the drivers behind many of the EEG frequencies have yet to be confirmed, and it is only in the case of the rhythmic activity arising from a network of neurons in the cortex, the reticular thalamus and the dorsal thalamus that the process generating sleep EEG phenomena has been fully elucidated.

1.2.1.2 Sleep EEG and the thalamocortical circuit

The thalamocortical circuit has a functional role in governing transitions between arousal and sleep, and the EEG oscillations that are observed during these states are generated in the thalamus either alone or in concert with the cortex (Steriade et al., 1993b). The thalamus is the main gateway for the flow of incoming information to the cortex, and in sleep a formation of cells in the reticular thalamus block this flow by inducing inhibitory postsynaptic potentials in the dorsal thalamus, closing the brain to signals from the outside world. During sleep onset cortical neurons spontaneously oscillate creating a characteristic shape in the EEG known as the K-complex (Loomis et al., 1938), a functionally significant phenomenon that governs increasing hyperpolarisation of thalamic neurons by triggering two types of oscillatory activity that regulate sleep (Amzica and Steriade, 2002). Firstly, the cortical neurons that initiate a K-complex project along downward connections to large numbers of reticular thalamic nuclei. Intracellular field potentials measured in these cells show a 2–3 second series of inhibitory postsynaptic 7–14 Hz activity referred to as "sleep spindles" due to their visual appearance on an EEG trace. Reticular thalamic cells synchronously hyperpolarise dorsal thalamic cells which, following a large decrease of positive charge, experience a rebound of positive ions back into the cell triggering a burst of action potentials that stimulate excitatory action potentials in connected pyramidal cells the cortex. These cortical potentials mirror the thalamic oscillations with the same 7–14 Hz in the scalp EEG. Secondly, the cortical K-complex also prefigures the widespread formation of delta oscillations in the dorsal thalamus, which are more hyperpolarised than during the production of sleep spindles, indicating the progression into a deeper level of sleep (Steriade et al., 1993b).

Evidence that the generation of sleep oscillations emanate from the thalamus has been obtained from *in vivo* and *in vitro* experiments that isolated and measured activity in each brain area in the thalamocortical network independently. It has thus been found that when severing network connections, sleep spindles only continue to occur in reticular thalamic cells (Steriade et al., 1987), and that the same is true of the dorsal thalamus in generating delta oscillations (Steriade et al., 1991). These findings have provided evidence that spontaneously firing cells act as a 'pacemaker' for oscillatory activity, and have the functional role of maintaining the brain at rest, allowing cellular energetic stores to be replenished. During wakefulness, the production of sleep oscillations in thalamic and reticular thalamic nuclei is prevented by the release of various neurotransmitters (acetylcholine, norepinephrine, serotonin, histamine and glutamate) from the upper brainstem, posterior thalamus and basal forebrain. *In vivo* studies have shown that electrical stimulation of cholinergic or noradrenergic neurons, or insertion of acetylcholine or norepinephrine into the thalamus depolarises thalamocortical cells (McCormick and Huguenard, 1992), suppressing the formation of delta oscillations, and norepinephrine and serotonin depolarise reticular thalamic nuclei, preventing sleep spindles (McCormick et al., 1993), and these patterns also disappear from scalp recorded EEG and are replaced by fast-wave activity caused by depolarisation of pyramidal cells (Steriade et al., 1993a).

1.2.1.3 Non-sleep EEG phenomena

Whilst the pacemakers underlying the production of EEG signatures prevalent during sleep and awakening have been isolated, other rhythmic components of the EEG are not as clearly understood.

Theta EEG Theta wave EEG is thought to arise from the limbic system with network activity that reflects the on-line state of the hippocampus in humans, a brain area involved in the encoding of new autobiographical or spatial information in working memory (Buzsáki, 2005). The theta rhythm is observed in frontal midline areas of the cortex during working memory task processing, however the process by which this oscillation emerges remains the subject of continued exploration (Buzsáki, 2002). Theta waves are also found in widespread areas of the cortex during drowsiness, sleep transition and REM sleep, however it has been demonstrated that they are not coherent with accompanying theta oscillations measured in the hippocampus (Cantero et al., 2003). It has therefore been proposed that cortical and hippocampal theta waves may be produced by unrelated mechanisms.

Alpha EEG Alpha band EEG is also the subject of continuing investigation as to its origin. Like sleep oscillations alpha generation was initially associated with the thalamocortical circuit (Andersen and Andersson, 1968), however the attempts of subsequent research to clarify this assertion, have resulted in a number of different mechanisms being proposed with both intracortical and corticothalamic coherence being implicated in alpha pace setting (da Silva et al., 1973). A lesion study in which thalamic alpha was measured in decorticated cats demonstrated that in the absence of cortical projections, thalamic oscillations were disorganised and lacked localised synchrony, indicating that thalamic alpha is moderated by the cortex (Contreras et al., 1996). More recent studies that combined neuroelectric (EEG) and neuroimaging (PET/fMRI) measures provided further evidence that increased alpha power in the EEG was positively correlated with thalamic metabolism (Schreckenberger et al., 2004) or

MRI signal (Goldman et al., 2002). The PET study measured alpha activity following the effects of the sedative lorazepam against a placebo control, and additionally reported that the close functional relationship between the cortex and thalamus in the production of alpha rhythms is not affected by the amount of incoming sensory information. This finding along with the lesion study suggests that as a sensory gateway, the thalamus is less implicated in the generation of the alpha rhythm than the sleep rhythms described previously, and that alpha activity might be more likely to stem from network interactions.

Beta and gamma EEG The origins of faster beta and gamma rhythms also remain only partly disclosed, partly due to the large number of ways in which these rhythms are generated. The depolarisation of cortical cells occurs intrinsically in both somatosensory and visual cortices (Gray and McCormick, 1996) as a function of wakeful modes of processing including movement and sensory perception. Network interactions between cortical neurons also serve to generate fast rhythms, and these possibly arise from the integration of different sources of sensory information in time (Singer and Gray, 1995), whilst pre-thalamic sites such as the cerebellum have additionally been implicated in the initiation of fast rhythms (Timofeev and Steriade, 1997).

In summary, and taking into consideration the previously described EEG frequencies, it can be broadly stated that with the exception of theta rhythms possibly mediated by interaction with the limbic system, the modulation of EEG rhythms in a neurofeedback application would typically effect changes in network activity amongst cortical neurons below the electrode and the other cortical or thalamic neurons they interact with. Changes in rhythmicity would be effected through direct alteration of neuronal excitability in specific cells, through changes to neuromodulator systems, or a combination of the two.

1.3 A Brief History of Neurofeedback

This section will start by briefly introducing the different types of neurofeedback applications in current use, before summarising the discoveries that led to the formation of the two EEG biofeedback protocols most widely used today: the alpha-theta and sensorimotor rhythm (SMR) protocols.

1.3.1 The foundation of neurofeedback methods

Neurofeedback is part of a wider group of biofeedback applications, all of which have the goal of facilitating the self-regulation of physiological functions with the goal of normalising them in clinical populations or optimising them in healthy subjects. In the earliest experiments that went on to influence the subsequent development of neurofeedback methods, researchers sought to establish whether operant conditioning (Skinner, 1937) methods could be used to direct changes in the EEG (Kamiya, 1962; Wyrwicka and Sterman, 1968).

1.3.1.1 Early EEG studies

In the first studies (Kamiya, 1962) subjects were asked to keep their eyes closed and periodically prompted to report whether they were producing dominant alpha waves or not. Participants were also told whether they were responding correctly, and they exhibited an increasing ability to associate with subjective experience with the presence of alpha EEG oscillations. In following research, participants demonstrated their ability to produce alpha oscillations on demand, effectively bringing EEG parameters under operant control (Kamiya, 1969). A different type of EEG oscillation, the SMR rhythm, was found to be controllable by cats that learned to associate the inhibition of the sensorimotor system in order to be rewarded with food (Wyrwicka and Sterman, 1968).

Developing from the initial use of retrospective verbal or behavioural indicators of operant control, realtime biofeedback methods became more closely integrated into the practice of NFT. The control of the EEG component under review is facilitated by the provision of simultaneous feedback of the current state of that component, usually in the form of a continuous representation of the EEG, which is combined with positive reinforcement if the desired response takes place, or negative reinforcement if an undesired response occurs. In this way the activity of populations of cortical neurons and the subcortical networks they are a part of can be directed to behave in a targeted way, and their ability to do so is both continuously monitored *and* appraised.

Figure 1.1: Joe Kamiya pictured recording EEG in 1972

1.3.1.2 Slow cortical potentials and fMRI studies

Following from the discovery that EEG oscillations could be adjusted by combining self-monitoring with operant conditioning methods a number of other cortical and subcortical measures have been shown to be open to learned self-regulation by means of biofeedback.

Slow cortical potentials Slow cortical potential (SCP) changes reflect gradual changes in the DC polarity of cortical neurons, and thus the likelihood of an action potential being produced — which is referred to as the excitability of a neuron. SCPs have been demonstrated to be both associated with specific brain functions and modifiable by self-regulation with consequent effects on those functions. Increased cortical excitability is correlated with epileptic seizure (Speckmann and Elger, 1991), and a group of researchers in Tübingen investigating the self-regulation of SCPs have demonstrated that it can reduce the frequency of seizures in epileptic patients by raising cortical excitation thresholds (Birbaumer et al., 1991; Daum et al., 1993; Birbaumer, 1999; Strehl et al., 2006). In another SCP application, the lowering of excitatory thresholds has been found to offset hyperactivity and inattention symptoms in ADHD (Gevensleben et al., 2009b). Whilst it operates as a distinct neurofeedback protocol, SCP is thought to moderate the same underlying neurophysiology as SMR biofeedback training. Both protocols have been found to have similar effects in treating epilepsy *and* ADHD, and both procedures are used to modulate cortical excitability: slow potentials reflect the polarity of apical dendrites of cortical pyramidal neurons, whilst the SMR rhythm reflects inhibition of the sensorimotor system (Sterman and Egner, 2006; Egner and Sterman, 2006). Neuroimaging of the basal ganglia has demonstrated that increase of SCPs and the presence of SMR oscillations are both associated with increased metabolic activity in the striatum of the basal ganglia nuclear complex, which suggests a shared mechanism underlying both forms of training (Birbaumer, 2006).

fMRI Since the 1990's the development of functional magnetic resonance imaging (fMRI), a non-invasive measure of blood oxygen within cerebral structures has seen it change from being purely retrospective in terms of its utility, to having the potential for realtime applications including neurofeedback training and brain computer interfaces (BCIs). The most widely used fMRI method is the measure of the Blood Oxygenation Level Dependency BOLD response that follows neuronal activation. When a neuron acts upon incoming neurotransmission (Logothetis et al., 2001), it exhausts its supply of glucose and oxygen, and the process of hemodynamic response takes place subsequently by increasing blood flow to that neuron in order to replenish the cell stores of energy. The movement of oxygenated blood into a brain area increases the ratio of oxyhemoglobin to deoxyhemoglobin in the surrounding veins, and this change, as observed by fMRI, is directly related to brain function (Raichle, 2009).

In its application in cognitive neuroscience, the BOLD response under a test condition is contrasted with that observed during a control condition, and the resulting difference indicates which brain areas were functionally (in)active during task processing. The three dimensional image of the BOLD response is spatially accurate up to 1 millimetre, and the entire brain is imaged, however, it takes up to six seconds following neural activity for the BOLD signal to reach its peak, and the timing of activations are approximate. If two separate neural assemblies were active within a short timespan, it would not be possible to infer which area was active at which point.

Starting in the 2000's the first attempts at analysing fMRI in realtime began, firstly with an application that sought to re-calibrate images following head motion in the scanner (Thesen et al., 2000). The authors argued that on-the-fly head motion correction gave better measurement of BOLD responses indicated by greater test-retest reliability. In 2002 it was reported that retrospective visual feedback of neural activations in the somatosensory cortex following a short simple hand motor task could be used in assisting participants to activate wider somatosensory areas (Yoo and Jolesz, 2002). This finding provided the first evidence that the BOLD response could be brought under operant control, even with an activity-feedback latency of 60 seconds.

Whilst near-realtime feedback was shown to have utility in an operant conditioning exercise, the need to be able give a time specific representation of brain activity remains pressing, as has been discussed previously. Spatially separate brain activations that occur within a short timeframe might not be temporally distinguished in measures of the BOLD response, and this distinction would be a requirement in a more complex task that required physiological self-regulation of more than one BOLD signal, for example distributed activity in the thalamocortical circuit, or concurrent processing in auditory and visual areas.

Attempts to reduce fMRI latency have considerably reduced the BOLD signal processing time to less than 2 seconds, largely by increasing the rapidity of signal processing, and using online signal estimation algorithms (deCharms et al., 2005; Hinds et al., 2010). The significance of this development is that once brain activation in specific areas can be self-regulated as an independent variable, the functional consequences on cognition, affect and behaviour can be assessed in experimental designs, with subsequent implications for clinical or cognitive questions (Weiskopf et al., 2004). The development of this technique remains largely in the experimental stages however, with methodological issues remaining central to research efforts.

1.3.1.3 The continued importance of EEG protocols

Despite the strong empirical support for the practical application of SCP neurofeedback, and the emerging potential for the self regulation of spatially distinct brain areas in near-realtime fMRI applications, EEG oscillations remain by far the most widely used training measure in clinical and research based NFT. The reason for this is probably due to the fact that EEG frequency components were the first measures of neuronal activity to be used in clinical applications in the 1960's, and have remained in use ever since, building a significant foundation from which to conduct follow-on work.

Not only is EEG biofeedback the most widely used in clinical practice, it also has the highest public profile of any form of biofeedback. This is largely thanks to the popularisation of biofeedback in the 1970's that followed from the publication of several books by Barbara Brown, the first president of the Association for Applied Psychophysiology and Biofeedback (Brown, 1974, 1975a,b). Early meetings of this association were attended by a considerable number of members of the public (Robbins, 2008), and EEG biofeedback has a high level of awareness in the public sphere in contrast with more recently developed neurofeedback methods.

Modern EEG NFT Current EEG neurofeedback research falls into two distinct camps, on one hand, the slow-wave protocols (the alpha and alpha-theta protocols), and on the other the fast-wave protocols (such as SMR, beta or gamma enhancement protocols).

Fast-wave In recent years the quality and amount of research conducted in fast-wave protocols has increased rapidly, and to the extent that both rhythmic EEG and SCP biofeedback have been empirically demonstrated to function as clinical alternatives to pharmacological treatments for ADHD symptoms (for a review see the summary in Table B.1 on page 288 from Arns et al. (2009)).

Slow-wave Slow-wave regulation research has however has not seen such dramatic advances being made, although a small number of researchers in the US and UK (including my own lab) have continued to investigate this topic since the inception of the alpha-theta protocol in the mid 1970's (Green et al., 1974).

In addition to these 'standard' protocols, experimental neurofeedback applications have been tested in treating a range of conditions including autism, asthma, coma and tinnitus (Hammond, 2008). Nonetheless, alpha-theta and SMR based protocols continue to dominate the field, remaining the most extensively investigated and applied, and the ensuing historical and literature reviews will cover them both, showing how their clinical applications have developed. The literature review will also document more recent applications of NFT in 'peak-performance' applications designed to optimise brain functions in healthy subjects.

1.3.2 The history of slow-wave protocols

The modern alpha-theta protocol has its roots in the very first EEG neurofeedback training studies, which were based solely on the alpha rhythm. The first alpha conditioning studies are introduced here, along with the investigations into the role of alpha NFT as a possible treatment for anxiety. The decline in this particular line of inquiry is then charted, as is the subsequent shift towards investigating the application of the alpha-theta protocol during recovery from alcohol addiction.

1.3.2.1 Alpha NFT in anxiety

Joe Kamiya Joe Kamiya is considered the pioneer of NFT, and it is possible to trace a direct line of descent from his studies of the operant conditioning of cortical alpha oscillations to the current use of the alpha-theta protocol. His early investigations into alpha conditioning were contemporary with a number of biofeedback experiments that sought to determine whether physiological monitoring techniques might facilitate the self-regulation of autonomic functions previously thought to be beyond volitional control. These included skin conductance (Crider et al., 1966), heart rate (Engel and Chism, 1967), blood pressure (Shapiro et al., 1969), and evoked cortical potentials (Fox and Rudell, 1968), however alpha conditioning in particular captured the imagination of the public and the research community alike.

The historical background to Kamiya's early investigations into alpha band EEG as an index of anxiety and relaxation stemmed from the work of Berger, the pioneer of modern EEG measurements who, observed alpha oscillations in relaxed individuals sitting with their eyes closed in a darkened room (Berger, 1929). Berger noted these oscillations disappeared when the individual became either drowsy or in response to a stimulus that induced anxiety. It was later proposed that alpha might be related to physiological and subjective arousal and anxiety according to an inverse U-shaped function (Yerkes and Dodson, 1908; Jasper, 1936), with alpha indicating optimal arousal. Subsequently attempts were made to validate this proposal (Lindsley, 1952; Stennett, 1957), and the possible therapeutic relevance of alpha began to emerge as a means of regulating both over and under arousal (anxiety and dysphoria) (Orne and Wilson, 1978).

In his earliest alpha experiments, Kamiya determined that it was possible with a combination of practice and feedback, for individuals to discriminate the alpha state. In Kamiya (1962) the findings of an experiment were reported in which subjects kept their eyes closed and were given verbal feedback when 8–12 Hz oscillations were present in measurements of occipital EEG. It was found that a significant number of subjects formed reliable associations between subjective experiences of pleasant calmness and the presence of alpha oscillations. Towards the end of the decade, Kamiya documented a case study in which the subject sat in a dimly lit room and was trained to produce/block alpha by voluntarily controlling feedback (Kamiya, 1969).

Kamiya's findings were well received, and enthusiasm for alpha biofeedback spread rapidly, and a number of independent replications confirmed that experimental subjects could exert volitional control of alpha (Stoyva and Kamiya, 1968; Mullholland, 1968; Brown, 1970a,b). With the exception of Mullholland (1968), these studies found that the alpha state was accompanied by subjective feelings of relaxation. From that point, the possible therapeutic application of alpha training began to be explored in earnest and Hardt and Kamiya (1978) reported that alpha training had a significant effect in reducing high (but not moderate) levels of trait-anxiety.

Martin Orne Not all attempts to replicate Kamiya's findings were able to demonstrate a clear link between alpha and relaxation. Paskewitz and Orne (1973) found that alpha increases were possibly predicted by eye lens refraction, which would in turn lead to inhibitory activity in the visual cortex. By testing subjects in complete darkness, they found that training levels of alpha simply returned to pre-training baseline levels. The authors also refuted the proposed inverse-U shaped relation between alpha and arousal (Lindsley, 1952; Stennett, 1957), finding alpha during both high arousal (fear of painful electric shock) and during changes in arousal during sleep (Orne and Wilson, 1978). The proposed link between alpha and anxiety was further weakened by Plotkin and Rice (1981), who reported a placebo effect wherein both alpha suppression and enhancement facilitated anxiety reduction.

By the end of the 1970's, ongoing investigations into alpha-biofeedback as therapy for anxiety had ground to a halt. Several factors were responsible for this: Paskewitz and Orne's (1973) discovery of confounding visual and placebo factors, the difficulties involved in comparing wide ranging individual differences in alpha production

(Kamiya, 1969), and Orne and Wilson's (1978) realisation that alpha production did not modulate as an inverse-U shaped function of neurophysiological arousal.

1.3.2.2 Alpha-Theta NFT and alcohol recovery

Treating alpha deficiency and using theta therapeutically Although the alpha-anxiety relationship was largely disproved during the 1970's, another potential application of alpha biofeedback training emerged at this time. On the basis that those predisposed to alcohol addiction exhibited a deficiency of alpha production compared to controls (Funderburk, 1949), and that ethanol induces alpha production, a rationale was derived for treating alcoholism with alpha biofeedback training. A series of case studies were published during this period which suggested that neurofeedback procedures might have clinical efficacy in treating substance use disorder (SUD), and alpha training was reported to reduce anxiety in alcoholics (Passini et al., 1977; Watson et al., 1978).

Also during 1970's, and based on early observations of a 'crossover' from alpha to theta wave dominance in meditation (Green et al., 1970) (see Figure 1.2), a new NFT procedure, the alpha-theta protocol, was developed to facilitate deeper relaxation than alpha NFT (Green et al., 1974). The transition from alpha to theta signal dominance is one of a set of phenomena that occur during SLEEP STAGE I and is referred to as the hypnagogic state (Schacter, 1976). This transient period is also characterised by qualitative changes in mental content (Tanaka et al., 1996) and reductions in muscle tone (which can lead to a sensation of falling which triggers the involuntary hypnagogic myoclonus), and Green et al. (1970) reported that the point of crossover was aligned to subjective reports of profound relaxation and reverie accompanied by a sense of focus. The first applications of the alpha-theta protocol were reported in uncontrolled studies of its use in supporting alcohol withdrawal by augmenting psychotherapy with controlled relaxation (Goslinga, 1975), promoting self-actualisation as a product of imagery experienced in theta states (Twemlow and Bowen, 1976), and promoting insight and attitude change (Twemlow et al., 1977).

The Peniston protocol It was from these initial attempts to treat SUD with alpha and then alpha-theta NFT, that this form of relaxation based EEG training was ultimately given a further opportunity to demonstrate its practical use. Following a ten-year

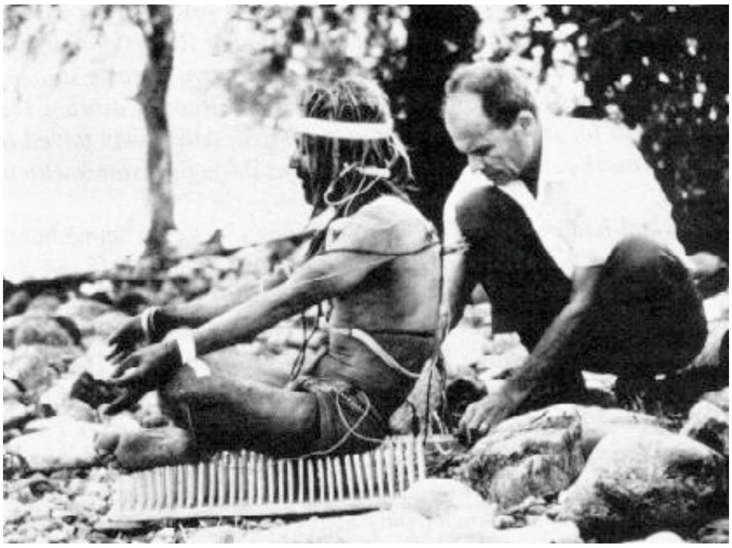


Figure 1.2: Elmer Green pictured recording the EEG of yogic meditation.

hiatus, it was reported that a combination of alpha-theta NFT, temperature biofeedback and guided imagery normalised the EEG of recovering alcoholics and improved long-term abstention (Peniston and Kulkosky, 1989). This combined treatment came to be known as the Peniston protocol. The same authors further applied alpha-theta NFT in the treatment of Post Traumatic Stress Disorder (PTSD), reporting that the use of hypnagogic imagery was used to reveal repressed traumatic memories during talk therapy.

Over the next ten years, independent attempts to describe the specific contribution of alpha-theta NFT in relation to the other components of the Peniston protocol were inconclusive, and subsequent alpha-theta research (but not practice) has abandoned the Peniston protocol. This has happened in two areas, firstly in clinical research (Scott and Kaiser, 1998; Scott et al., 2002, 2005), or in 'optimal performance' applications that have searched for NFT effects in healthy subjects as they undertake lab-based cognitive or real-world performing arts exercises (Egner et al., 2002; Egner and Gruzelier, 2003; Egner et al., 2004; Egner and Gruzelier, 2004a; Raymond et al., 2005a,b).

The clinical alpha and alpha-theta NFT literature is reviewed in Appendix A on page 250, and the optimal performance alpha-theta literature is reviewed in Section 1.4.3.2 on page 43.

1.3.3 The history of fast-wave protocols

1.3.3.1 SMR NFT in epilepsy

Barry Sterman The second main strand of NFT research was pioneered by Barry Sterman's research laboratory investigating operant conditioning in cats (Roth et al., 1967; Sterman and Wyrwicka, 1967; Wyrwicka and Sterman, 1968). At the time, the EEG correlates of sleep onset had begun to be investigated, and Barry Sterman and his colleagues used EEG measurements to compare sleep to Ivan Pavlov's proposed state of 'internal inhibition.'[1]

Cats were initially taught to gain food rewards by pressing a lever. Then a tone acting as a 'conditional stimulus' was gradually associated with absence of reward: pressing the lever when the tone sounded prevented reward and prolonged the tone sound; the cats would have to use internal inhibition to prevent the lever pressing response until the tone stopped. However, unlike Pavlov's dogs, the cats responded by assuming a motionless posture, much like that of hunting cat waiting to attack (see Figure 1.3). The EEG correlate of this response was the appearance of a distinct rhythm (12–20 Hz with spectral power peaking at 12–14 Hz) over the sensorimotor cortex leading the authors to label it the Sensorimotor Rhythm (SMR). They also observed that it was similar to EEG spindles observed in SLEEP STAGE II and suggested that the elicited state of internal-inhibition did have similar physiological properties to sleep.

Noting that Kamiya (1962) had previously discussed self-regulation of the EEG alpha rhythm, Sterman then used SMR production in place of lever pressing and found it could be elicited voluntarily to obtain food Wyrwicka and Sterman (1968) (see Figure 1.4).

In addition to discovering SMR and that it could be self-regulated by cats, Sterman also found that SMR training could increase the epileptic seizure threshold by reducing cortical excitability. This discovery occurred when the cats that had participated in early SMR studies were amongst those recruited into an experiment investigating the epileptogenic properties of rocket fuel. Sterman found that cats who had previously

[1]Pavlov proposed that when conflicting conditioned responses are simultaneously elicited (i.e. reward and punishment), the organism enters a state of internal inhibition identical to sleep onset.

Figure 1.3: Bipolar EEG recordings from sensorimotor (coronal) and parietal (marginal) cortex in a cat during alert motionless waking behaviour and quiet (non-REM) sleep — Sterman et al. (1970). When cats were trying to suppress a conditioned response, the EEG signature over the Sensorimotor cortex resembled that of 'sleep spindling.' He termed it the Sensorimotor rhythm SMR due to its specific location in the brain.

Figure 1.4: SMR conditioning in polygraphic traces reported in Howe and Sterman (1972) at sites in descending order: Sensorimotor cortex (R Pre-Post Cruc Gy); Ventralis Posteriolateralis of thalamus (R VPL); Parietal cortex (L Post Morg Gy); plus Electro-oculogram (EOG), SMR signifier (12-14 CPS Relay) and finally the Feeder which denotes the conditioned reward for producing targeted SMR EEG. The parietal trace shows post reinforcement synchronisation (PRS), a response encoding reward.

learned to regulate SMR had a much higher seizure threshold compared to those that hadn't (Sterman et al., 1969). Subsequently a member of Sterman's lab who had epilepsy volunteered to undergo SMR training, and reported a reduction in seizures, and Sterman went on to conduct a series of studies establishing the clinical efficacy of SMR NFT in reducing epileptic seizure rates in humans (Sterman and Friar, 1972; Sterman et al., 1974; Sterman and Macdonald, 1978; Lantz and Sterman, 1988).

1.3.3.2 SMR/theta NFT in ADHD

Joel Lubar In response to Sterman's findings, a laboratory run by Joel Lubar began to explore SMR applications in relation to cortical excitability in Attention Deficit Hyperactive Disorder (ADHD). They modified the protocol to simultaneously elevate SMR whilst reducing theta (4–8 Hz) reporting that this protocol led to reductions in observations of hyperactive behaviour (Lubar and Shouse, 1976). This protocol was further modified to include the training of higher frequency EEG components in the beta range (16–22 Hz) in efforts to increase attentiveness in place of regulating motor excitability. Neurofeedback applications for ADHD have since gone on to become the most widely used forms of NFT in clinical and research use today, and the critical literature review will focus specifically on this these. The empirical rigour with which NFT for attention has been tested has recently enabled strong conclusions to be drawn as to its clinical efficacy (Arns et al., 2009), and, as with alpha-theta, 'optimal performance' applications of SMR NFT have begun to be explored.

The clinical fast-wave NFT literature is reviewed in Appendix B on page 271 and optimal performance fast-wave NFT, Section 1.4.3.3 on page 58.

1.4 Optimal Performance Neurofeedback

The previous sections briefly reviewed the historical development of what have gone on to become the two dominant training procedures used in EEG Neurofeedback: the slow-wave types used to reduce anxiety, substance use and PTSD, and the fast-wave types associated with treating epilepsy and ADHD.

This section will examine how NFT has come to be applied in healthy subjects, following a brief introduction to the background of NFT for healthy subjects, and a realisation of how the term 'Optimal performance' is used to define interventions that optmise physiology against impairments occurring under performance conditions.

1.4.1 The background to optimal performance applications of NFT

Despite the majority of NFT research being currently conducted through two broadly defined protocols, investigators occasionally test novel, mainly clinical applications of NFT including in autism, asthma, coma, tinnitus (Hammond, 2008).

In some cases, researchers have devised new protocols either by training at sites and/or frequencies based on theoretical considerations or abnormalities detected in topographical QEEG diagnostics. Nonetheless, it is slow-wave (alpha-theta) and fast-wave (beta/SMR) protocols that continue to dominate the field, and are the most extensively developed and tested. The ensuing literature review will cover these two approaches in depth.

The review will also show how the initial themes of clinical efficacy (which are reviewed in Appendices A on page 250 and B on page 271) have been extended into the more recent non-clinical applications of NFT in 'optimal performance' applications.

1.4.2 Problematising optimal performance

1.4.2.1 The Yerkes-Dodson law and performance anxiety

In physiology, the term optimal performance stems from the Yerkes-Dodson law (Yerkes and Dodson, 1908), which describes an inverse-U shaped relationship between arousal and performance. Increases in arousal predict improvements in performance up to an optimal level, beyond which performance degrades.

As described in Section 1.3.2 on page 32 Berger (1929) had noted that normal alpha wave EEG activity reduced in intensity during drowsiness or anxiety. Lindsley (1952); Stennett (1957) then proposed that alpha production might be related to physiological and anxiety according to the Yerkes-Dodson law and Kamiya (1962) tested NFT augmenting alpha regulation as a possible means of optimising the neurophysiology of anxiety. As has been demonstrated, the reports of Orne and Wilson (1978) and Plotkin and Rice (1981) contested the inverse-U shaped relationship between alpha and anxiety. Despite this, the idea that neurophysiological awareness can be learned and regulated to support the execution of a given task is still worthy of investigation. In the current work both the alpha-theta and SMR protocols are explored as possible ways of optimising music performance against the impairing effect of performance anxiety by training neural activity underlying spontaneous emotional creative expression and motor performance respectively.

1.4.2.2 Stage fright

Performance anxiety, commonly referred to as stage fright in performers, has been found to stem from the threat of evaluation (Brotons, 1994). Steptoe (1982) also reported that evaluation threat was the main source of anxiety for performers, and he examined different types of music performance for evidence of the role of performance anxiety in moderating self-perceived performance quality. His findings demonstrated a relationship that echoed the Yerkes-Dodson law (see Figure 1.5 on page 40): reportedly better performances were accompanied by a relatively medial degree of anxiety compared to low- and high-anxiety performance scenarios which were thought to elicit a lower standard of performance.

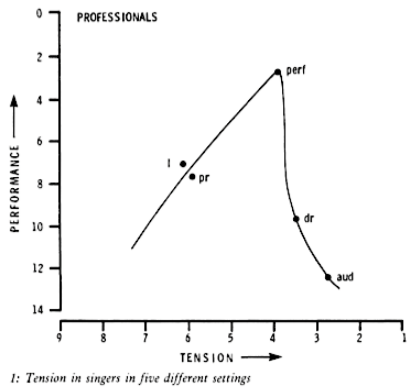


Figure 1.5: *from Steptoe (1982)*, who collected self-reported tension and performance quality data for musicians playing in (labels from left to right) **l**essons; **pr**actice; public **perf**ormance; **d**ress **r**ehearsal; **aud**ition.

So how does the threat of evaluation affect performance? Brotons (1994) described it as four ways of manifesting itself:

1. Physiological changes: e.g. increased heart rate, sweating, shortness of breath,

shaking, numb fingers, clammy hands, dry mouth, upset stomach, headache, dizziness, nausea, and diarrhoea.

2. Psychological/emotional conditions: e.g. exaggerated feelings of apprehension, fear of failure, irritability, and panic.
3. Cognitive problems: e.g. loss of confidence, lack of concentration because of worries about the situation, memory lapses, and inability to infuse life and colour into the music (Hingley, 1985).
4. Behavioural changes: e.g. lips moistening, knees and hands trembling, arm and neck stiffness, shoulder lifting, and deadpan face.

The potential for optimising neurophysiology with NFT to mitigate against the above symptoms can be defined according to the two training protocols currently being explored:

Threat and creative behaviour In applying the alpha-theta protocol, performance optimisation is defined as a means of regulating and thereby sustaining under threat, the neural processes that form spontaneous emotional responses (see Section 1.5.1 on page 72 for the working definition of creativity) against the drive for enhanced sensory processing. It has already been found that evaluation threat hinders performance on a divergent thinking task (Chamorro-Premuzic and Reichenbacher, 2008), and it may also be the case that the spontaneous emotional type of creativity is also diminished by this threat in less experienced performers (Kokotsaki and Davidson, 2003; Vuust et al., 2010).

The debilitating effect of fear on behaviours contributing to creativity are hypothesised to stem from a fight-or-flight type response, in which the signal-to-noise ratio is raised to increase sensory information processing capacity in a threatening situation — conversely, a creative response is thought to stem from distributed neural processes that take longer as they draw from more far reaching semantic networks (Heilman et al., 2003).

Threat and motor performance In applying the SMR protocol, optimal performance is defined as a means of mitigating against fear related impairments to the motor response. Given that Sterman and Friar (1972) used the protocol to suppress epileptic seizure, it may also be plausible that fine motor control, such as playing a musical instrument or singing, could be optimised against the impairment related to fear induced shaking for example. Impairments may differ according to the level of skill acquisition and expert music performers may have developed higher tolerance to stage fright so that they can actually benefit from it (Kokotsaki and Davidson, 2003; Vuust et al., 2010), whereas novice musicians may be more likely to suffer motor impairments without having developed such coping mechanisms.

1.4.2.3 Novice performance

As well as differentiating performance based on fear, skill acquisition is another factor that may be optimised by regulating neurophysiology.

Trained musicians are known to have highly developed interactions between auditory and motor processing in the brain, and incoming auditory stimuli can automatically evoke finger movements in pianists (Haueisen and Knösche, 2001), and expert musicians have also been found to be able to block stimulus driven sensory information in an improvising task (Berkowitz and Ansari, 2010). Whether the sensory-motor link can be optimised by NFT as well as sheer practice is a relatively new question, but Ros et al. (2009) reported that SMR NFT optimised perceptuomotor skills in novice micro-surgery. Novice musicians then, present another group whose sensory motor skills may be considered in relation to the sensory motor optimisations explored in SMR NFT.

1.4.2.4 Motor creativity

Brennan (1982) looked for inter-relationships between measures of 'Divergent thinking' and perceived creativity ability in dance. As Gorder (1980) had previously found with music creation, no real relationship existed, leading Brennan to conclude that the cognitive behaviours contributing to 'Divergent thinking' were distinct from "… divergent production in dance."

Considering that stage-fright has been argued to manifest differently in effecting cognitive and motor performance, and that spontaneous aspects of music performance such as jazz improvising trigger sequences of implicit procedures rather than explicit cortical representations (see Sections 1.5.3.3 (p.87) and 5.2.4 (p.206)) Brennan's distinction of creativity in motor production may be plausible. This then invites the research question "Based on Dietrich's (2004a) attempts to make creativity tractable, can creativity be further distinguished into explicit (higher-order cognitive responses) and implicit (reflexive motor responses) types?"

1.4.3 Review of optimal performance NFT applications

1.4.3.1 Comparing neurofeedback studies

In order to be able to systematically compare different neurofeedback studies, the following aspects of each NFT publication will (where possible) be evaluated: (a) the effect of neurofeedback on the EEG (b) the effect of neurofeedback on an outcome measure (c) evidence of covariance between the above, in order to demonstrate that the mechanisms governing changes in both are associated.

1.4.3.2 Slow-wave neurofeedback

The criticism of clinical alpha-theta training During the course of the study of clinical applications of the Peniston protocol (which combined alpha-theta NFT with thermal biofeedback and guided hypnagogic imagery — for a review, see Appendix A on page 250), a number of critical points were raised that cast doubt on the necessity of its alpha-theta NFT component in promoting therapeutically insightful hypnagogic EEG and imagery. Lowe (1999) and Moore et al. (2000) found that members of relaxation control groups modulated the theta/alpha (t/a) ratio just as effectively as those receiving alpha-theta training. These findings apparently confirmed the assertion by Sterman (1996) that alpha-theta feedback might not train a distinct theta state as proposed by Green and Green (1977) and Peniston and Kulkosky (1989) but rather "facilitates a functional transition towards sleep." Sterman concluded that whilst alpha-theta feedback may promote hypnagogia in practice, it does not bring it under operant control.

A renewed emphasis on alpha-theta and creatvity Perhaps because of the difficulties encountered by some replications of the Peniston studies, subsequent investigations of alpha-theta training have returned to the earlier theme of associations between theta and creativity (Green et al., 1972; Hall, 1977). Green had observed in two cases that 'reverie' accompanying theta production was associated with the manipulation of images leading to the creative synthesis of ideas and integrative experiences. Hall conducted follow-on work with 26 male college students, who apparently learned how to raise occipital alpha and theta waves, although no details of EEG measurements were documented. Hall's report did however describe the content of the students' hypnagogic imageries, which centred on their relationships, their self-regard, and their college work. Hall additionally observed that 20 of the students associated extended theta training with integrative experiences, commenting on the psychological benefits of the creative handling of these imageries.

Despite the anecdotal nature of Hall's (1977) two reports, they did pose the testable empirical question that theta, hypnagogia and creativity might be linked, and since the turn of the century this three-way link has become the rationale for testing applications of alpha-theta training in healthy populations. Subsequent work in this area has investigated the electrophysiological effects of alpha-theta NFT (Egner et al., 2002, 2004; Egner and Gruzelier, 2004a), its association with hypnagogic imagery (Boynton, 2001), and its effects on behavioural, cognitive and affective measures in healthy adults (Boynton, 2001; Egner and Gruzelier, 2003; Raymond et al., 2005a,b). Each of the relevant studies will be reviewed in the remainder of this section.

Alpha-theta literature In the first controlled experiment attempting to expand on prior associations between in alpha-theta training, hypnagogia and creativity Boynton (2001) explored the effects of the alpha-theta protocol by comparing it to an eyes closed relaxation control condition on measures of hypnagogic EEG and a psychometric measure of creative behaviour.

Boynton's participants were 62 in number, 29%/71% male/female, had a mean age of 46, and were rated as healthy on clinical measures of PTSD and anxiety. Participants were randomly allocated to NFT treatment (n=30) and control (n=32) conditions upon entry to the study, and went on to attend weekly 20-minute training sessions for 8 weeks in which they reclined in comfortable chair with their eyes closed. Training sessions were conducted in groups of between two and four people. All participants had alpha (8–12 Hz) and theta (4–8 Hz) frequency bands recorded from Pz, and were shown visual feedback of their EEG at the end of each session. Only NFT participants received real-time audio feedback, which consisted of alpha and theta mapped midi audio signals whose pitch modulated in line with fluctuations in signal amplitude. No details regarding instructions given to participants were reported.

Three measurements designed to identify hypnagogic EEG per session were used in this study; the t/a relationship was expressed as a proportion of their difference relative to their sum $(theta - alpha)/(theta + alpha)$.[2] In addition to the overall per-session measure of the t/a relationship, Boynton also measured the percentage of time spent in crossover (time where theta was greater than alpha), and finally the depth of crossover, expressed as the value of theta minus alpha during periods of crossover.

Creativity was measured with the Torrance Tests of Creative Thinking (Torrance, 1974) and the Alternate Uses Test (AUT) (Guilford, 1978). Both these tests are comprised of sub scales measuring fluency, flexibility and originality. In addition to operational measures of creativity, Boynton collected pre and post intervention assessments using the Friedman Well-Being Scale (Friedman, 1994), on the basis that creativity and well-being co-vary (Rogers, 1954; Maslow et al., 1963).

The results section of Boynton's report does not include any EEG data stating simply that there were no significant changes in any of the EEG measures used, although it is not clear what comparisons were made in analysing the data. The author does remark that participants were able to attain light to deep hypnagogic states in all recordings made, which implies that one of the measures made was of within-session change. The exclusion of any EEG data makes it impossible to compare Boynton's reported findings with those of previous controlled alpha-theta studies. She goes on to remark that control participants exhibited deeper measures of crossover than NFT subjects, which appears to corroborate Sterman's (1996) critique, that the ability of alpha-theta training to sustain early hypnagogic EEG in practice rests on the presence of interruptive feedback that prevents progress into deeper sleep, and not the instru-

[2]Simple ratios (t/a, beta/theta) are commonly used in neurofeedback protocols as relative measures are less sensitive to inter-session differences in uncontrolled factors that modulate absolute EEG amplitudes. Boynton criticised the use of simple ratios however on the grounds that they are not symmetrical around the point of equality, and can lead to misleading information when session ratios are averaged across a large number of data points; by using theta as the numerator and alpha as denominator in a fraction, at times when alpha is greater than theta, the expressed value will be somewhere between 0 and 1, whilst when alpha is less than theta, values can range infinitely upwards from 1 and can create the impression that the difference is far greater than it is. Despite this, it is rarely that t/a ratios exceed a value of 2, so Boynton's revised measure wouldn't result in substantially different results.

mental conditioning of a distinct theta state. This finding may also bear some relation to that of Moore et al. (2000) in which the occurrence of imagery was found to be inversely related to the degree by which theta was larger than alpha, and Lowe (1999), who found that participants receiving sham NFT reported more imagery.

Group differences on measures of creativity were reported, and the author stated that groups were neither significantly different on pre, post or change measures of fluency, flexibility or originality. Boynton did however find that as a whole, the population sample improved significantly on measures of flexibility in the AUT, suggesting that general relaxation therapy may benefit creativity, although this change may result from test-familiarity in its second instance. Well-being changed in a similar way, with increases in all participants being reported.

The study by Boynton (2001) represents the largest controlled study of alpha-theta training to date, based on a population sample of 62 healthy adults. Despite this promising start, a number of issues undermine the ability to draw clear conclusions from this research. Whilst it is reported that groups of 2–6 people received the intervention each week, the effect of variations in pattern of attendance and later absenteeism are not elaborated. The author acknowledged that post-training group discussions varied a great deal, and may have impacted on later test measures in uncontrolled ways. It was further revealed that a range of background music accompanied training sessions, which again may have confounded the results of the study, and that a series of lectures given before the trial might have raised the possibility of placebo effects.

Overall, the experimental design appears to have a number of limitations that may blur its ability to draw specific conclusions regarding the effect of alpha-theta NFT or general relaxation on creativity and well-being. However, the picture that emerges this and the other turn of the century alpha-theta studies is that when an attempt is made to control for the effects of relaxation or placebo, the effect of alpha-theta training itself becomes practically indiscernible.

The next investigation into the alpha-theta protocol sought to resolve the ambiguities highlighted by previous studies that controlled for relaxation. In addition to including a suitably relaxing sham NFT condition, the study by Egner et al. (2002) also documented a much closer analysis of the EEG by examining previously unexplored differences in temporal dynamics of EEG components recorded during training.

A population sample of 18 undergraduate medical students (6 females and 12 males, mean age 23) participated in this study, and were randomly allocated into equal sized groups of 9. Each participant received 5 training sessions lasting 15 minutes, preceded by a 2-minute period in which initial alpha (8–11 Hz) and theta (5–8 Hz) thresholds were measured at Pz. The intervention was completed over a two-week period. During training experimental participants sat in a reclining chair with their eyes closed and listened to continual feedback that faded between a babbling brook if alpha amplitude was greater in relation to baseline measures than theta and ocean waves if theta was greater in relation to baseline thresholds. After baseline amplitude thresholds had been set to ensure both bands exceeded the level 50% of the time, the experimenters manually adjusted thresholds for both bands during the remainder of the session to ensure alpha and theta exceeded threshold 30 and 65% of the time respectively. During training participants were instructed to "relax very deeply in order to achieve an increase in the amount of theta sound representation," while avoiding falling asleep. The control participants had their EEG recorded, but received pre-recorded feedback from a typical training session, in which alpha feedback predominated at the start of the session and theta towards the end.

As well as measuring EEG parameters the authors were interested in determining whether any EEG differences would be accompanied by alterations in subjective measures of activation. This was measured before and after each session using the Activation-Deactivation Adjective Checklist (AD-ACL; (Thayer, 1967)) which incorporates four scales: General Activation (e.g. lively), General Deactivation (e.g. calm), High Activation (e.g. tense), and Deactivation-Sleep (e.g. drowsy).

The experimental hypothesis was that the group receiving real alpha-theta feedback would display higher t/a ratios and steeper t/a ratio increases within, and between sessions, and that these trends would be accompanied by differences in subjective measures of activation.

The changes of alpha and theta amplitudes within sessions were analysed by dividing each session into a series of 3-minute blocks, and comparing the mean t/a ratio of each period. Between-sessions comparisons were based on the mean t/a ratio of each session.

The two groups were assessed and compared on their mean t/a ratios and within-session as well as between-session t/a regression by 2 × 5 (Real vs. Sham Feedback

Group × Period/Session Levels) mixed-effects ANOVAS. AD-ACL variable scores were analysed in 2 × 2 (Before vs. After × Contingent vs. Mock Feedback Group) mixed-effects ANOVAS, and subsequently AD-ACL change scores were correlated with AD-ACL measures.

The within-session analyses demonstrated that the NFT group increased the t/a ratio linearly whilst the mock feedback group did not. This resulted in significant difference between group t/a ratios in the last two periods of an average session. Session comparisons revealed that sessions 2 and 4 exhibited significantly greater t/a ratios in the NFT group. On comparisons of pre/post subjective measures of activation, both groups reported significant reductions in activation and increases in deactivation during an average session — with no differences between groups.

The experiment by Egner et al. (2002) is the first to isolate protocol specific effects of alpha-theta training on the EEG: In a non-clinical sample, and within an average feedback session from a series of 5, the t/a ratio can be progressively raised to levels that can not by controls. The linear rate at which the training ratio was raised was interpreted as evidence of a learning process in which subjects increasingly gained volitional control of the t/a ratio. Similar evidence of linearity was not however found in the between-session analyses, although variation in tiredness might have affected EEG levels in ways that were not controlled for in the study.

The finding that both groups reported significantly lower activational states after training reveals a mismatch between the participants' objective and subjective data. One reason all participants may have felt less activated following sessions was that their instructions were to relax deeply, and their responses to questions on activation may have reflected this expectancy. The fact that participants were not informed whether their feedback was real or from a previous recording may have also produced similar levels of expectation between groups. In terms of further attempting to isolate the effects of alpha-theta training on subjective experience, the authors suggest that a subjective measure of physiology might not be able to capture small yet significant changes in physiological activation. The disparity between the study's objective and subjective measures is further demonstrated by the lack of correlation between changes in t/a ratio and AD-ACL scores. Again, this indicates either that the reported relaxation in both groups may have been confounded by the effect of expectation on subjective experience, or that subjective activation is not a close enough approximation of alpha-theta NFT effects in terms of personal experience.

The main question concerning whether this study discloses a specific effect of NFT centres around its use of sham feedback as a control condition. Some clinical NFT practitioners have rejected the use of sham feedback on ethical and validity grounds. Kotchoubey et al. (2001) reported on an epilepsy study where both experimenters and patients were initially blind to the treatment modality, SCP treatment or alpha training control. Therapists and patients quickly detected that alpha training was not affecting seizure rates, and refused to continue what they felt was an unethical study. Kaiser and Othmer (2000) reported that sham feedback is easily identifiable as such, stating that it does not constitute a scientifically valid comparison — and proposes instead that a viable alternative is used as a control. Several recent randomised controlled trials of NFT have used such a viable ('active') control, contrasting NFT with treatments such as EMG feedback or clinically effective attention training software (Bakhshayesh, 2010; Gevensleben et al., 2009b; Holtmann et al., 2009). In the study of healthy subjects by Egner et al. (2002), ethical concerns were not as stringent however, as there were no apparent negative implications of receiving placebo training. In terms of group awareness, the authors stressed that both groups had doubts whether the feedback they monitored was a sham, and so the use of pre-recorded session data appears to represent a good control. The fact that the experimenters were not blind to participants' group membership may still have affected the outcome of the study however.

By demonstrating protocol specific changes in the t/a ratio, this study contradicts the findings of Moore et al. (2000); Boynton (2001) who found that t/a ratios increased to a greater extent in EMG biofeedback or simple relaxation than in alpha-theta NFT. This contradiction may arise from a number of possible differences in the studies; firstly, the previous studies used viable alternatives that had been previously demonstrated to support deep relaxation. Mock feedback on the other hand had not been shown to actively promote relaxation, it may even be that subjects listening to mock feedback were not able to reduce their level of arousal as they were continually frustrated in their attempts to map feedback to subjective experience, as has been suggested by Kaiser and Othmer (2000). A second difference between the studies is that whilst Moore and Boynton compared entire sessions, this study found that reliable differences only emerged towards the end of a session. This more fine-grained temporal analysis of EEG change during NFT constitutes an important step forward in attempts to isolate NFT effects on physiological change.

The dynamic changes occurring within and between alpha-theta were explored in a further study (Egner and Gruzelier, 2004a) which sought to further elucidate the EEG changes underlying shifts in the t/a ratio. The study also analysed EEG changes in alpha-theta training based on EEG training contingent on activity at a frontal site (Fz) in comparison to that of a parietal one (Pz). Theta activity at frontal midline sites is of interest as it is distinct from sleep electrophysiology, and is thought to emanate from hippocampal-cortical projections implicated in higher cognitive process including working memory performance (Klimesch, 1999; Burgess and Gruzelier, 2000). The authors hypothesised that whilst alpha-theta training had hitherto been carried out at occipital and parietal sites, the training effects may have manifested in alterations to frontal theta, and so tried to train this directly.

The methods of the experiment were largely identical to the previously reviewed study of 5 alpha-theta training sessions (Egner et al., 2002), as some of the participant data (n=10) was taken from this study. Additional data from a study in which participants (n=28) received 10 sessions of alpha-theta training, was also included (Egner and Gruzelier, 2003). Previously undocumented data of alpha-theta training at Fz was included from a population of undergraduate students at Imperial College, London (n=10).

The study employed a correlational analysis comparing progressive increments in training time to those in the t/a ratio during an average session. A significant association was found only in the group receiving 10 sessions of alpha-theta training at Pz, although a polynomial (linear) trend for change was observed in sessions 1–5 in both studies. Changes in the t/a ratio were described by decrements in theta amplitude and larger decrements in alpha amplitude. This common reduction in amplitude demonstrates a different EEG signature to that seen in sleep onset studies, which report that SLEEP STAGE I is expressed by decreases in alpha and increases in theta power, with both frequency bands increasing in absolute power during stage 2 sleep (Morikawa et al., 1997; De Gennaro et al., 2001). In the light of this difference, it seems that this study might lend some weight to earlier claims by Green and Green (1977) and Peniston and Kulkosky (1989) that alpha-theta NFT promotes a physiological state distinct from sleep onset. Another interpretation is that the falling amplitudes in both bands represent the EEG of wakefulness prior to sleep onset (De Gennaro et al., 2001).

Between session EEG analysis also showed a differential effect of alpha-theta training in significantly raising theta amplitudes over the course of 10 sessions of training at Pz. This difference was found by comparing the final 5 sessions to the preceding 5, and indicates that NFT had a long-term effect of promoting theta production.

The experimental alpha-theta NFT conducted at the Fz site revealed that increases in theta production occurred both within and between-sessions, leading the authors to draw a distinction between generators of theta activity recorded at frontal and parietal sites, concluding that Pz based alpha-theta training does not influence frontal theta circuitry as had been provisionally speculated.

Just as the study showing that t/a ratio increases were not related to subjective feelings of deactivation (Egner et al., 2002), this study provides further evidence that the effects of alpha-theta NFT on the EEG are distinct from those observed in normal sleep physiology. The observed reduction of within-session theta and alpha amplitudes in Pz training suggests that on average participants were in a state of wakefulness prior to early sleep as expressed by a general fall in spectral EEG power and a relatively greater fall in alpha power (Dumermuth et al., 1983). Overall, the study continues to suggest that although a 15-min alpha-theta training session may accelerate the process of wake-sleep transition, and does so increasingly over the course of training, it does not on average provide scope for SLEEP STAGE I to occur widely.

A third study looking at electrophysiological change related to alpha-theta NFT was documented by the same authors. They measured resting EEG at a range of scalp locations prior to and following two alpha-theta interventions NFT (Egner et al., 2004). Participants (n=22/8) in the first/second experiments of Egner and Gruzelier (2003) received alpha-theta NFT procedures identical to those described in the two previously reviewed studies,[3]. Pre/post training measures of resting spectral EEG were recorded at 28 scalp locations whilst participants remained with their eyes closed for 3 minutes.

In both experiments, post-training measures of prefrontal beta1 (15–18 Hz) were found to be correlated with measures of alpha-theta 'learning,' indexed as "the slope of regression across sessions of the correlation between theta-to-alpha amplitude ratios and the number of 3-min periods within each session." This measure represents an attempt to describe the changes in within-session dynamics across-sessions. The re-

[3]The study also examined the effects of training SMR at c4 and beta1 c3 on resting EEG these findings are discussed in Section 1.4.3.3 on page 58.

ductions in resting measures of frontal beta following alpha-theta NFT were interpreted as indicating reduced vigilant arousal and anxiety, and therefore possibly explained the anxiety reductions previously reported in a study of Vietnam veterans suffering with combat related post traumatic stress disorder (PTSD) Peniston and Kulkosky (1991). This interpretation was supported by the evidence that PTSD is characterised by excessive frontal beta1 and beta2 activity (Begic et al., 2001), and the authors concluded that the clinical efficacy of alpha-theta NFT may lie in its ability to down-regulate this component of resting EEG.

The authors of the three previously evaluated electrophysiological studies also conducted a further alpha-theta study that extended the scope of the investigation beyond physiology into a previously unexplored domain: music performance (Egner and Gruzelier, 2003). At the outset, the rationale of the study was to determine whether clinical NFT protocols (alpha-theta, SMR and beta1) could effect changes in ecologically valid measures of behaviour in healthy music students. The participant data was taken from the same source as the previously reviewed study, and was comprised of two separate experiments. In experiment 1 NFT participants (n=22) received training in a combined SMR/beta1 protocol, followed by an alpha-theta protocol, a sub-sample of which (n=12) then received training in physical exercise and mental skills training. A separate group (n=12) were assigned to a no-training control group. In experiment 2, a different cohort of students were randomly allocated to one of six training groups: alpha-theta neurofeedback (n=8), beta1 neurofeedback (n=9), SMR neurofeedback (n=9), physical exercise (n=16), mental skills training used in a sport psychology consultancy (Williamon, 2004) (n=9), and Alexander technique training (n=10).[4]

Before and after intervention all participants were filmed performing two musical pieces of their choice. The footage was evaluated by 2 and 3 independent raters in experiments 1 and 2 respectively. Panellists were blind to order of performance and experimental grouping, and scored performances on a series of criteria using a 10-point scale. The criteria were adapted from examination standards used in the Royal Schools of Music (Harvey, 1994). Self-reported measures of state-anxiety (Spielberger

[4]The Alexander technique refers to a system of kinaesthetic education aimed at avoiding excessive postural tension, and constitutes the most widely practised behavioural training in professional orchestral musicians.

et al., 1983) were collected prior to performances.

In experiment 1 only participants who received the neurofeedback protocols exhibited improved performance after the intervention. They improved on all measures, and the improvements correlated with the NFT learning index described in the previous study. In experiment 2 participants receiving alpha-theta training alone improved on ratings in the categories of 'Musicality' ('stylistic accuracy,' 'interpretative imagination' and 'overall musicality') and 'Overall' scores. In both experiments, it was found that all participants reported lowered state-anxiety in the second performance.

In combination, the above findings represented the first evidence of NFT effects on real-world behavioural measures in a healthy population. Experiment 1, a within-subjects correlational design, disclosed a relationship between increases in technical, musicality and communication measures of music performance and t/a ratios in training. Experiment 2, a between-groups design, observed improvements in musicality and overall ratings of performance in an alpha-theta group equivalent to a class of degree honours or more. The results of experiment 2 did not find the previously observed correlation between changes in t/a ratios and music performance to be replicable, which suggests that prior NFT training in SMR/beta1 protocols may have played a part in previous results. A similar sequence of SMR/beta followed by alpha-theta NFT has been reported to increase treatment-participation and drug-abstinence in a population of mixed substance users (Scott et al., 2005), which suggests that prior beta and SMR NFT may affect the subsequent response to alpha-theta neurofeedback. Overall, the fact that a more closely controlled experiment led to significant post-alpha-theta improvements under the heading of musicality, which included measures of interpretative imagination, led to further associations between alpha-theta NFT and creativity (Gruzelier and Egner, 2005; Gruzelier et al., 2006). This directly informed the approach of the current thesis, which is using alpha-theta NFT in attempts to isolate and modulate the proposed relationship between hypnagogia and creativity.

Following the series of alpha-theta studies demonstrating NFT efficacy in modulating the t/a training ratio, resting frontal beta1, and music performance, members of the same laboratory went on to conduct two further studies examining the effects of alpha-theta NFT on mood and dance performance. In the first of these studies, Raymond et al. (2005b) recruited undergraduate medical students (n=12) who scored highly on a measure of 'social withdrawal'. Half the group were given an average of 9

× 20-minute alpha-theta NFT sessions similar to those used in the previous 4 reports. However 3 Hz EEG frequency bands were shifted up or down the spectrum according to individual differences in the spectral alpha peak (Doppelmayr et al., 1998). NFT participants were instructed to achieve predominance of theta feedback and to use it as a cue to "visualise themselves being the sort of person they most wanted to be and solving problems in the best way possible." The other half of the sample received mock feedback, which consisted of a demonstration session supplied with the NFT software. All sessions started and ended with self-reported measures of mood using the Profile of Mood States (POMS) questionnaire (McNair et al., 1992).

The results of the experiment demonstrated training effects on t/a ratios and mood measures. Both groups expressed confidence in their ability to control the feedback, indicating that the control group had not detected the placebo. The personality measure used to select participants was also conducted following the intervention, and no changes in measures of social withdrawal were found. The authors discussed this finding in relation to those of Peniston and Kulkosky (1990) who did observe personality improvements, concluding that the smaller amount of sessions and the different populations probably confounded direct comparison. Overall, measures of mood indicated that real NFT participants exhibited within-group improvements that fell marginally short of significance compared to control subjects looking at averaged session data. Measures of within-session EEG parameters disclosed a significant correlation between increments in time and t/a ratios.

In comparison with measures of subjective activation in response to alpha-theta NFT, which didn't show any difference compared to mock feedback (Egner et al., 2002), this study showed that a mood based measure of the subjective response to alpha-theta NFT can disclose significant changes in self-reports not seen in controls. The improvements approached independence from those observed in a control condition, and confirm the prediction by Egner et al. (2002) that an 'emotive' as opposed to an activational report might disclose personal effects more accurately. Unfortunately this study did not document any correlational analysis between the physiological and experiential measures, so whilst this is a promising result, it remains unclear as to whether the changes were linked.

Raymond et al. (2005a) published another alpha-theta NFT report including the results of a preliminary investigation into its application in a novel area: dance performance. In following from the previous work on music performance (Egner and Gruzelier, 2003) this study set out to determine whether alpha-theta benefits might extend into other areas of performance art.

Undergraduate students in a dancing team were recruited, and after adjusting for study dropouts, the sample was comprised of an alpha-theta NFT group (n=6), a heart-rate variability (HRV) biofeedback group (n=4), and a no-training control group (n=8). NFT training was conducted as in the previous study, although participants were instructed to "visualise themselves dancing in the way they most wanted to dance" upon hearing theta feedback. The HRV group had the goal of breathing at their 'resonant' frequency,[5] and this intervention was included as a suitable alternative performance-enhancing treatment as it had previously been found to reduce anxiety and improve performance in gymnasts (Bessel and Gevirtz, 1998).

Prior to and following the experiment, participants were filmed dancing in pairs, and an order and group blind panel of two dance adjudicators assessed the footage.

The results of the study demonstrated that both biofeedback interventions improved the overall measure of dance performance relative to no-training controls, but they were not significantly different from each other following the intervention. Measures of biofeedback 'learning,' i.e. the correlation between time and t/a ratio or HRV increase did not reach significance on within-session measures and were not documented for between-session measures. The authors reported no correlation existed between physiological and performance changes.

As a preliminary study with a small sample size, a potentially confounding dropout rate (n=6), the results of the study do not generalise to the wider population. Additionally, at the end of the study, the three groups had each had differing amounts of dance practice, and this was corrected by dividing the change in performance ratings by the amount of practice each participant had. The resulting figure may be a suitable correction to apply, as it effectively lowered the music change scores of the controls and HRV group relative to alpha-theta. However, such an offset does assume that all dance practice sessions confer the same improvement on performance.

Despite the difficulties within operational comparisons, the design of the study

[5]The resonant frequency rate of breathing results in the largest swing in heart rate. In humans the resonant frequency depends on the individual, and usually lies between four and seven breaths per minute

represents a significant advance in NFT research methodology, as Lowe (1999) had previously called for alpha-theta NFT to be compared not just to no-training controls, but suitable alternatives in efforts to isolate protocol specific effects.[6]

In Raymond et al. (2005a), comparing alpha-theta NFT to both inactive and active controls represents a groundbreaking attempt to isolate protocol specific effects in relation to a feasible alternative intervention. The results did indicate some differences between the two active interventions, with alpha-theta NFT improving measures of timing and HRV improving those of technique, so these results provide suggestive evidence that alpha-theta training has protocol-specific effects on performance art.

In reference to the growing body of empirical work that identified effects of alpha-theta NFT, a theoretical investigation into the possible mediators of those effects has been contributed to the literature (Gruzelier, 2009). This paper considers the range of documented behavioural and affective responses to alpha-theta training, and that these effects extended beyond early associations with hypnagogic creativity. The wider significance of conditioning theta activity is then considered in the light of the evidence that theta correlates not only with posterior EEG in sleep-onset (De Gennaro et al., 2001), but hippocampal-frontocortical working memory encoding processes (Klimesch, 1999). Theta also influences attention, (Sauseng et al., 2007) sensori-motor effort and sensory-motor integration (Kay, 2005), and mediates limbic emotional and motivational functions (Buzsáki, 2002), and arousal (O'Keefe, 1990).

The wider implications of theta oscillations are included into an integrative framework predicated on the basis that theta is paced in two distinct neuroanatomical circuits: "the ascending mescencephalic-cortical arousal system and limbic circuits subserving cognitive as well as affective/motivational functions". These theta-generating circuits project to widely distributed neural connections mediating distributed networks in the brain, which is interpreted as evidence that theta underlies both neural and as a result psychological integration between distributed functions.

The effects of training theta oscillations in the cortex, and by association their sub-cortical pacemakers is rarely investigated directly in humans, and the strongest evidence for the hippocampal pacing of cortical theta has hitherto come from direct

[6] In the ADHD literature, this approach has been applied in a number of recent studies following the difficulties encountered in mounting double blind placebo controlled trials (for a discussion of the research methodology in ADHD see Appendix B on page 271).

electrode recordings of hippocampal cells in studies of animals (Whishaw and Vanderwolf, 1973). However combined fMRI/EEG human studies have begun to take place in the 21st century that have been able to accelerate the investigation of brain activity underlying cortical theta. A relevant result that recently emerged from this line of inquiry discovered an inverse correlation between frontal theta and the default mode network Scheeringa et al. (2008). This network activates during states of defocused-attention, a proposed correlate of creative ideation (Martindale, 1977), which implies that hippocampal-frontocortical theta activity does not contribute to the alpha-theta learning process, and in turn suggests that a different theta pacer contributes to slow-wave NFT. In relation to this distinction, it has been found that frontal theta-to-alpha ratio enhancement training was found to modulate the t/a relationship differently to the parietal protocol, with theta increments observed over time as opposed to the lesser decrease in theta than alpha (Egner and Gruzelier, 2004a). This suggests that frontal theta is generated differently from the form seen in the classic alpha-theta protocol, and is possibly underlined by hippocampal-frontocortical phasic theta bursts accompanying highly focused concentration (Gevins et al., 1997). Accordingly, this sets the stage for an fMRI study of alpha-theta NFT to take place, which would be able to test the explanatory framework described — in particular by determining the location of sub-cortical parietal theta oscillations.

From the current review it can be concluded that alpha-theta specific effects have been documented on measures of the t/a ratio in training, post-training measures of resting prefrontal beta1 EEG, and measures of music and dance performance. Changes in music performance suggested that a possible link between alpha-theta training and factors influencing creative behaviour may exist due to the isolation of alpha/theta effects in measures of musicality. The current thesis seeks to develop this line of inquiry through further changes in the research methodology incorporating tasks requiring spontaneous music creation behaviours, and though attempts to derive EEG measures of music performance that might be used in identifying the physiological mediators of alpha-theta effects on music performance.

1.4.3.3 Fast-wave neurofeedback

As with the optimal performance trials that sought to explore the potential of alpha-theta NFT beyond its clinical applications, the possibilities of training faster elements of the EEG spectrum in healthy subjects have also been explored.

Motor inhibition as a safeguard against performance anxiety Whilst SMR and beta protocols were initially conceived of in terms of their ability to normalise EEG pathologies, the optimal performance applications have focused more specifically on reinforcing specific neural processes under conditions of load – e.g. the performance of a musical task during stage fright induced shaking. For example, high levels of performance anxiety impair attention and memory according to the Yerkes-Dodson law (Yerkes and Dodson, 1908), which predicts that performance is modulated as an inverse-U shaped function of arousal. In relation to this, the association between SMR NFT and improved motor inhibition (Sterman, 1996) and SMR/beta protocols and improved attentional performance (Lubar et al., 1995) raised the possibility that NFT may be able to mitigate against the affects of performance anxiety on motoric and cognitive tasks.

Fast-wave literature In Section 1.4.3.2 on page 43 experiments on music students at the Royal College of Music were evaluated for their effects in terms of alpha-theta NFT, but they also documented effects arising from SMR and beta protocols, which are now reviewed here.

In the first of these experiments (Egner and Gruzelier, 2001), 22 healthy participants received a mixed beta1 (15–18 Hz)/SMR (12–15 Hz) protocol training each frequency band at C3/C4 respectively. Training rewards in the form of audio-visual signals were provided when band activity voltages were more than 0.8 of pre-training average. If theta (4–7 Hz) and the higher beta2 band (22–30 Hz) values exceeded baseline averages by 1.2 and 1.6 times respectively, then feedback was inhibited. There were 10 sessions in total.

In this experiment, cognitive performance was measured as attentional performance on the Test of Variables of Attention (TOVA) test, and as 'target detection' expressed by P300 event related potentials (ERPs) in an auditory oddball task. NFT learning was indexed as the number of 3-minute periods within each session that participants raised training band amplitudes (both absolute and relative to inhibit band measures) above mean amplitudes in the preceding period.

The outcome of the experiment was that TOVA commission errors were significantly reduced, and perceptual sensitivity (a ratio of correct to false responses (Green and Swets, 1966)) was marginally improved. The SMR learning index was positively correlated with changes in commission errors and perceptual sensitivity, whilst the opposite was true of beta1. Significant target detection improvements in ERP measures correlated positively with both SMR and beta1 learning. Both training indices correlated with each other.

The authors concluded that because the learning-outcome associations were inverted between protocols, this demonstrated their specificity: beta1 elevation was interpreted as increasing excitability in the motor cortex, thus increasing impulsivity and commission errors by promoting responsive but error-prone vigilant attention. On the other hand, SMR elevation was found to improve response inhibition, possibly by promoting the inhibitory function of reticular thalamic cells projecting to the motor cortex. Increases in perceptually driven cortical ERPs were similarly associated with learning in both protocols, indicating that both protocols improved sensory integration similarly, despite their contrasting effects on the motor response.

By using the TOVA as an attentional measure the authors presented here the first evidence that attention in healthy subjects can be improved by NFT, extending the application of SMR and beta1 training beyond the normalisation of attentional pathologies. Significant changes in attentional measures were demonstrated and correlated with training measures, however it was not documented whether training measures changed significantly. The study was the first to introduce task-related measures of cortical activity as a means of evaluating a neurofeedback intervention, and this in itself represents is an important advance in experimental methodology. Some commentators have observed that EEG differences or pathologies pertaining to attention may not be manifest in resting measures of the EEG, which currently predominate over task-dependent measures in NFT trials (Arns et al., 2009). This distinction between resting and task-related measures is even more pertinent in healthy subjects, in whom cognitive impairments are only predicted to become observable during task-performance itself (Yerkes and Dodson, 1908). Thus, cognitively demanding task-based measures of attention would be more likely to expose an optimising effect of NFT.

In continuing to explore event related measures of attention, Egner et al. (2004) documented a similar experiment to Egner and Gruzelier (2001). The population sample was again taken from music students, but here participants were trained in independent groups as part of the second RCM experiment: SMR (n=9), beta1 (n=8), and a group receiving Alexander technique training (n=8). All NFT interventions were comprised of 10 sessions lasting 15 minutes each, with SMR (12–15 Hz) and beta1 (15–18 Hz) recorded from Cz. As with Egner and Gruzelier (2001), the authors measured TOVA and P300 ERPs prior to and following training, and additionally measured performance on a divided attention CPT.

Protocol-specific effects were discovered in that SMR training participants exhibited increased perceptual sensitivity in TOVA performance, as well as reduced omission errors and reaction time variability. Beta1 training participants demonstrated faster reaction times and increased target detection P300 amplitudes post-training. No changes were shown amongst the Alexander training group. In following Egner and Gruzelier (2001), these results replicated improvements in perceptual sensitivity associated with SMR previously, and target detection P300 ERPs following beta1 training. The additional SMR results indicated a broader attentional effect than in regulating impulsivity alone, whilst beta1 continued to be associated with vigilant arousal, increasing sensory processing speed at the expense of accuracy. The previous correlations between NFT learning indices and attentional outcomes were found not to be replicable in this study, although the independent groups design made it possible to draw associations in the absence of correlation. This indicates however that prior correlation may have been a function of the combined effects of the two protocols on outcome measures, and accordingly justifies the addition of this between-groups experiment in disambiguating prior results.

Members of the same laboratory also further expanded the scope of optimal performance research by documenting the effects of SMR NFT on semantic working memory performance (Vernon et al., 2003). In a controlled trial, medical students were allocated to 3 groups of n=10 matched on age, gender and measures of memory recall and attentional performance. NFT participants received either 8 sessions elevating SMR (12–15 Hz) whilst suppressing beta (18–22 Hz) and theta (4–8 Hz), or 8 sessions elevating theta and inhibiting delta (0–4 Hz) and alpha (8–12 Hz). The latter group received an experimental NFT protocol, hypothesised to improve memory recall by up-regulating theta related long-term potentiation between neurons (Pavlides et al., 1988) and thus mnemonic function. Theta activity observed during memory encoding (Klimesch et al., 1997) and retrieval (Burgess and Gruzelier, 1997) also support the rationale that bringing theta under voluntary control might help to sustain theta and thus working memory function under conditions that place demands on storage and recall. As with Egner and Gruzelier (2001), SMR training was hypothesised to facilitate attentional performance. All training was conducted with the Cz electrode placement, and a third control group received no intervention.

Somewhat surprisingly the results of the experiment disclosed improvements in memory performance following SMR training and not theta as had been anticipated. SMR training was also shown to have elevated within-session SMR amplitudes alongside concomitant decreases in both theta and beta bands. Attentional performance was also improved to a limited extent in SMR cases. The authors speculated that the memory improvements arose from 10–14 Hz oscillations, which overlapped the SMR range and underpin fronto-posterior connectivity seen in maintaining sensory information in working memory (Haarmann and Cameron, 2005). The inability of theta trainees to modulate theta in training or cognitive performance subsequently suggests that a physiological response incorporating theta activity is not as accessible to operant control as the motor response. The authors consider this in relation to the fact that theta enhancement protocols usually include eyes-closed training, which naturally elevates theta as a function of cortical deactivation during the wake-sleep transition. In Egner and Gruzelier (2004a) we have already seen how eyes-closed theta training at Fz did lead to theta rises across 10 sessions, which appears to confirm Vernon's interpretation.

This report does not document inter-session EEG changes – although this is justified on the grounds that within-session measures of EEG are less affected by interference from uncontrolled factors impacting on the EEG such time of day and time since eating. Additionally, the report does not document correlations between training and outcome measures, although the independent groups design nonetheless supports the notion that SMR training improved memory whereas no-training controls and an expectation and experimenter contact matched group didn't.

A novel application of the SMR/theta protocol into reading performance was tested in this period that hypothesised that hemispheric dynamics, measured as hemispheric contributions to word recognition, could be optimised by up-regulating the SMR/theta ratio over the right hemisphere relative to the left hemisphere (Barnea et al., 2005). This experimental application was based on the grounds that (Weems and Zaidel, 2004) had disclosed superior right hemispheric contributions to lexical processing. The experimenters trained SMR/theta at central sites in 20 children aged 10–12 years, half boys and half girls. Half of the subjects received C3 training, which was hypothesised to impair lateralised lexical performance, and the other half C4 training to improve it. Training consisted of 20 half-hour sessions over a four-week period.

Training did affect lexical processing differentially between C3 and C4, and increased hemispheric independence, although C3 training did not selectively affect the left hemisphere and C4 training did not selectively affect the right hemisphere.. The authors also noted unanticipated sex differences: in boys, C4 training improved LH accuracy, whereas in girls C3 training improved LH accuracy. The authors concluded that lateralised NFT is effective in changing hemispheric word recognition, and that cerebral asymmetries differentiated the sexes.

Overall, the results of the study suggest that despite attempts to train specific hemispheric activity, the operant response recruited inter-hemispheric networks, and that these networks were organised by gender. This is the first neurofeedback study to consider the operant response by sex, which suggests that NFT protocols might be tailored to individual differences in the EEG.

Another approach introduced by Hanslmayr et al. (2005) sought to examine individual differences in the NFT response by measuring performance on a mental rotation task dichotomously based on high and low responsiveness to NFT contingencies in the upper 2Hz of the alpha band. A further difference between this and prior studies was that comparisons were made following only one training session, and so by comparing responders to non-responders after a single session, this study introduced a new accelerated research design to the literature. Although the alpha-band NFT applied here is not directly relevant to the thesis that follows, this study is included for completeness.

The study recruited healthy students (n=18) who were initially measured on baseline readings of eyes open/closed alpha and theta frequencies at F3, Fz, F4, P3, Pz, and P4. Subsequently they performed a mental rotation task (Amthauer, 1970), then trained eyes-open upper-alpha/theta band enhancement; then performed mental rotation; then trained theta/upper-alpha band suppression; and finally performed the mental rotation task — the order of training was counterbalanced among participants. This design enabled within-subjects comparisons between alpha enhancement and theta suppression NFT, both of which were hypothesised to increase cognitive performance in relation to a previous Transcranical Magnetic Stimulation (TMS) study (Klimesch et al., 2003). The feedback was presented visually in the form of coloured squares that changed between blue and red when training amplitudes were respectively low or high in relation to baseline measures of the frequency being trained: the goal of upper alpha enhancement was to turn the square red, and in theta suppression to turn the square blue.

The results of the study showed that mental rotation was only improved in one scenario: in upper alpha responders following upper alpha NFT. This improvement correlated positively with a significant increase in upper alpha power following upper alpha NFT. The authors also documented tonic enhancements in post-training parietal alpha power during rest and in pre-stimulus measures during task performance. These EEG findings indicate that upper-alpha training does tend to regulate alpha activity in the same locations as trained.

The authors discuss the results in relation to performance gains in Egner and Gruzelier (2001, 2004b) emphasising that in this case cognitive improvements are seen after a single training session. As with Vernon et al. (2003), attempts to being theta under operant control were unsuccessful, although in this case theta inhibition was attempted during training.

In evaluating this study, arguably its greatest contribution is to demonstrate the feasibility of an accelerated testing procedure that sees groups split not by randomisation but by NFT responsiveness. This group selection method does affect generalisation of the effects to the wider population however, nonetheless, the fact that cognitive and EEG differences can be observed following a single intervention indicates that in the design of pilot studies for example, a rapid research methodology can be implemented to explore novel NFT applications. This is also an important study in that it not only documented EEG changes in NFT, but also during subsequent rest and task performance, enabling a close physiological assessment of how NFT effects impacted post-training activities.

The next optimal performance study returned to the more familiar method of conducting a series of training sessions, and examining post-training differences on ratings of technique and task duration in a population of eye surgeons (Ros et al., 2009). The rationale for investigating effects on surgery were based on the prior evidence that SMR enhancement with theta suppression NFT improved sustained attention and working memory (Egner and Gruzelier, 2001; Vernon et al., 2003; Egner and Gruzelier, 2004b) — it was thought that these improvements may have useful work-based applications in helping surgeons maintain task-performance standards under fatigue related cognitive impairment. It was also hypothesised that SMR training might improve fine motor control via increased inhibitory regulation of thalamic projections to the motor cortex, as demonstrated in the epilepsy and ADHD literature (Sterman, 1996). In the light of performance improvements seen in performing artists (Egner and Gruzelier, 2003; Raymond et al., 2005a), it was additionally hypothesised that an alpha-theta training intervention might improve surgical performance.

The design of this study employed a novel combination of qualitative and quantitative analysis by combining 2 independent ratings of surgical video-footage with measures of time spent on task. Trainee ophthalmic microsurgeons (n = 20) were randomly assigned to either SMR or alpha-theta groups, whilst a subset of participants also formed part of a prior wait-list control group (n = 8) measured prior to the NFT intervention. Neurofeedback groups received 8 × 30-minute training sessions, and training was based on the same alpha-theta and SMR protocols previously described in evaluations of Egner and Gruzelier (2001, 2003). Pre-post assessment included a filmed surgical training procedure with measures of execution time and expert ratings of technique. State and trait anxiety were also measured (STAI).

SMR training demonstrated improvements not seen during the control period, with increased ratings of surgical skill and reductions in task-time. Both outcome measures correlated significantly, and task-time reductions correlated with growing inhibition of theta during training. As with Hanslmayr et al. (2005) the authors investigated relative NFT responsiveness. In the SMR group they found that some cases *increased* theta production towards the end of the study, and that significantly longer inter-session delays could be observed in these participants, suggesting that patterns of attendance are a factor in measures of NFT learning; whether good attenders learn well, or good learners attend well remains unknown however. In terms of anxiety, trait measures were found to reduce following SMR training, and within-session alpha-theta learning correlated with (non-significant) changes in state anxiety. Alpha-theta training was marginally associated with improved technique.

In evaluating this study, the authors highlighted a number of methodological issues that limit the interpretation and generalisation of these results. The control condition was based on a within-subjects design, with training following controls, so practice related improvements might have benefited the NFT groups to a greater extent. There is an additional problem that although several NFT related improvements were seen, none of them were significantly different from control measures; this lack of clear separation is compounded by the fact that the SMR group exhibited higher initial overall and task times than the other groups, introducing sampling error variance into the study. Overall, the key contribution of this study was to combine qualitative and objective measures of performance in demonstrating a novel application of SMR based NFT. The examination of training attendance is also an important contribution to research as it shows that learning progress is not straightforwardly related to the amount of training received.

The next SMR study to be reported discovered an association between NFT and improved memory performance (Hoedlmoser et al., 2008). Whilst Vernon et al. (2003) had previously found SMR training led to improvements in short-term memory, this study examined post sleep differences in declarative memory recall compared to a control group that received a novel form of NFT. In this study participants either trained SMR (12–1Hz) or a 3Hz control band that changed randomly in each training session (between 7–20Hz).

Participants were randomly and blindly assigned to SMR (n=16) and control (n=11) groups, and received 10 sessions of NFT. Before and after NFT experimenters measured performance on a word pair recall test (Plihal and Born, 1997) carried out prior to and following a 90-minute afternoon nap.

Following the intervention, a pooled within-session analysis of SMR training revealed increases of in-training SMR amplitudes, more sleep spindles, and faster sleep onset. Improved performance on post-NFT memory recall tests conducted prior to sleep was significantly greater in the SMR group than in controls. Furthermore, these improvements correlated with in-training SMR increases.

This study was initiated in an attempt to elucidate the possible role of sleep spindles in the process of memory consolidation. Based on a prior study in which post-sleep memory performance was found to be predicted by nocturnal sleep spindle activity (Schabus et al., 2004), the authors had hypothesised that SMR training might facilitate memory consolidation in napping. The results of the study did not confirm this however, leading the authors to speculate that pre-sleep memory improvements in SMR participants may have derived from attentional gains, which parallels the conclusions drawn by (Vernon et al., 2003). The use of a novel control condition deserves some further consideration as a novel implementation of an active alternative. Certainly, providing a training procedure that is both immediately responsive yet has no long-term training contingency seems to avoid the potential problem observed in some studies where experiments and/or participants have detected sham feedback Kaiser and Othmer (2000); Picard (2006); DeBeus (2006). Compared to the other approach used by researchers, that of a viable cognitive training exercise, using an ever-changing NFT protocol might be seen as a superior comparison condition as it most closely resembles the main NFT condition. This means that most of the possible extraneous effects of NFT are controlled for, even experimenter effects. Despite this, the changeable protocol may still see participants lose motivation resulting from a lack of long-term contingencies.

The previously explored theme of upper-alpha training was reprised in (Zoefel et al., 2011), who applied a protocol similar to that of Hanslmayr et al. (2005), but in this case over a longer-term of 5 sessions. In this study, the upper alpha frequency band in EEG was once again investigated in relation to its ability to modulate performance on a mental rotation task. In this study however, trainees were compared to no-training controls, as opposed to NFT responders versus non-responders.

NFT (n=14) subjects were trained on five sessions within 5 days by means of feedback dependent on the upper alpha amplitude of each participant's spectral peak frequency. On the first and fifth day, cognitive ability was tested by a mental rotation test. A no training control group (n=10) performed the mental rotation task on days one and five only. The feedback was presented visually over 25-minutes in the form of coloured squares that changed between blue and red when alpha amplitudes were respectively low or high in relation to baseline levels.

By comparing the baseline measures of session one to the last five minutes of session five, NFT upper alpha was shown to have increased independently of other frequency bands, and eleven of the fourteen NFT subjects showed significant amplitude rises. The enhancement of performance on the mental rotation task was significantly larger for the NFT group than for controls. This second upper-alpha study confirms that this form of eyes-open upper-alpha training is amenable to instrumental conditioning in the longer term in a randomised population sample. Prior measures of post-training improvements on mental rotation performance were replicated. Overall, this study supports the findings from the earlier single-session NFT trial documented by (Hanslmayr et al., 2005). Taken together, these upper-alpha studies have reintroduced alpha training into the literature by avoiding some of the criticisms of eyes-closed alpha training discussed in the work of Orne and Paskewitz (1974) (see Appendix A on page 250). Unlike the single-session study, this paper does not document correlations between upper alpha and performance changes, which appears to confirm the validity of the single-session approach as a possible means of controlling for interference from extraneous factors that change the EEG across training sessions.

The recent period of innovation giving rise to novel neurofeedback applications, protocols and methodologies has recently seen a diversification into the examination of training gamma frequency EEG components. In the last year, two studies of gamma (36–44Hz) in relation to beta (12–20 Hz) have been added to the optimal performance literature (Keizer et al., 2010b,a). Whilst all of the previously examined studies in this field have revealed attentional or attention mediated memory improvements, gamma band EEG activity was trained in efforts to modulate its association with intelligence, which is purportedly mediated by visual feature-binding costs (Jausovec, 2004).

The first gamma NFT study measured intelligence with Raven's standard progressive matrices (Raven, 1938) and a task based on Hommel (1998) designed to measure the cost of feature binding expressed in timing and error. These measures were carried out prior to and following the experiment, and their sequencing was counterbalanced to adjust for order effects.

Each of the subjects was allocated randomly to a group promoting occipital (Oz) gamma relative to beta (n=7) or vice-versa (n=7). Participants completed 8 × 30-minute neurofeedback sessions over a period of 10 or 11 days. In a move to increase experimental control, the experimenters implemented a double-blind design, whereby expectation related effects were controlled for by making both participants and experimenters blind to the training protocol under review.

Following the intervention period, within-group comparisons saw the gamma training participants had successfully elevated gamma across sessions. They also demonstrated that their general gamma power was correlated positively with intelligence measures, and that changes in gamma were reflected in changes in intelligence measures. Additionally, post-training between groups comparisons showed that the gamma NFT group exhibited improved feature binding performance compared to controls.

As with the Hoedlmoser et al. (2008) study, the innovative use of another NFT intervention as a control condition does appear to constitute a valid attempt to detect protocol specific effects. The fact that beta training had no advance likelihood of optimising intelligence and feature binding does not detract from this design, as beta acted as the placebo in what effectively constitutes a double-blind placebo controlled trial. It does however seem worth arguing that gamma NFT might demonstrate its efficacy best in comparison with a feasible alternative, although this is a preliminary study which entails that effects should be exposed as fully as possible in low powered statistical analysis (group n=7).

Keizer et al. (2010a) is a very similar study to the one above with some extensions. Firstly the electrode at Oz was complemented by one at Fz. Frontal EEG was added into the beta promotion protocol only, but both electrodes were measured for evidence of synchronous EEG patterns. Single band rewards were used here in a simplification of the previous design that used relative measures. The final change was in the inclusion of a long term (episodic) memory recall task, which was added to extend further the exploration in the relationship of NFT to memory performance.

Feature binding was measured as in the previous study, and long term memory was assessed by a cued pictorial colour recall test (Cycowicz et al., 2001). The healthy participants were randomly assigned to NFT groups in gamma (n=8) and beta (n=9), and received 7–8 daily sessions lasting 30-minutes.

By comparing first to final five minutes of sessions, and entire first and final sessions, the authors showed that participants in the gamma group could significantly raise gamma by the end of the study. Inter-electrode coherence was also increased, particularly in the beta group, who disclosed post-training Oz-Fz EEG coherence increases in both gamma and beta bands, whilst the gamma group disclosed gamma coherence. The feature binding improvements associated with gamma were replicated from the prior study. Both groups improved on measures of long-term memory recall; with gamma participants achieving changes via recall type memory, and the beta group using familiarity type memory.

Taken together, this and the previous study, alongside (Hoedlmoser et al., 2008) and (Vernon et al., 2003) are representative of the growing interest in investigating memory using NFT applications. The finding that fronto-occipital beta coherence rather than power seemed to be more related to improved memory performance appears to support Vernon et al.'s (2003) speculation that long-range connections demonstrate memory function rather than site specific activity. The 12–20 Hz beta band in this study incorporates the SMR component, which additionally supports this interpretation. Despite concerns over the use of bipolar montages expressed elsewhere in the clinical NFT appendices, this study referenced each electrode separately to a null EEG site, and as such the inclusion of long range coherence measures constitutes a promising development for the use of NFT in exploring widely distributed neural processes.

The penultimate study in this review sees a return to the performing arts applications of NFT. In this case two types of SMR feedback methodology were compared to each other: one providing visual feedback via the standard computer monitor, and one using a 3D virtual reality (VR) environment (Gruzelier et al., 2010). In both types of feedback the display was based on an auditorium, with current SMR (12–15Hz) amplitude represented by stage light levels, and theta (4–8 Hz) and beta (15–21 Hz) represented by crowd noise levels.

Student actor participants were randomly allocated to VR (n=5) or screen (n=6) type training, with 4 students who were not able to fully participate acting as no-training controls. Between 7 and 10 × 30-minute NFT sessions were given to participants, and training followed 3-minute baseline periods to establish reward and inhibit thresholds at 0.8 and 1.2 of initial EEG averages respectively.

Prior to and following NFT, acting performance (consisting of studio monologues and Hamlet excerpts) was filmed. The pre- and post-training performances were evaluated from a randomised sequence of video clips by an order and group blind panel of three acting teachers. Pre-post training measures of flow (Csikszentmihalyi, 1997) were also recorded, and were used to measure subjective reports of optimal experience.

In the comparison of screen and VR training, it was found that both groups increases the SMR to theta/beta ratio significantly, and exhibited the same learning curve in the training ratio across 6 sessions. Polynomial contrast analysis revealed a significant quadratic trend difference between interventions, with the VR group reaching the maximal training ratio at 4 sessions as opposed to 5 in the screen group. Between-group comparisons of acting performance revealed a group (2) × rating (11 scales) interaction, underpinned by significant within-VR improvements on five subscales. In measures of Flow both SMR groups scored higher than controls on reported sense of control, confidence and feeling at-one, and there were numerous positive correlations between the actors' flow reports and their panel ratings, highlighting an interesting link between actor and audience perception.

This study is small and consequently lacks sufficient statistical power to demonstrate reliable between group differences, and in terms of design, the control group were formed not out of a process of randomisation but through self-selection, making group comparisons harder to interpret and generalise. Despite this, the comparisons between 2D and 3D feedback suggest that VR training brings training parameters under operant control more rapidly than a 2D display, and delivers greater benefits to acting performance. This finding was interpreted in terms of the immersive qualities of the 3D display, which assisted performers in engaging with the feedback.

The final study in this review (Ros et al., 2010), is not an optimal performance study as such, and does not measure post-training performance, although it does investigate the motor response to training, so has some relevance to the scope of this thesis. In continuation of the theme of exploring transient NFT effects introduced by (Hanslmayr et al., 2005), this study explored the effects of alpha reduction and SMR enhancement on the corticomotor response and intracortical inhibition, both measured via TMS induced motor evoked potentials (MEP) in the hand. It was found that intrinsic suppression of alpha cortical rhythms increases corticospinal excitability and decreases intracortical inhibition for a period of at least 20 min. Twenty-four healthy participants were randomised into two protocol groups receiving a single 30-min NFT session: alpha suppression (n = 12) or SMR enhancement (n = 12). Protocols were trained at approximately C3 close to the location that the right first dorsal interosseous (FDI) muscle is represented in the sensorimotor cortex. The experiment hypothesised that reducing alpha (8–12 Hz) would increase the motor response to TMS, whilst the SMR (12–15 Hz) procedure would have the opposite effect.

The results of the study documented that the alpha reduction protocol did significantly reduce alpha amplitude from baseline resting measures, whilst SMR enhancement did not. This 'suboptimal' NFT response was interpreted as the use of a possibly inappropriate training approach amongst participants. Post alpha-suppression training measures of EEG and TMS triggered FDI potentials were made over a 20-minute period, and derived measures of corticospinal activity were significantly higher, and intracortical inhibition significantly lower than pre-training measures. Despite this, the between-groups differences on post-training measures were not significant, although some of the SMR participants had appeared to actually achieve the opposite of training goals, disclosing increases in later MEPs, suggesting that group differences were blurred somewhat. Furthermore the linear trend of alpha reduction (measured as the correlation coefficient of time-in-training and the decline of alpha amplitudes) was significantly correlated with MEP increases, suggesting that a protocol specific effect was in evidence. Interestingly, although the relationship of each hemisphere was analysed independently of the other in terms of the MEP response to trained or untrained hemispheres, the prior study of Barnea et al. (2005) had suggested that lateralised training protocols nonetheless led to activation in inter-hemispheric networks. This suggests that the analysis of hemispheres in isolation in this study did not allow for the interaction between hemispheres to account for training effects. Overall, the application on an alpha suppression protocol over the somatosensory cortex produced reliable within-group changes in alpha amplitudes, MEPs and cortical inhibition, suggesting that performance related applications of this protocol could be explored, with a potential role in attempting to raise suboptimal corticospinal activity following stroke, or in optimising the effect of practice in the learning of motor tasks.

This section has reviewed the optimal performance applications of fast-wave EEG training protocols incorporating SMR beta and more recently gamma components. As with the clinical applications of fast-wave NFT (reviewed in Appendix B on page 271), this area of investigation has seen considerable innovation in the design of experiments: including the use of either feasible 'active' alternative interventions, an accelerated research programme exploring transient training effects, and the first apparently successful attempt at mounting a double-blind placebo controlled NFT experiment. The research methodologies used have also been meaningfully advanced, with the inclusion of task-related EEG measures that allow for electrophysiological comparisons between NFT and task performance. This level of comparison suggests it has the promise of being able to disclose how NFT effects on performance are mediated by the brain. The major findings of the fast-wave research in healthy subjects have been the improvement of cognitive performance in measures of sustained attention, memory encoding/retrieval, and preliminary findings indicating a role for SMR NFT in modulating acting performance.

1.4.3.4 Summary of optimal performance studies

This section has reviewed the literature documenting optimal performance applications of EEG neurofeedback as a precursor to detailing my own studies of music performance that include both alpha-theta and SMR training procedures. Measures of training, electrophysiology and task performance, and their inter-relations have been assessed, as have the research methods used.

1.5 Creativity, Hypnagogia and Music performance

As discussed in Section 1.4.3.2 on page 43 and also Appendix A on page 250, alpha-theta training seeks to modulate the t/a ratio with the objective of initiating and sustaining hypnagogic EEG, operationalised as SLEEP STAGE 1. The following section will define how creativity will be realised in the fieldwork, assess the hypnagogia-creativity link that underscores the research methodology of this thesis, and conclude by demonstrating the distinct role that music performance has in the empirical observation of creative behaviour.

1.5.1 Problematising creativity

Within psychology there are both reductionist and holistic approaches to bringing creativity under experimental control. In the former category, psychometric techniques have been derived beginning with the *process* driven work of Guilford (1950) and Mednick et al. (1965); taking a *product* driven view, Amabile (1982) and Simonton (1997) emphasised the role of selective behaviour as the principal determinant of creative value. Most recently, the research community has returned to exploring the role of the *process* underlying creative behaviour, and Dietrich (2004a) has attempted to overcome the problems facing psychometric definitions by reducing the complex edifice of human creation into four hypothetically distinct neural phenomena.

1.5.1.1 Psychometric concepts

Starting in the 1950's, attempts to quantify the cognitive basis for creation have measured individual differences in idea formation tasks.

Joy Paul Guilford Guilford conceptualised creativity as a process of 'Divergent thinking' – the ability to elicit multiple responses from a given stimuli – and Christensen et al.'s (1960b) 'Alternate uses task' encompasses this thought process by soliciting non-standard uses for household objects, and establishes the following metrics:

- Fluency (The number of uses)
- Flexibility (The number of usage categories - as judged by a panel)
- Originality (The distinctiveness of a given use in relation to the whole sample)
- Elaborateness (The extent of detail)

The alternate uses task Here is an example of the script given to test participants:

> ***Please consider some common objects. Each object has a common use, which will be stated. You are to list as many as six other uses for which the object or parts of the object could serve.***
>
> ***EXAMPLE:***
> ***Given: A NEWSPAPER (used for reading). You might think of the following other uses for a newspaper:***
>
> ***a. start a fire***
> ***b. wrap rubbish***
> ***c. swat flies***
> ***d. stuffing to pack boxes***
> ***e. line drawers or shelves***
> ***f. make a kidnap note***
>
> ***Notice that all of the uses listed are different from each other and different from the primary use of a newspaper. Each acceptable use must be different from others and from the common use.***
> ***Do not spend too much time on any one item. Write down those uses that occur to you and go on to the others in the same part. You may return to the incomplete items in a Part if time for that part permits.***

> ***There are two parts to this test, with three items per part. You will have 4 minutes for each part. — Christensen et al. (1960b,a)***

In test scenarios, the written responses of participants to provided stimuli are scored by independent raters, and the raters' attribution of categories, originality and elaborateness is then assessed by means of Inter-Rater-Agreement statistics, e.g. Fink et al. (2006).

Sarnoff A. Mednick Whilst Guilford typified creativity as divergent thinking, his contemporary Mednick (1962) argued that the creative process was based on a form of combinatory association in which seemingly disparate concepts converge, citing Poincaré as a compelling articulation of this:

> ***``To create consists of making new combinations of associative elements which are useful. The mathematical facts worthy of being studied ... are those which reveal to us unsuspected kinships between other facts well known but wrongly believed to be strangers to one another. Among chosen combinations the most fertile will often be those formed of elements drawn from domains which are far apart." — Poincaré and Halsted (1913)***

Mednick's inferred measure of creativity, the 'Remote associates test' was then examined for construct validity against college tutors' subjective ratings of how creative their students were, and the extent to which leading architects score high or low on measures of originality. Furthermore, high scorers on the R.A.T test were not generally high scorers on gross point average measures of academic performance, possibly distinguishing associational ability from general intelligence.

The Remote associates test The 'Remote associates test' (Mednick and Mednick, 1967a,b) measures the extent to which a subject can associate three words by pairing each of them with a fourth. For example the words: `Broken`, `Clear` and `Eye` can all be interconnected with the word `Glass` (More examples at varying levels of difficulty are shown in Table 1.1). The test is scored according to the number and difficulty of correct associations drawn.

Table 1.1: Example stimuli used in the Remote associates test (Mednick and Mednick, 1967b)

R.A.T item	Solution	Difficulty
Dollar / Stop / Language	Sign	Very Easy
Set / Program / Cable	Television	Very Easy
Cottage / Brick / Cake	Cheese	Very Easy
Head / Street / Dark	Light	Easy
Surprise / Line / Birthday	Party	Easy
Red / Go / Car	Stop	Easy
Food / Front / Drug	Store	Medium
Noise / Collar / Wash	White	Medium
Bay / Picture / Washer	Window	Medium
Desert / Ice / Spell	Dry	Hard
Magic / Plush / Floor	Carpet	Hard
Soap / Shoe / Tissue	Box	Hard
Self / Attorney / Spending	Defense	Very Hard
Artist / Hatch / Route	Escape	Very Hard
Reading / Service / Stick	Lip	Very Hard

Continued use of psychometric thinking tests Despite appearing contradictory in their conception, both the divergent and associative definitions and measures of creativity both require the ability to generate a wide assortment of responses to original stimuli (see Figure 1.6), and as such may both be measuring the ability to generate multiple responses. The Remote associates task goes further however by eliciting the drawing of parallels between the responses.

Psychometric measures of creativity have remained popular and are widely used to this day. Following Guilford, Torrance (1974) formalised and drew further measures of divergent thinking, and Mccrae (1987) found a positive correlation between 'Divergent thinking' aptitude and the five-factor personality dimension of 'Openness to experience' (Costa and McCrae, 1985), concluding that "Individuals who easily generate new ideas, whose cognitive processes are flexible, may develop an interest in varied experience." This finding adds some weight to the case for the reliability of tests of divergent thinking, although conversely it has been found the outcome of these tests can be altered by subliminal exposure to corporate logos (Fitzsimons et al., 2008). This suggests that rather than being stable across test conditions (as IQ tests

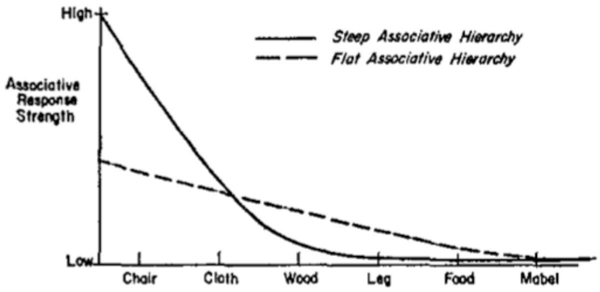


Figure 1.6: Mednick's (1962) associative hierarchy of the word 'Table' - respondents with a flatter associational hierarchy tend to be able to imagine a wider collection of associations, and tend to perform better on the Remote associates task by virtue of their fluency.

are agreed to be), divergent thinking methods can be quickly and easily subverted. In any case, for continued want of an approach that clearly associates thinking tests with for example achievements in real-world creative output (Sawyer, 2012), these psychometric measures continue to be widely assumed to serve as measures of creativity itself.

Starting with Martindale and Armstrong (1974) in the 1970's, and then in rapidly increasing numbers since the beginning of the 21^{st} century, a procession of cognitive neuroscientists have used these tests in an effort to disclose distinct neural activities underpinning creation behaviour, yet the results so far have been highly variable, replications have not been observed, and when reviewed together, the assembled data effectively preclude interpretation (Dietrich and Kanso, 2010; Arden et al., 2010) – more of this later.

1.5.1.2 Social and evolutionary concepts of creativity

Bearing in mind the conceptual difficulties posed by the work of Guilford and Mednick in defining creativity as a distinct thought process, later psychologists moved away from attempts to make the process tractable, focussing instead on a more outcome driven definition of creativity.

Teresa Amabile Amabile (1982) set out a method called the 'Consensual assessment technique' with which a given product could be deemed inherently creative insofar as:

1. A subsection of the population are able to achieve consensus as to *what* is a creative outcome, according to their own subjectively held views
2. They are also able to agree *how* creative a given outcome is
3. Their consensus can be distinguished from aesthetic and technical factors, which can confound creative judgement.

The 'Criterion problem' in creativity research In her critique of the earlier psychometric attempts to study creativity, Amabile argued that they had only been successful in isolating abilities that contribute to creative performance by observing behavioural characteristics – consequently, neither divergent thinking nor remote association tests are able to define the creative value of an outcome, only the characteristics of the person who produced it. Amabile characterised this as the 'Criterion problem': "The lack of a clear operational definition and an appropriate assessment methodology."

The 'Consensual assessment technique' Arguing that creativity could effectively be both operationalised and assessed with reference to its value in a social context, Amabile's method uses the social environment to both subjectively define *and* measure creative value by gauging the extent to which an audience can agree on the creative merit of a given real-world outcome.

Dean Keith Simonton In common with Amabile, Simonton (1999) also emphasised the importance of the audience in defining creative merit, although he doesn't focus on the immediate social context. Instead his conceptualisation of the audience is as a receiver of a random mix of variability, from which creativity is selected out.

Simonton defines the selection of creative value from random variation at three distinct levels: the individual; the social; the cultural. His view is that creative outcomes originate from an entirely random process of variation, and that randomly generated outcomes are selectively retained according to a heuristic he compares to the evolution of species.

The evolutionary basis of creativity Simonton (1999) argues that the 'Random variation' and 'Selective retention' of creative outcomes occurs in each of the three audiences: at the individual level, outcomes are generated seemingly at random but retained according to personal selection heuristics; the same process then repeats in the social plane as individual outcomes join a randomly assembled mix of outcomes, with selection proceeding according to socially derived criteria (which is what Amabile's (1982) technique captures); finally, a culture continually encounters new creations at random, and selectively retains some according to cultural requirements.

The 'Equal odds rule' Unlike Amabile's (1982) approach to defining judgements about creative value, Simonton doesn't describe the mechanism underlying the 'Selective retention' of creation. Instead, his empirical work focusses predominantly on making the case for 'Random variation' as the basis of creative behaviour by presenting evidence in support of his 'equal odds rule' (Simonton, 1997): On average, the *quantity* of a person's creations will predict the *quality* with which they will be perceived in any sphere. Two types of evidence are submitted to support this view: life-span and cross-sectional success rate measures.

In his longitudinal analysis of the successes and failures of the great composers, Simonton (1997) demonstrated that, on average, the ratio of successes to failures remained constant. At the height of productivity, composers produced what went on to become critical hits and misses at the same rate as they did later in life, when it might be anticipated that their hit rate would rise as a product of their experience. This is taken as evidence that the composers' creative values can not predict social and cultural values because of the essential randomness with which they join the fray.

Simonton (2003) also observed the equal odds rule when looking cross-sectionally at the relationship between academic productivity and extent of critical acceptance, which he expressed as the citation count. He found that on average, the most prolific scientists were those who produced the most cited works, *furthermore*, these prolific academics also produced the majority of works receiving fewest citations. This was interpreted as evidence that the social or cultural retention of a given creation cannot reliably be foreseen by the individual, and that the key determinant of academic success is prolificacy. There are exceptions to this general rule, but Simonton maintains that each level of selection takes place amid a random mix of outcomes.

The return of the behavioural paradigm Although Amabile and Simonton both advanced the view that creativity is, by definition, selection rather than inception, their refusal to define selection behaviour, coupled with the advent of cognitive neuroscience methods, has seen a return to the focus on individual differences within the behavioural paradigm.

1.5.1.3 The cognitive neuroscience of creative behaviour

Existing psychometric measures of creativity appear untractable in the brain Originating in the EEG studies of Martindale and Armstrong (1974), and increasingly greatly with advances in of neuroelectric and neuroimaging methods, a great number of studies comparing 'Divergent thinking' and 'Remote association' to control tasks have emerged. The accumulated studies have been reviewed by Dietrich and Kanso (2010) and Arden et al. (2010) who found that in combination, the results provided no reliable evidence of a distinct neural signature underlying performance on creative tasks. Dietrich and Kanso's (2010) review of 63 studies concluded that the neuroelectric results varied hugely and neuroimaging outcomes agreed only on "diffuse prefrontal activation." Arden et al. (2010) reviewed 45 studies, and found the neuroelectric and neuroimaging evidence so variable as to preclude interpretation.

In both reviews, a way out of the current disarray was suggested. Arden et al. (2010) produced a manifesto proposing various methodological alignments that could be observed by the research community, including one that Dietrich and Kanso (2010) also promoted, that of domain specificity. Citing his earlier attempt to deconstruct the creative edifice, (see Figure 1.7 on page 80), Dietrich suggested that for neuroscientists, a more promising approach to finding creativity in the brain would be to depart from tests of 'Divergent thinking' and instead concentrate on capturing specific modes and domains of creation.

The subsequent work in this thesis accepts Dietrich's (2004a) invitation to approach a behavioural subset of creativity, and attempts to encapsulate his conception of 'Emotional knowledge' being exercised in the 'Spontaneous processing' mode. In his definition, the representation of emotional signals in working memory have a distinct revelatory phenomenology, and he cites Coleridge's (1816) conception of the poem 'Kubla Khan, or Vision in a Dream' as a classic example of this type of creative

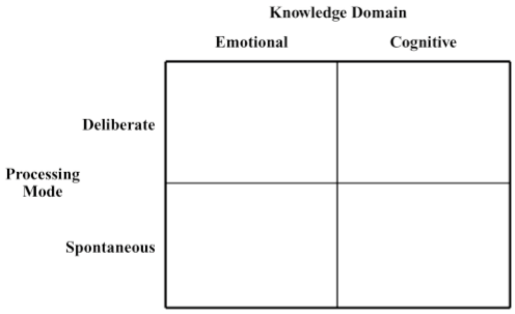


Figure 1.7: *from Dietrich (2004a)* who hypothesised that: "... there are four basic types of creative, each mediated by a distinctive neural circuit. Creative insight can be the result of two processing modes, deliberate and spontaneous, each of which can guide neural computation in structures that contribute emotional content and in structures that provide cognitive analysis. Crossing the two processing modes with the type of information yields the four basic types of creativity."

insight:

> ***``The author continued for about three hours in a profound sleep, at least of the external senses, during which time he has the most vivid confidence, that he could not have composed less than from two to three hundred lines; if that indeed can be called composition in which all the images rose up before him as things, with a parallel production of the correspondent expressions, without any sensation or consciousness of effort." — Coleridge (1816).***

Spontaneous processing of emotional content as a tractable creative state? Unlike Arden et al.'s (2010) call for domain specificity in experimental tasks, Dietrich (2004a) emphasises that emotions do not require domain specific knowledge to be communicated, although appropriate skills must be used to express them in creative work. As I will discuss in Section 1.5.3 on page 86, music improvisation appears to be a plausible candidate to observe this distinct category of creativity. The remainder of the thesis will centre on the operational definition of creativity as *'spontaneous processing of emotional content'* with an emphasis on music improvisation as a means of realising this in the fieldwork.

As will be discussed in following Section 1.5.2, the question is posed as to whether the neurophysiology of *'spontaneous processing of emotional content'* bears the same hallmarks as that of hypnagogia.

In terms of measuring outcomes, the musical attempts to realise Dietrich's (2004a) proposed state will be evaluated in reference to Amabile's (1982) consensual assessment technique to arrive at a socially valid representation of what a spontaneous process of emotional content must provide to indicate its relevance beyond the state itself.

1.5.2 Hypnagogic Creativity

In this section I will summarise the historical association between hypnagogia and creativity, leading to the outline of an empirical framework that uses alpha/theta NFT to try to moderate this relationship experimentally.

1.5.2.1 Historical accounts of hypnagogic creativity

Prior to the scientific work investigating the potential practical application of alpha-theta NFT in regulating hypnagogia, the association between hypnagogia and creativity had been described for millennia, with historical accounts of hypnagogic imagery in creative endeavour being compiled by Koestler (1964) and Mavromatis (1987).

Arthur Koestler Considering the apparently fertile ground for creative endeavour offered by early sleep, Koestler (1964) considered whether the hypnagogic state might be a physiological correlate of creativity, and proposed that creative insight occurrs as a product of 'bisociation,' a form of thinking where apparently unrelated concepts are either 'juxtaposed' in the arts, 'inverted' in humour, or 'synthesised' in science.

Koestler argued that many of the great creative insights throughout history had occurred when the originators were in semi-conscious states, and that semi-consciousness established the right kind of thought conditions in which 'bisociation' could occur. To support this proposal, Koestler provided a list of historical examples, with one of the best known being Kekulé's account of how he discovered the structure of benzene. In a speech made 25 years after his breakthrough, Kekulé described how, following an extended period of difficulty he had reached an impasse in his work, but then finally made his breakthrough during a semi-conscious dream:

> ***``I was sitting writing on my textbook, but the work did not progress; my thoughts were elsewhere. I turned my chair to the fire and dozed. Again the atoms were gambolling before my eyes. This time the smaller groups kept modestly in the background. My mental eye, rendered more acute by the repeated visions of the kind, could now distinguish larger structures of manifold conformation; long rows sometimes more closely fitted together all twining and twisting in snake-like motion. But look! What was that? One of the snakes had seized hold of its own tail, and the form whirled mockingly before my eyes. As if by a flash of lightning I awoke; and this time also I spent the rest of the night in working out the consequences of the hypothesis.'' — from Koestler (1964)***

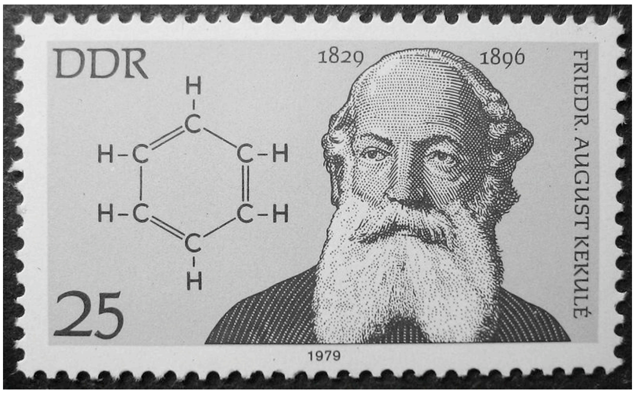


Figure 1.8: Image showing the structure of Benzene, as Kekulé claimed to have first visualised as hypnagogic imagery of a snake holding its own tail.

Whilst it can not be confirmed whether Kekulé's creative inspiration occurred as a product of hypnagogic imagery and/or bisociation, the description of visual imagery appears consistent with the hypnagogic state (Hayashi et al., 1999b).

Andreas Mavromatis Another commentator to explore the potential relationship between hypnagogia and creative insight was Mavromatis (1987), who also collected evidence in the form of anecdotal reports – one of the earliest accounts was attributed to Aristotle, who described the "affections we experience when sinking into slumber," and "the images which present themselves to us in sleep." In Mavromatis's (1987) examination of creativity, it was reported that some historical figures engaged the hypnagogic state in their creative endeavours. One account came from Charles Dickens, who wrote of the hypnagogia also described as hypnopompia, that is sleep-offset:

> ***``It is a curiosity of broken sleep that I made immense quantities of verses ... and that I spoke a certain language, once familiar to me, but which I have nearly forgotten from disuse, with fluency. Of both these phenomena I have such frequent experience in the state between sleeping and waking, that I sometimes argue with myself that I know I cannot be awake ..."*** — ***Dickens (1894)***

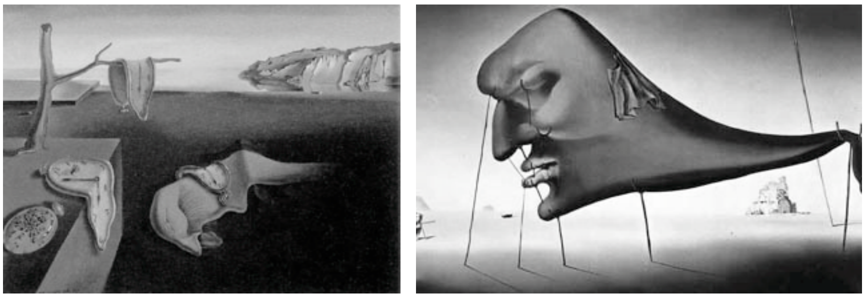
Figure 1.9: Image from Mavromatis's (1987) recounting of Dickens's hypnagogic experiences.

Another of Mavromatis's (1987) examples describes how Thomas Edison, upon encountering an impasse in his work, would doze at his desk whilst holding steel balls in his hands; one of the physical effects of hypnagogia is the loss of muscle tone [7] and as Edison approached sleep, his hands would release the steel balls, and the sound of them hitting the floor would stir him from his reverie, during the course of which he may have overcome his impasse.

Figure 1.10: The Edison statue at his home in Fort Myers, Florida. He's shown holding a steel ball, the type of which he reportedly used in capturing hypnagogic insights.

[7]The loss of muscle tone during sleep onset can sometimes be accompanied by a conscious sensation of falling, producing an involuntary response known as the hypnagogic myoclonus, like a startled flinch.

Mavromatis similarly recounts how Salvador Dalí would doze whilst holding a spoon over the floor in order that at the point of hypnagogia where muscle tone is lost, he would drop the spoon and be awoken. In so doing, he was able to retain conscious awareness of dreamlike imagery. The importance of sleep for surrealism, and the nature of its role in the work of Dalí is shown in some of his famous paintings concerning the transformational qualities and delicate balance of sleep in surrealist art (see Figure 1.11).



(a) The Persistence of Memory (1931) (b) Sleep (1937)

Figure 1.11: The time-warping effects (1.11a) and precariousness (1.11b) of sleep in the work of Salvador Dalí.

Prior to these examples of sleep imagery in surrealist painting, the founder of the Paris surrealists, poet Andre Bréton, prescribed the use of hypnagogic imagery in his 'Manifesto of Surrealism':

> ***``(I had been led to) concentrate my attention on the more or less partial sentences which, when one is quite alone and on the verge of falling asleep, become perceptible for the mind without its being possible to discover what provoked them.'' — Breton (1924)***

Historical accounts such as those given previously are not subject to direct empirical inquiry, but they provide a context in which to consider the efforts of neurofeedback researchers to deploy alpha-theta NFT as a way to control mechanisms proposed to underpin creativity.

1.5.2.2 Alpha-theta neurofeedback and hypnagogia

Taking the previous accounts as a starting point, and comparing them with the knowledge that alpha-theta NFT promotes hypnagogia via t/a ratio elevation (Egner et al., 2002), an outline of an empirical framework can be drawn.

This proposes that changes in t/a measures during NFT, modulate the same psychological mechanisms that also accompany creative insight. Accordingly, changing these mechanisms could thus predict changes in creativity (musicality) to a greater extent than technique and communication. On this basis, the current thesis additionally sought to further isolate the possible link between alpha-theta and musical creativity by including an outcome measure specifically associated with music creation: music improvisation, which, as will emerge, is also thought to exhibit a similar pattern of neuronal deactivation.

1.5.3 Musical creativity in performance

In recent years research into musical creativity in particular has increasingly used improvisation as a means of observing the creative process as it takes place under laboratory conditions. Whilst it has been argued that all music performance is inherently creative, and the rendition of a score still requires interpretation, which may in itself be creative (Heilman et al., 2003), the use of spontaneous ideation makes a more explicit call on the performer(s) to create at a given time, i.e. during an experiment.

Improvisation has been used in a series of experiments exploring the psychological correlates of music creation and assessment. (Sawyer, 2000) stresses the important role of improvisation as a tool for examining creativity empirically, as it allows not only the final creative product to be examined, but it also discloses the process by which it was created.

1.5.3.1 Improvisation as creative process

Human-human interaction has been documented as characterising the co-ordinating behaviours used to generate and select the content of group improvisation (Bryan-Kinns et al., 2007). In assessing musical creativity computationally, algorithmic composition and improvisation have been compared due to their shared emergent properties (Papadopoulos and Wiggins, 1999), and the cognitive constraints on improvisation and creativity have also been compared in terms of the psychological structures that both enable and constrain both phenomena (Pearce and Wiggins, 2002).

In other psychological characterisations, musical improvisation has been likened to Guilford's (1950) psychometric definition of creativity as 'Divergent Thinking' (Gorder, 1980; Wang, 1985) with ensuing attempts to bring musical creativity under experimental control as measures of improvisational fluency, flexibility, elaboration and originality. These attempts could not however distinguish measures of musical divergent thinking from technical competence and general intelligence. These attempts appeared to suffer from the same criterion problem posed by 'Divergent Thinking' as a definition of creativity in that they only encompass some attributes that may help with creativity, but not creativity itself.

1.5.3.2 Improvisation as creative product

More recently, the explicitly quantitative and process based approach to creativity measurement in improvisation has been eschewed in favour of the outcome evaluation method based on audience responses.

Eisenberg and Thompson (2003) asked a panel to evaluate improvisation using rating scales based on Amabile's (1982) 3 factor Consensual Assessment Technique (CAT). The CAT explicitly sets out to distinguish evaluations of creativity from technical and aesthetic valence, although as with Gorder (1980), the authors found that it was not possible to identify creative behaviour as a unitary phenomenon distinct from technical and aesthetic factors.

1.5.3.3 Comparing music rendition and improvisation

In response to the difficulties experienced in isolating improvisational creativity from other elements of music performance, some studies have explored the hypothesis that music improvisation, as an explicit form of music creation, is substantively different from music rendition. Before proceeding to consider this comparative approach, it should however be qualified with Pressing's (1988) assertion that no improvisation is completely novel, and no rendition is completely lacking in novelty.

In terms of music creation, in an online, experimentally comparable setting, improvisation provides an operational means of observing the mechanisms underlying music creation. In comparison with offline, asynchronous music composition, improvisation is more easily integrated into a research method as it controls for additional influences on creative behaviour, and constrains the time-span in which musical representations can be evaluated, compared, and selected. This is not to say that feed-forward editing does not take place in improvisation (Pressing, 1988), however, the online nature of both improvisation and rendition means that they are more directly comparable than composition and rendition.

On this basis, and despite the ambiguities concerning the creative as opposed to technical/aesthetic merits of improvisation, this comparative approach is used in *process* based analyses of creativity, with a series of recent attempts to reveal the neural correlates of improvisation appearing in neuroimaging studies.

The studies of Brown et al. (2006); Bengtsson et al. (2007); Limb and Braun (2008); Berkowitz and Ansari (2008) found activations across multiple brain areas during music creation, suggesting that creativity can not be specifically associated with any brain region in isolation; this form of creativity is, in other words, a 'moving target' (Dietrich, 2004a). However, one salient point that emerges from these studies is that of activity in the prefrontal cortex. On the one hand Limb and Braun (2008) observed that prefrontal areas deactivated during jazz-blues improvisation at a keyboard, whilst on the other, Brown et al. (2006) found prefrontal activation during the vocalisation of a musical response; (Bengtsson et al., 2007) found activations during an improvisation recalled from memory; whilst (Berkowitz and Ansari, 2008) also found prefrontal activations during the use of a five note diatonic keyboard.

This difference between fMRI studies has led Dietrich and Kanso (2010) to surmise that novel response generation in the Limb and Braun (2008) study was likely to have arisen from freely selected 'implicitly' recalled motor sequences which did not require the intervention of higher order cognitive functions, whilst the remaining studies all included tasks requiring a greater degree of working memory and attentional organisation that would be expected to activate prefrontal brain areas. Dietrich then goes on to draw parallels between Limb and Braun's (2008) finding and his own hypothesis (Dietrich, 2003), that creative responses can occur during fleeting moments of hypofrontality: the transient inhibition of processes that organise working memory, thereby allowing random and potentially creative combinations to be mnemonically represented.

1.5.3.4 Hypnagogia, alpha-theta, and improvisation

It is worth noting at this point that in Dietrich's (2003) hypothesis, it is argued that the EEG signature (De Gennaro et al., 2001) that discloses "executive deficiencies" (Muzur et al., 2002) in sleep-onset, is the same signature that can be seen in alpha-theta NFT (Egner and Gruzelier, 2004a) and the spontaneous processing of emotional content.

Therefore, the previously described neurophysiolgical similarity between hypnagogia, alpha-theta NFT and the spontaneous processing of emotional content (creativity), now expresses the latter as music improvisation, paving the way for a scientific investigation which examines whether modulating the common physiology modulates creativity.

1.6 Summarising the background context

This chapter first reviewed the origin of EEG in the brain, and consequent the history of NFT.

Consequently, I reviewed applications of NFT in healthy subjects designed to optimise the self-regulation of hypnagogia (alpha-theta NFT) and motor inhibition (SMR NFT). Hypnagogia later forms the basis for the principal research question of this thesis, and motor inhibition is examined secondarily.

The concept of 'Optimal performance' in the context of NFT applications was considered as a means of regulating the debilitating effects of performance anxiety on task execution, and the literature presenting prior optimal performance NFT applications was reviewed.

The question of defining and measuring creativity, which forms that overriding research question of this dissertation was then reviewed, and the current operational definition was set as the 'Spontaneous processing of emotional content' the product of which is subjectively and consensually agreed to be creative by a social audience.

Hypnagogia, a candidate neural correlate of creativity, was then examined as a potential mechanism for regulating creativity, especially in the light of the fact that alpha-theta NFT is thought to bring hypnagogia under volitional control.

Finally, music improvisation was presented as an experimental method for observing both creative processing *and* the evoked social response, encapsulating the combined process+product definition of creativity.

2
Aims

2.1 Research aims

2.1.1 Primary aims

Exploring creativity by attempting to quantify and modulate it The overall aim of the research is to disclose creativity in a tractable way, and to attempt to modulate it.

This aim is composed of three smaller aims:

1. Define creativity in an experimentally tractable way Define creativity in a way that addresses the tensions in psychology and cognitive neuroscience about how to make it experimentally tractable. The introduction to this dissertation tried to reduce this problem by exploring a proposed single basic type of creative behaviour — spontaneous processing of emotional content — through a social psychology of its creative value.

2. Regulate creativity via hypnagogia To use applied neuroscience to modulate hypnagogia, a candidate neural correlate of spontaneous creative insight — and in so doing reinforce physiologies underlying spontaneous creative insight.

This is a prospective aim that seeks to reinforce hypnagogic electrophysiology using alpha-theta NFT.

This EEG reinforcement can be looked at as a short-term transient after-effect, or a long-term reinforcement effect.

3. Disclose creativity through improvisation To explore the application and cognitive neuroscience of music improvisation as a candidate scenario for observing creativity. This is because improvisation provides a context in which two things can plausibly take place: a) the spontaneous processing of emotional content, b) the outcome of the process can be evaluated socially.

In combination, it is possible to explore whether a social definition of creativity (b) has a reliable personal antecedent (a).

2.1.2 Secondary aims

Optimise novice performance The possibility of optimising sensory-motor skill regulation in novice musicians is explored.

Replicate and re-focus Egner and Gruzelier (2003) Replication of the first study associating NFT with creativity is a starting point from which to advance the current methodology, and to begin re-focussing the approach to handle the type of basic type creativity addressed here.

2.2 Research questions

2.2.1 Converting aims to questions

Given the aims of disclosing creativity as the spontaneous processing of emotional content using music improvisation, and modulating this processing through reinforcing hypnagogic EEG with alpha-theta, plus the aim of reinforcing sensory-motor control in novice performance — the main research questions of this dissertation are as follows:

2.2.1.1 List of research questions

1. Creativity Can measures of creativity be modulated by hypnagogia and alpha-theta NFT?

2. EEG TRAINING Can alpha-theta NFT be shown to regulate hypnagogic electrophysiology? Additionally, and in relation to Research question 3, can SMR training be shown to regulate sensorimotor activity?

3. Novice performance Can measures relating to sensory-motor control in novice performance be elevated by reinforcement of sensory-motor inhibitory control via SMR NFT?

4. Effect relation Can changes in NFT be associated with changes in performance?

5. Hypnagogia and improvisation EEG As candidate neurophysiologies thought to disclose the spontaneous processing of emotional content, can these states be shown to address the transient hypofrontality hypothesis (Dietrich, 2003) using applied neuroscience methods?

6. Improvisation as creativity Does the operational definition of improvisation as spontaneous processing of emotional content work in distinction from other types of performance — as a candidate for disclosing creativity in the brain and eliciting a social response that validates creative judgement, which forms of improvisation are most useful to the experimenter.

There's also an additional research question about replication and picking up form prior work in this field:

7. Is Egner and Gruzelier (2003) replicable Are relevant earlier reports replicable?

2.3 Research method

To address the research questions, I will present the results of three studies:

2.3.1 Experiment 1 — Optimising music performance with neurofeedback, a constructive replication

As the literature review has shown, alpha-theta NFT has been associated with creativity improvements in musicians (Egner and Gruzelier, 2003) and timing in dancers (Raymond et al., 2005a). This study serves as an attempt to replication and extend Egner and Gruzelier (2003). As ever, replication is required, and even more so here given that Keizer et al. (2010a) have referred to their own failed attempt to enhance theta band EEG activity with NFT. The replication part of Experiment 1 addresses Research question 7.

The proposed creativity association, has been interpreted as an interaction between alpha-theta NFT and performance, possibly mediated by regulating frontal brain deactivation through 'Transient hypofrontality' in hypnagogia (Dietrich, 2003).

Hypofrontality has been shown to occur as a function of alpha-theta training (Egner et al., 2004), sleep onset (Muzur et al., 2002), psychometric tests of creative thinking (Fink et al., 2006) and spontaneous musical creativity (Limb and Braun, 2008).

Experiment 1 replicates Egner and Gruzelier (2003), and in so doing addresses Research questions 1, 2, & 4, with the additional standpoint of the transient hypofrontality hypothesis (Dietrich, 2003) as the mediating factor in the interaction between alpha-theta and creativity.

Experiment 1 also introduces the question of novice performance (Research question 3) into the mix, given that the 'Optimal performance' application of NFT may potentially augment sensory-motor processing in an unaccustomed music task.

Experiment 1 touches on the need for Research question 6 (Improvisation as creativity), although without systematically addressing the issue of improvisation type and creative disclosure.

Finally, Experiment 1 serves as a replication of Egner and Gruzelier (2003) in addressing Research question 7.

2.3.2 Experiment 2 — Interpreting the transient effects of neurofeedback on music performance

Experiment 1 had low statistical power due to the size of the three participant groups ($n = 8$). Given that the design had nonetheless appeared to shine a light on differences in improvisation after NFT — addressing Research questions 1 & 6 — it was decided to add an additional cohort to this study.

Accordingly, Experiment 2 has the same design as that of Experiment 1, however the final NFT session was immediately followed by the post-training performances, and in so doing, the design of the study was effectively changed to one that explored not only the long-term training effects of NFT but also the transient after-effects.

Investigations of short-term NFT effects in Hoedlmoser et al. (2008); Ros et al. (2010) have indicated that for at least 20 minutes after NFT, training related physiological effects can be observed. Exploratory comparisons between the two cohorts confirmed that reliable differences occurred between the two alpha-theta cohorts, rationalising the break-up of this design into two studies.

As a consequence, Experiment 2 becomes an examination of short-term NFT effects as an adjunct to addressing Research questions 1, 2, 3, 4 & 6 in common with Experiment 1.

2.3.3 Experiment 3 — Neuroelectric measures of music improvisation and rendition, and the after-effects of transient diurnal sleep on motor performance and cognition

Whilst the prior work had operated on the assumption that the transient hypofrontality in hypnagogia had parallels in the spontaneous processing of emotional content in improvisation; the missing link — confirmatory EEG measures of improvisation — had yet to be established.

Accordingly this study set out to address Research question 5 (Hypnagogia and improvisation) by examining evidence for transient hypofrontality in improvisation as a preliminary step in confirming the parallels between different scenarios giving rise to spontaneous processing of emotional content.

Additionally, and in extensions of Experiments 1 & 2, the aim of Experiment 3 was to systematically address Research question 6 (Improvisation as creativity) by considering the merits of different improvisation types for creative disclosure.

Finally, and considering that Experiment 2 had raised the question of transient after-effects of hypnagogia on motor performance, Experiment 3 considered Research question 1 (Creativity) from a new perspective. It considered frontal lobe and motor function in cognitive and music performance tasks following hypnagogia. This examined whether the short-term priming of hypofrontality with hypnagogia might transiently down-regulate motor function whilst up-regulating cognitive function - effectively leading to the divergent post alpha-theta NFT results in Experiments 1 and 2.

2.4 Commonalities, differences, and links between the studies

The studies share Research question 1 (Creativity) in common. In building on prior associations between alpha-theta, hypnagogia and creativity, all the studies consider attempt to address Dietrich's (2003) proposal that "transient hypofrontality is the unifying feature of all altered states," including sleep and moments underlying spontaneous creative insight. In the first two studies, this proposal is assumed to be the case, whereas the third actively explores this by examining the EEG of improvisation for frontal hypofunction.

The studies also share Research question 6 (Improvisation as creativity) in common. The overall design of the fieldwork holds that improvisation is the ideal candidate to observe the working definition of creativity as a spontaneous processing of emotional content (online) that can also be socially evaluated as being creative (offline). The studies also ask the question "Which type of improvisation is appropriate for this aim?" Experiment 3 in particular considers that improvisational skill may be a pre-requisite for attaining spontaneous processing.

The first two experiments are ostensibly part of the same data capture, yet their design diverged on the key issue of post-NFT test timing. Participants in Experiment 1 waited at least one hour before carrying out post-NFT assessments of music performance, whereas those in Experiment 2 performed immediately - revealing a hitherto undocumented transient effect of alpha-theta NFT. This design alteration led to the data being treated independently.

Experiment 3 is quite different from its predecessors in that it does not employ NFT methods to regulate hypnagogia and creativity. It does however continue to examine creativity after of hypnagogia, particularly in transient mode as a response to the surprise encounter of Experiment 2. Additionally, the role of improvisation as a means of disclosing creativity is further developed from prior work.

The appearance of RESEARCH QUESTIONS 1 & 6 in all three studies provides the common thread that unites the dissertation, and will hopefully provide useful information for those wishing to work with creativity as spontaneous processing of emotional content, perceived as creative in the social context.

3
Experiment One

3.1 Introduction

The problem addressed by this experiment is that whilst alpha-theta NFT has been associated with changes in creative behaviour in at least four neurofeedback studies (Green et al., 1972; Boynton, 2001; Egner and Gruzelier, 2003; Raymond et al., 2005a), clear, controlled evidence of this has yet to be discovered. The theoretical implications of this will be considered in the light of the long held yet empirically lacking link between hypnagogia and creative insight, and the practical implications will be considered in relation to the introduction of musical improvisation as a means of observing creative insight in laboratory conditions.

An additional problem is introduced in this study: the previously unexplored possibility that NFT may benefit novice music performance.

This experiment is a constructive replication of second of two NFT studies carried out in a population of conservatory instrumentalists, both studies were reported in Egner and Gruzelier (2003). The first study, a correlational design, provided evidence that changes in theta/alpha (t/a) dynamics across 10 sessions of alpha-theta training were associated with improvements in evaluations of *instrumental competence, musicality, and communication*. The first experiment also showed within-subject effects of a mixed SMR/beta protocol in reducing attentional errors on the TOVA Go-NoGo task (Egner and Gruzelier, 2001). The second experiment, a between-subjects design, provided further evidence of modulated attentional performance following SMR and beta NFT (Egner and Gruzelier, 2004b), and some of its data were used in disclosing resting frontal beta reductions following alpha-theta NFT (Egner et al., 2004). This second trial also showed further musical changes following alpha-theta NFT, with improvements in measures of *musicality* and, as a result, overall quality.

This musicality finding of the latter RCM experiment drew some parallels with the prior observation that alpha-theta training and the practice of hypnagogia it is thought to regulate might be harnessed in raising creative achievement (Green et al., 1972). As documented in Section 1.4.3.2, Boynton (2001) explored this association empirically, suggesting that the wilful use of hypnagogia in either alpha-theta *or* relaxation training predicted increased creative flexibility as measured psychometrically with the Torrance Tests of Creative Thinking (Torrance, 1974). Additionally, Raymond et al. (2005a) provided some evidence that evaluations of timing and overall performance in ballroom dance was improved following alpha-theta NFT. Taken together, the empirical support for the association between alpha-theta and creativity as well as overall performance is equivocal, although it is considered promising that the strongest evidence thus far came from the most rigourous investigation (Egner and Gruzelier, 2003).

An empirical framework encompassing historical associations between hypnagogia and creativity, and the potential role of alpha-theta NFT as a means of moderating this relationship is outlined in Chapter 1 Section 1.5. The framework incorporates the role of music improvisation as an operational measure of creativity.

In the current study, the next step in using music performance to analyse the possible link between alpha-theta, hypnagogia and creativity was to select a form of improvisation that whilst providing scope for creative behaviour, nonetheless allowed different performances to be compared against each other. Most musical improvisation (with the possible exception of free improvisation) explicitly incorporates forms of musical constraint in time and/or frequency domains, and all the empirical studies discussed in Section 1.5, with the exception of Bryan-Kinns et al. (2007), used a highly constrained 'melodic template' approach to measuring performance: In this approach, a melodic framework is provided, within which the performer makes variations. The current study adopted a different method however, selecting a graphic score called Stripsody (Berberian, 1966) (Figure 3.3 shows an excerpt of the score). Unlike the prevailing 'melodic template' technique, the use of a graphic score places less constraint on the actual pitches used, but more constraint on the way content changes over time. It does so by maintaining the same stimuli over the course of the performance - and this may help judges to compare one performance to another as the creative differences can be compared against a set series of stimuli-response pairs rather than an evolving process of variation.

The criteria for selecting Stripsody for this study was that a vocal only improvisation was sought - principally to explore whether reducing instrument differences might also reduce error variance in analysis. Stripsody is one of the two vocal improvisations practised at Trinity's voice faculty[1]. The technical details of the Stripsody score are further discussed in Section 3.3.5. The other voice improvisation technique used at Trinity is singing based on a phrase, e.g. "A walk in the woods." Further examples of the phrase stimuli used are listed in Section 3.3.5.3. This technique was also used in the study, although not for voice but instrumental improvisations, as the study also sought a non-vocal improvisation test that was based on the repertory that Trinity staff were accustomed to evaluating. It was considered important that panel who evaluated the performances had some familiarity with the improvisation methods being practised as Amabile (1982) asserts that prior experience of a subject provides the basis for identifying creativity within that subject.

In addition to testing whether the findings of the RCM study are replicable in relation to creativity, the current study introduces some further additional music performance tasks in order to consider a previously unexplored rationale for using SMR training in music performance. Considering that the preceding RCM studies assessed expert instrumental performance, it was proposed that novel music performance might be differentially affected following SMR training.

The rationale underlying this statement is based on two points, firstly musical expertise in relation to sensory-motor performance shows marked differences between novices and experts, with trained musicians exhibiting much stronger interaction between auditory and motor processing in the brain, with auditory stimuli even evoking involuntary finger movements in pianists (Haueisen and Knösche, 2001), and expert musicians disclosing a greater ability to sustain attention on a musical task (Berkowitz and Ansari, 2010); secondly, Ros et al. (2009) reported technical improvements and reduced task-time of perceptuo-motor performance in trainee micro-surgeons follow-

[1]Trinity's head of voice, Linda Hirst, was recorded giving a performance of Stripsody on the album "Songs Cathy Sang" (1988)

ing SMR training. Given these two points, it is speculated that SMR training, which has already been shown to optimise trainee surgical skills, may be more likely to raise perceptuo-motor performance in novice performance than its expert counterpart, as the stimulus-response interaction is less likely to be operating at ceiling levels than has been observed in conservatory musicians, who even at undergraduate level have experienced many more years of practice than surgeons at a similar stage in their training.

A further consideration taken in staging a constructive replication of the RCM studies was in the attempt to increase the experimental control of the trial by controlling for instrument. In both the RCM experiments alpha-theta protocol NFT was associated with improvements in music performance, yet clear difference between alpha-theta and other groups was not observed. A possible confounding factor was that performances were made using different instruments, which may have interfered with ratings to some extent as the instrument played or the instrument played by the assessor changes how performance is evaluated (Stanley et al., 2002). For this reason, the novice-singing task also had the advantage of reducing the difference in instrument to some degree.

In summary the current study addresses both the theoretical and practical implications of previous NFT investigations into optimising aspects of task performance. The implication of Egner and Gruzelier (2003), that alpha-theta NFT may specifically modulate measures relating to creativity gave rise to a new experiment, focussed on using explicitly creative performance as an outcome measure of an NFT intervention. Ros et al. (2009) indicated that motor performance was modulated by SMR NFT, giving rise to an experimental rationale for using SMR to facilitate inhibitory control in novice music performance.

3.2 Research questions

Primarily, this study explored whether sleep-onset EEG regulation can modulate creative performance. The creative behaviours explored either replicate those used in preceding studies at the same lab (Egner and Gruzelier, 2003), or reflected the accumulating research interest in improvised performance as a means of observing music creation in the action.

Secondarily, this research also sought to examine whether the regulation of sensorimotor EEG would modulate novice music performance.

3.2.0.1 List of research questions

There were five research questions in this study (see Section 2.2.1.1):

1. Creativity Can measures of creativity be modulated by hypnagogia and alpha-theta NFT?

2. EEG training Can alpha-theta NFT be shown to regulate hypnagogic electrophysiology? Additionally, and in relation to Research question 3, can SMR training be shown to regulate sensorimotor activity?

3. Novice performance Can measures relating to sensory-motor control in novice performance be elevated by reinforcement of sensory-motor inhibitory control via SMR NFT?

4. Effect relation Can changes in NFT be associated with changes in performance?

7. Is Egner and Gruzelier (2003) replicable Are relevant earlier reports replicable?

3.2.1 1. Creativity

Given the previously described framework, which proposes that alpha-theta NFT, hypnagogia and creative insight all share the same reduction in higher order cognitive functionality, it is explored whether evaluations of musicality will be elevated following alpha-theta NFT.

3.2.2 2. EEG training

In the alpha-theta protocol, it was explored whether that the t/a ratio would be elevated as a function of training, both within- and across-sessions. In prior work, (Egner et al., 2002; Egner and Gruzelier, 2004a) it was found that the within-session t/a increases could be predicted more reliably, with only the latter study observing t/a increases by comparing the first and final five sessions. In the SMR protocol it was explored whether the SMR/(theta+beta) ratio would be elevated. Reliable within-session increases in the SMR to theta, and a trend for within-session increases in the SMR to beta ratio have previously been documented by Vernon et al. (2003).

3.2.3 3. Novice performance

As described previously, motor aspects of novice performance were explored for improvement by SMR NFT. The previous theoretical discussion had proposed that self-regulation of task-based motor responses are already highly adapted in student musicians due to their many years of prior training, and it was held that motor regulation was already at or close to a ceiling level in expert performance in that population, which may account for the lack of appreciable SMR effects on music performance in (Egner and Gruzelier, 2003). In contrast, it was explored whether novice performance would be optimised following SMR NFT, and that this would be manifested in improved measures of technical competence.

3.2.4 4. Effect relation

Although the experiment was primarily designed to enable between-groups comparisons in identifying protocol specific effects on aspects of music performance, it was additionally explored whether within-subjects measures of changes in music performance would co-vary as a function of within-subjects measures of neurofeedback related EEG.

EEG changes are characterised as within- and across-session changes in NFT ratios (t/a within the alpha-theta group, and SMR/(theta+beta) within the SMR group), and it was explored whether that changes in these measures would correspond to changes in audience evaluations of creativity and technical competence within the alpha-theta and SMR groups respectively.

3.2.5 7. Is Egner and Gruzelier (2003) replicable

Are relevant prior post alpha-theta results replicable?

3.3 Method

3.3.1 Participants

An advertisement inviting volunteers to join the experiment was distributed by email and flyer around TCM, the Royal College of Music, Goldsmiths University of London, Guildhall and Kings College. 24 music students volunteered for participation in the experiment (10 females, 13 males; mean age 26, ± 9.20). All of the participants were instrumentalists with a non-expert level of singing ability - this ensured participants were able to perform both non-expert singing and expert instrumental tasks. They were allocated to experimental groups in the order of joining the study. No payment was made for participation. An internal ethics committee at Goldsmiths approved the study with no alterations.

Creech et al. (2008) provided evidence disclosing differences of musical history on musical behaviour by comparing musicians that played in non-classical and classical traditions. The current study was comprised of 1 Jazz bassist, and 23 classical instrumentalists: 7 pianists, 4 guitarists, 3 flautists, two violinists, and a single bassist, percussionist, oboeist, cellist, clarinetist, and trumpeter. Creech et al.'s (2008) study found that non-classical musicians attached greater importance to improvising music, whereas their classical counterparts ranked ability to improvise as the least important musical skill. In a study such as this, which uses improvisation to elicit and measure creative behaviour, the effect of such musical histories on performance is likely to be a contributory factor in the response of participants to the NFT intervention.

From a neuroscientific perspective, recent electrophysiological studies of classical and jazz improvisation (Bengtsson et al. (2007) and Limb and Braun (2008) respectively) have shown differing frontal neurophysiologies. The neural differences were, in part, attributed to the finely developed improvisational skill of Jazz musicians (Limb and Braun, 2008), and the relative deactivation of frontal cortices seen in the Jazz study supports the approach transient hypofrontality hypothesis (Dietrich, 2003) that this study also explores. Given the dominance of classical musicians in this study, the participants' level of improvisation skills was basic at best, and thus the study investigated improvisation ability from a position of minimal prior engagement.

3.3.1.1 Power

In the preceding study of instrumental performance reported in Egner and Gruzelier (2003), the estimated effect size of TIME × GROUP interactions fell within the "small" range (.02 - .25 Cohen (1988)). The small participation count (n=8) coupled with the small effect size gave a low observed power of 0.24.

In order to establish whether Egner and Gruzelier (2003) is replicable in a study with sufficient statistical power to differentiate an effect size of .2 - 25, with a statistical power of 0.8 (as recommended by Cohen (1988)), a total of 42 participants would be required in a three group study.

The current study recruited 24 participants, and the implied power of a 24 person 3 group pre/post intervention GROUP × TIME interaction only achieves a level of power=0.42, raising the likelihood of false negatives being declared towards 60%.

The logistics of mounting an appropriately powered study have been addressed in an ADHD treatment study by Gevensleben et al. (2009b), who collected data from three collaborating laboratories across Germany. The current study attempted to increase the statistical power in a similar way, although not by recruiting simultaneously from other sites, but by waiting for more participants to become available.

Data collection was extended to a second cohort from the following academic year's intake, and it was hoped to raise statistical power towards 0.8. A further 19 recruits at Goldsmiths College were given NFT, preceded and followed by measures of musical creativity. However, due to differences in the execution and outcome of second-cohort research, the pooling of data across interventions was ruled out (see Section 2.3.2).

The observed power of changes in performance types for experiments 1 and 2 is shown in Table 3.1, and confirms that investigating a small effect size in studies composed of small population groups resulted in low-powered studies.

Table 3.1: Mean observed power of music changes across repeated measures analyses

	Instrumental	Stripsody	Folk song	Improvisation
Exp. 1	0.08	0.17	0.25	0.16
Exp. 2	0.09	0.26	0.25	0.27

3.3.2 Design

Instrumental musicians volunteering to participate in the study were allocated into three experimental groups in the order of joining the study: the first, second and third members were allocated to alpha-theta, SMR and control groups respectively, and this pattern continued with all following participants.

In total participant groups numbered:

- alpha-theta (n=8)
- SMR (n=8)
- no-training controls (n=8).

On joining, all participants commenced the experiment with a filmed performance comprising 4 pieces:

- Folk song with accompaniment (Britten, 1948)
- Vocal improvisation from graphic score (Berberian, 1966)
- Instrumental from participant's own repertoire
- Instrumental improvisation on a theme

Subsequently, participants in NFT groups received training sessions every 3 (±4) until they had received 10 sessions; controls received no intervention for 30 (±17) days. This group was included to control for the effects of time and practice on the post-training measures. One control participant dropped out of the study as they were unable to attend post-intervention testing appointments.

Finally, all participants repeated the performance carried out at the start of the study.

3.3.3 Neurofeedback Procedure

Neurofeedback training was carried out with EEG Spectrum International, Inc. EEger software (Version 4.13c) using the Thought Technology pre-amp and Procomp amplifier. The software provides both alpha-theta and SMR feedback protocols.

The signal was recorded referentially with 3 passive electrodes: the signal electrode over the cortical location being recorded (Pz in alpha-theta and Cz in SMR); the reference electrode on the left earlobe; the ground electrode on the right earlobe. The electrode locations were prepared with 'NuPrep,' a gentle abrasive detergent to remove loose skin, and the electrodes were attached with 'Ten20' conductive paste. The EEG is interpreted as voltage differences between signal and reference, with respect to the ground electrode, an isolated current-limited input used to provide a zero voltage point.

The recording was amplified, impedance was kept below 5 kilo-ohms, and the signal acquired at a 256 Hz sampling rate. The raw samples were lowpass-filtered by a 40 Hz filter to remove ambient noise (mainly in the form of European standard electrical mains interference at 50 Hz). A voltage threshold was set at 60 microvolts to remove electrical potentials created by muscle cells, which have an average range of between 50 microvolts and 30 millivolts.

The resulting lowpass signal was fed to a number of processing streams, which either trigger the provision of rewarding feedback, or inhibit rewards. In each stream, the lowpass signal is bandpass-filtered into various frequency bands using Infinite Impulse Response (IIR) digital filters. The filter output is fed to an exponentially weighted 30 second moving average filter which produces a short-term average (peak-to-peak), the time constant of the averaging filter being 0.5 seconds. The peak-to-peak voltage is calculated as the voltage difference between the maximum and minimum points of a signal. The moving average from each stream is displayed to the trainee, and is used to determine whether reward should be provided (EEGer Neurofeedback Software, 2005).

Training and protocol specific details regarding feedback are given in the following section.

3.3.4 Neurofeedback Training

In order to determine whether neurofeedback can be used to learn how to change EEG parameters, participants attended a course of ten training sessions. Training sessions were time-tabled and carried out by the experimenter who ensured EEG recordings were made above the same cortical location each time, with the minimum of interference from movement related or other electrical interference that might mask the EEG. Additionally the experimenter functioned as a training coach, as is the case in the therapeutic practice of neurofeedback, providing initial instruction participants in how the feedback presents EEG parameters and ways in which behavioural responses might change those parameters. The coaching was not however built into the process of learning, and was not adjusted in response to changes in the ability of participants to control the EEG. Each session was conducted by the experimenter, who prepared the recording equipment, observed the session, and brought each session to a close by ending feedback stopping the recording, and removing recording EEG electrodes.

3.3.4.1 Alpha-Theta Neurofeedback Training

In this protocol the training electrode was placed at Pz (parietal midline) according to the international 10–20 system of EEG electrode placement. In each session the participant rested in a comfortable chair with their eyes closed for 15 minutes, whilst receiving auditory feedback (see Figure 3.1). Participants were instructed to relax as if going to sleep whilst engaging with the feedback in the practice of sustaining themselves in the normally fleeting state of the wake-sleep transition.

Figure 3.1: Photo of an alpha-theta training session

The feedback consisted of one of two continuous sounds representing the dominant slow wave EEG frequency: a predominance of alpha activity alpha (8–11 Hz) is represented by the sound of a running stream, whilst theta (5–8 Hz) predominance is presented as the sound of ocean waves. As well as giving a general indication of the alpha-theta relationship, the system uses amplitude thresholds to detect and signal fleeting changes in EEG band activity. Thresholds for feedback were set automatically every 10 seconds, and adjusted so that average amplitudes of alpha and theta were above threshold 55% and 25% of the time respectively. Supra-threshold voltage bursts in alpha and theta frequency bands are used to trigger bell or gong sounds respectively — which signal momentary above average increases in voltage. As SLEEP STAGE I initialises, the ongoing background sound will typically cross-fade from running stream to ocean wave sounds and gong tones will replace bell tones. If both frequency ranges are above threshold at the same time, the system signals that the alpha threshold has been exceeded (EEGer Neurofeedback Software, 2005).

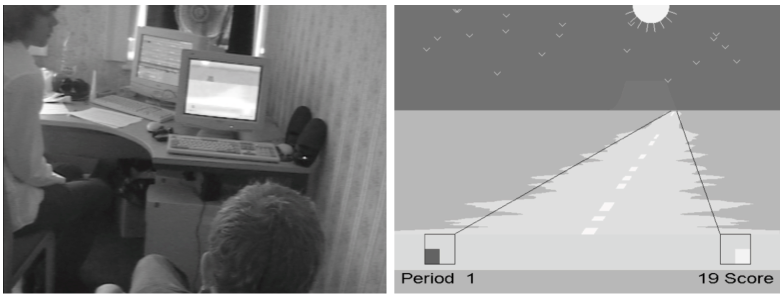
In addition to signalling alpha and theta activity changes, the EEGer system also uses activity in delta (2–4Hz) and high-beta (22–30Hz) to inhibit tone feedback. During a 10-second period if average amplitudes of high beta or delta were increased on the previous 10s epoch for 20% or 15% of the time, alpha and theta tones were not sounded. As with the other bands, the 'inhibit' thresholds were adjusted automatically every 10 seconds. The role of delta measurement is particularly important to this protocol as it indicates progress towards advanced stages of sleep, as does a partial increase in alpha activity during SLEEP STAGE II (De Gennaro et al., 2001), so intermittent alpha tones against a background of ocean wave theta audio is used to signal that the trainee has exceeded their target level of sleep onset.

3.3.4.2 SMR Neurofeedback Training

In this protocol the training electrode was placed at Cz (midline motor cortex) according to the international 10–20 system of EEG electrode placement. In each SMR training session the participant sat in a comfortable chair for 18 minutes whilst receiving audio-visual feedback (see Figure 3.2a). The objective is to use the feedback in sustaining attention whilst concurrently inhibiting inattention and high arousal.

SMR training began with a 2-minute baseline period during which EEG-band amplitudes were recorded at rest with eyes open. This baseline was then used as the criterion for feedback parameters during the first 170 second training period. The thresholds for reward were calculated by subtracting half the standard deviation of the mean baseline SMR amplitude, and theta and high-beta inhibit thresholds were set by adding half the standard deviation to the mean baseline amplitudes.

During training participants were instructed to regulate their EEG in controlling the feedback to elevate SMR power in relation theta and beta. They were asked to focus on increasing the breadth of the onscreen horizontal band which shows the current level of the SMR amplitude beyond the limits set by the boxes on each side (see Figure 3.2b), whilst concurrently maintaining the size of the left square (theta 4–7Hz) and right square (hi-beta 22–30Hz — henceforth referred to as beta) within their bounding boxes. During training, if each half-second cycle includes supra threshold SMR and sub threshold theta and beta amplitudes, 1 point is scored and the running total updated on screen. Additionally a tone is sounded with each point scored, and a seagull is added to the display. Each 500 points are further rewarded by the eruption of the onscreen volcano. A typical 15 minute training session saw participants scoring approximately 1000 points.



(a) SMR session setup (b) SMR island game display

Figure 3.2: Photo of an SMR training session
and an image of the feedback display

After each of the five 170 second training periods, the game was paused for 10 seconds, during which time the trainee could move if needed, and the EEGer system adjusted the reward and inhibit amplitude thresholds automatically based on the moving average calculated at the end of the previous section so that SMR activity would have been over threshold 65% of the time, with beta at 15% and theta at 20%.

3.3.5 Music Performance

All participants gave a performance staged as a sequence of 4 musical tasks before a small audience comprised of the investigators from TCM and Goldsmiths in performance or rehearsal spaces at TCM and Goldsmiths. From a position within the audience, a film camera and attached microphone recorded each performance. This footage was transferred to computer for editing and sequencing, and at the end of the study a panel of two assessors from TCM evaluated a randomised sequence of performances for each of the four tasks. The panel was blind to the participants' experimental grouping, and to whether each performance they saw was recorded before or after the intervention.

Evaluation was conducted using structured examination criteria and 10 point scales used in the RCM studies, which were in turn adapted from conservatory music examinations (Harvey, 1994). In each of the 4 tasks, evaluation proceeded in four categories: *Technical Competence, Musicality,* and *Communication,* plus an *Overall Rating*. In the case of the replication part of the study, the criteria were almost identical to those used in the RCM experiments, with minor alterations to communication related terms. The singing tasks saw criteria being adjusted or added to focus explicitly on vocal technique and musicality, and the improvisation task changed musicality assessment to focus more on how performers managed to maintain their performance spontaneously. The particulars of each task follow.

3.3.5.1 Task One, Folk Singing

At the pre-intervention performance participants they were asked to select an English folk song arrangement from Britten (1948), which they would rehearse (10-minutes) and then perform with a piano accompanist. In the post-intervention test participants repeated the same song. Folk songs were chosen in order to provide vocal material that contained relatively simple melodies making them more accessible to non-expert singers. The songs that participants chose were one of the following: *The Salley Garden, Little Sir William, The Bonny Earl o' Moray, O can ye sow cushions?, The Ash Grove, and Oliver Cromwell.* The assessment form used by the panellists is in Appendix C. The scale used in the assessment is not an absolute one, and the assessors watched 3 of the performances before agreeing that they were using roughly the same terms of reference to evaluate performance.

3.3.5.2 Task Two, Stripsody

Following the initial folk song, participants were given an unseen section of a graphical score called Stripsody (Berberian, 1966) from which to improvise vocally for two minutes. Stripsody is a 'graphic notation' taking its name from cartoon strips, and was briefly described in Section 3.1. The first page of the score is shown in Figure 3.3. It is a cued improvisation that is loosely constrained in time and frequency; musical stimuli are found within a series of cartoon-strips, and their position and size represent their pitch, timing and volume. In the pre-training performances participants were given the first half of the score from which to perform, and the latter half in post-training tests. The assessment form used by the panellists is in Appendix D, and as with the folk singing, the panel applied the scale in an ad-hoc, subjective way.

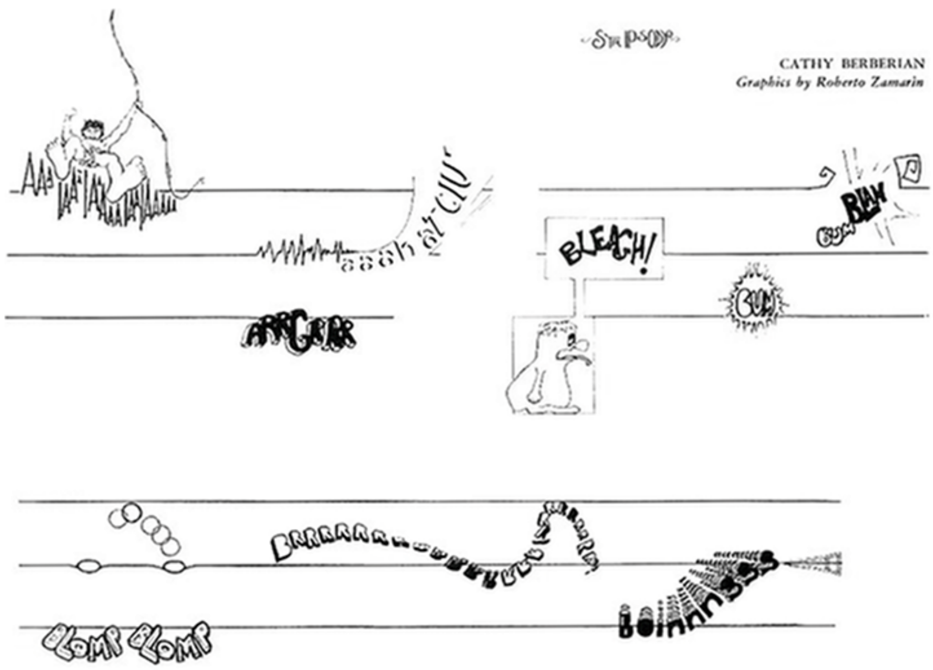


Figure 3.3: The strips are prefaced with the instructions: "**The score should be performed as if by a radio sound man who must provide all the sound effects with his voice.**" (Berberian, 1966)

3.3.5.3 Task Three, Instrumental Performance

In replication of the methods in the RCM study, participants were invited to play the same solo instrumental piece from their repertoire in pre- and post-training tests. The assessment form used by the panellists is in Appendix E. Unlike the vocal performances, the panel were encouraged to compare and assess instrumental performances in relation to music degree standards.

3.3.5.4 Instrumental Improvisation

Finally participants were given a task that was based on an auditioning exercise given to prospective students at TCM. At both pre- and post-training stages, participants selected any descriptive phrase from a list, which they then interpreted as the basis for a 2-minute instrumental improvisation. No further instructions were given. The phrases were: *"First steps on the moon," "Day at the market," "Afternoon at the zoo," "Trip on safari," "Flying over London," "Walk through the woods," "Bank robbery," "High speed car chase," "Crossing a derelict rope bridge," "Deep sea dive," "A tearful farewell," and "A raging storm."* As with the instrumental solo, the marking scheme applied here was based on degree classification standards, and is contained in Appendix F.

3.3.5.5 Contributions

Some of the NFT data for this experiment (12 cases) was collected with the collaboration of co-students Shama Rahman, Katie Bulpin, and Alexander Rass. These students also helped with arranging music performances for twelve cases, and filmed one performance. I completed filming, collected further NFT and control participant data (11 cases), and edited and presented the performance footage to the panellists (Linda Hirst and Patricia Holmes) who provided the music evaluations documented below. NFT equipment and training was provided by Tony Steffert and Tomas Ros, and Tony also helped to set up the NFT laboratory at Trinity College of Music. The music appraisal criteria were reviewed from the RCM studies, and agreed or added to in collaboration with Linda Hirst, Sophie Grimmer, Clare Nelson and Patricia Holmes at Trinity College of Music. Kit Venables and Tom Gisby assisted with the setup of sound and video recording equipment, and Claire Nelson and Fred Mollitor provided me with access to the Trinity College of Music site and resources, including the performance spaces, the laboratory, and the library and computing facilities.

3.3.6 Statistical Analysis

The study design included two main components to be analysed statistically: the training data in alpha-theta and SMR training groups, and the panel assessment of pre-post intervention music performance in three groups. The relations between the two were also examined.

3.3.6.1 Neurofeedback training

For logistical reasons, the time of day for training appointments could not be held constant across the study. Comparisons across sessions could consequently introduce confounding factors resulting from changes in amount of sleep on the preceding night or nights (Cajochen et al., 1995; Aeschbach et al., 2001), spontaneous cognitive activity (Laufs et al., 2003), and time between eating and EEG recording (Fishbein et al., 1990). Thus, according to the method introduced by Lubar et al. (1995) neurofeedback learning was assessed as an increase in the *training ratio*, that is the amplitude of the (rewarded) training frequency relative to another (inhibited) frequency or frequencies. In the case of the alpha-theta protocol training effectiveness was measured as the t/a ratio, and in the SMR protocol the SMR/(theta+beta) ratio.

Neurofeedback 'learning' was expressed as evidence of a progressive raising of training ratios either within or across sessions. This was analysed with a repeated measures two-way ANOVA[2] assessing two factors: the 10 sessions, and the 5 × 3-minute training periods[3] within each of those 15-minute sessions. This analytical approach is consistent with related studies (Egner et al. (2002); Egner and Gruzelier (2004a) documented within-session increases in the t/a ratio, and Vernon et al. (2003) found increases in SMR to theta and SMR to beta relations with this approach).

3.3.6.2 Music Performance

Summary of measures In summary, the selected music performances and their measures are shown in Table 3.2. The judges who provided performance measurements evaluated the vocal tasks as novice performances, applying scores in relation to the other performances in the set and according to their intuitions about performance value. In the assessing the creative value of behaviour, rater agreement and social

[2]In all ANOVA calculations, Mauchly's test was used to screen compared data sets for homogeneity of (co)variance; in cases where assumed sphericity was not met, Greenhouse-Geisser corrections to the degrees of freedom were applied.

[3]this method is in itself a product of SMR training procedures, in which trainees are given 10-second "blink-breaks" every three minutes to move if necessary, and review their performance.

psychology is the chosen method of determining creative worth relative to the domain in which it is being carried out (as practised by Amabile (1996) and Martindale (1999)). With instrumental performances, and since the participants were student instrumentalists, the judges used the music degree scoring framework, so a score of 7 to 10 would equate to a first class performance for example. The score sheets used by the panel are shown in Appendices C, D, E and F. Where panel ratings demonstrated agreement; their combined score was then used to generate a single measure of change for use as the dependent variable in an ANCOVA analysis that assessed NFT effects on performance. The participants were not provided with information on any of the measures being drawn from their performances.

The impact of a given creativity rating scheme on raters, and the way they apply the scheme, has been conceptualised in several ways in the area of creativity research. The initial psychometric style developed by (Mednick and Mednick, 1967a) and (Guilford, 1978) operationalises creativity into a metric enabling stimulus response pairs to be counted and compared under experimental conditions. Gorder (1980) applied Guilford's (1978) metric to music phrase completion tasks, but found that high counts of stimulus-response pairs were reliably predicted by high technical competence rather than perceived creativity. Amabile (1982) employed a holistic approach towards defining creativity, arguing that the reductionist approach was still prone to unmitigated subjectivity in the setting and measurement of creative metrics. Having confirmed the agreement within a given panel's subjective view, her technique then uses factor analysis to distinguish their conception of creativity from potentially confounding factors: aesthetics and technicality.

The conceptualisation of assessment dimensions has also taken place in the conservatory evaluation tradition, although McPherson and Thompson (1998) describe how this clashes to a greater degree with the holistic approach advocated by some assessors. Whilst it is true that the statistical approach to evaluating performance as components is a good way of profiling inter-rater-reliability; the validity of such an assessment is challenged by those who argue that the holistic impression supersedes the componential view because of the complex inter-variations that give an overall impression. Perhaps because of this conceptual tension, the conservatory literature has not advanced a specific measure of creativity in the way that psychologists have attempted to.

The current study employed assessment criteria from the conservatory tradition (Taylor, 2005), asking raters to score overall, technical, interpretative and presentational values. In their standard usage for music exams, these variables are used to produce a single final grade, and the selected panellists from Trinity college of music were familiar with their application. For the purpose of measuring inter-rater-reliability however, and of isolating possible creativity differences on interpretative measures, the individual ratings were used in the study's statistical analyses.

Table 3.2: Included performance types and their assessment criteria

Vocal		Instrumental	
Folk song	Stripsody	Performance from participant repertoire	Improvisation on descriptive theme
Overall rating of Performance Quality	Overall rating of Performance Quality	Overall rating of Performance Quality	Overall rating of Performance Quality
Overall Vocal Competence	Overall Vocal Competence	Overall Competence	Overall Improvisational Competence
Breathing with Music in Mind	Diction	Rhythmic Accuracy	Overall rating of Musical Understanding
Clarity of Diction	Pitch	Security (including state of preparation)	Appropriateness to Theme
Pitch	Breathing with the Music	Tonal Quality	Fluency
Overall rating of Musical Understanding	Tonal Quality	Overall Overall rating of Musical Understanding	Temporal Sense
Interpretative imagination	Overall Musicality	Stylistic Accuracy	Overall Communicative Ability
Expressive Range	Imagination	Imagination	Deportment on stage
Being at one with Voice	At One With Voice	Expressive Range	Emotional commitment
Stylistic Accuracy	Overall Communication	Overall Communication	Confidence in the situation
Rhythmic Accuracy	Deportment on Stage	Deportment on Stage	
Degree of Engagement	Emotional commitment	Emotional commitment	
Overall rating of Communicative Ability	Confidence in the situation	Confidence in the situation	
Deportment on stage	Enjoyment in performing	Sense of Performance	
Emotional commitment			
Confidence in the situation			
Sense of Performance			

Inter Rater Agreement Subjective ratings of performance amongst the panel were subject to agreement analysis as a first step to assessing the validity of the assessment exercise. An Intraclass Correlation Coefficient (ICC) was calculated to measure consistency of agreement. This is defined as a two-way random effects model, and was employed on the basis that both the performers and judges came from random samples. The average measures coefficient ('C-k type' — McGraw and Wong (1996)) is used to assess consistency between ratings.

Differences pre-intervention A one-way ANOVA was performed on the pre-intervention measures of music performance to probe for group differences at baseline. The results of this analysis determined the choice of test the measure post intervention change

Differences post-intervention Contingent on rater-consistency, a rater averaged pre- and post-intervention rating of performance was calculated for each participant, an approach used in comparable studies of panel assessment (Egner and Gruzelier, 2003; Thompson and Williamon, 2003; Thompson et al., 1998).

If groups differed at baseline on a given performance measure (see previous section 3.3.6.2), the post intervention means were compared in an analysis of covariance (ANCOVA), with the pre-intervention measure as the covariate, and the post-intervention measure as the dependent variable. The ANCOVA was chosen over the more widely used repeated measures ANOVA as it improves the analysis of the Independent/Dependent Variable relationship by minimising sampling error variance. Analysis of covariance achieves this by adjusting for pre-intervention differences, provided the regression of each group is sufficiently homogeneous with other groups.

If groups did not significantly differ at baseline, their pre-post changes were compared by means of a repeated measures ANOVA with two levels (pre and post intervention).

3.3.6.3 Music and training changes

The within-subjects relationship between changes in music performance and NFT ratios were assessed by assessing the significance of training EEG as a covariate of music change, the dependent variable. In both EEG and music measures, the index of change was calculated as latter data minus former data (e.g. second half of training minus former half), divided by former data. This approach measures late data in proportion to early data.

$$Change = \frac{(post - pre)}{pre}$$

3.4 Results

3.4.1 Neurofeedback training

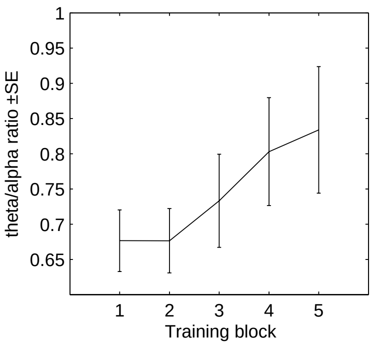
For reasons stated in Section 3.3.6.1 the training ratio is used as the most reliable NFT learning index, as it is less sensitive to uncontrolled EEG modulators. The data was analysed with a two-way repeated measures ANOVA with training period (within-session) and training session (across-sessions) as factors.

3.4.1.1 Alpha-theta neurofeedback training

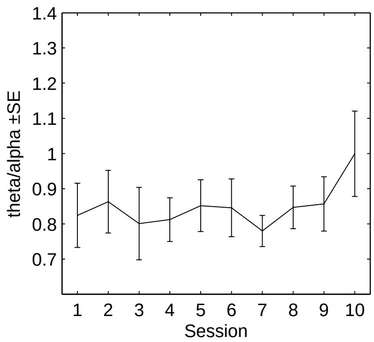
According to Research question 2 (EEG training) posed by the experiment, alpha-theta NFT would modulate the theta-alpha ratio progressively both within- and across-sessions, and as an interaction between the two factors. Within- and across-session training ratios, and their interaction are shown in Figures 3.4a, 3.4b and 3.4c respectively.

A repeated measures two-way (session × periods) ANOVA (with 10 × 5 levels respectively, sessions 1–10 and periods 1–5) disclosed marginal change in the global 'within-session' measure:

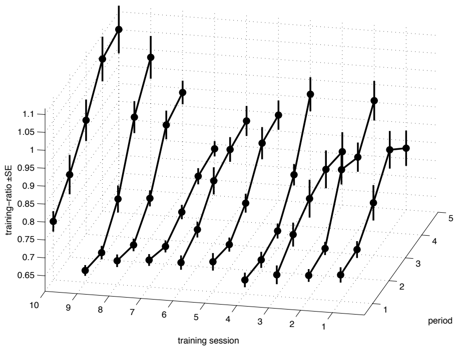
- The within-session factor of the ANOVA (with 5 levels, periods 1–5) revealed a marginally significant effect of period on the t/a ratio ($F(1.39, 9.75)=4.41$, $p=0.053$)
- The sessions factor of the ANOVA (with 10 levels, sessions 1–10), revealed that there were no significant differences between sessions ($F(9, 63)=1.48$, p=NS)
- Finally, the session × period interaction was examined for evidence of an effect of session on period t/a ratio. There was no significant interaction effect on t/a ratios ($F(36, 252)=1.156$, p=NS).



(a) theta/alpha ratios within a typical 15-minute session



(b) theta/alpha ratios across 10 sessions



(c) theta/alpha ratio: sessions × periods

Figure 3.4: Theta/alpha ratios shown over the course of the average session, course and session × course relationship.

3.4.1.2 SMR neurofeedback training

According to Research question 2 (eeg training) smr nft would raise the ratio of smr to both theta and beta amplitudes progressively both within- and across-sessions. Within-session changes are shown in Figure 3.5a, across session changes in Figure 3.5b and within-between interactions in Figure 3.5c.

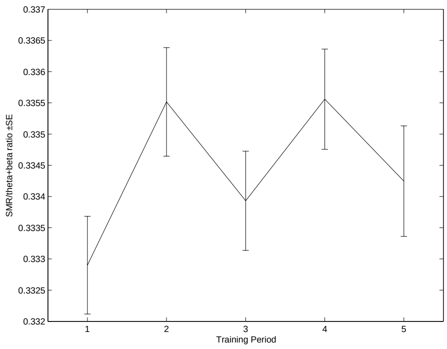
A repeated measures two-way (session × periods) anova (with 10 × 5 levels respectively, sessions 1–10 and periods 1–5) disclosed no significant changes:

- The within-session factor of the anova (with 5 levels, periods 1–5) revealed a non-significant effect of period on the training ratio ($F(1.91, 13.43)=0.39$, p=ns)
- The sessions factor of the anova (with 10 levels, sessions 1–10), revealed that there were no significant differences between sessions ($F(9, 63)=1.28$, p=ns)
- Finally, the session × period interaction was examined for evidence of an effect of session on period t/a ratio. There was no significant interaction effect on training ratios ($F(36, 252)=1.064$, p=ns).

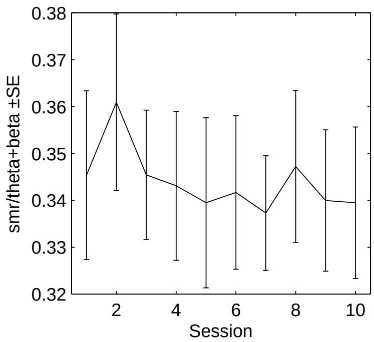
3.4.1.3 Neurofeedback Results Summary

In alpha-theta training, a marginally significant increase in the t/a ratio was seen on the aggregated within-session measure, a finding also seen in Egner and Gruzelier (2004a). This is a more robust indicator of nft dynamics as it pools data from across multiple sessions, thereby providing a more generalised estimate of eeg changes due to its smoothing of sampling error variance.

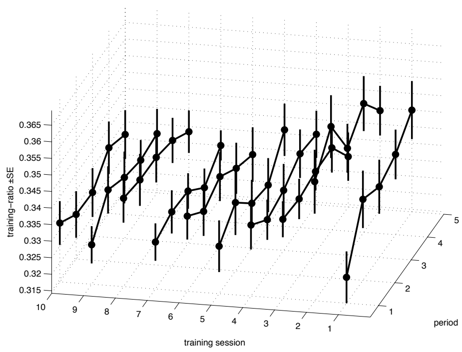
In smr participants, no significant training ratio changes were observed.



(a) SMR/theta+beta ratio within a typical 15-minute session



(b) SMR/theta+beta ratio across 10 sessions



(c) SMR/theta+beta ratio: sessions × periods

Figure 3.5: SMR/(theta+beta) ratios shown over the course of the average session, course and session × course relationship.

3.4.2 Music Performance

3.4.2.1 Instrumental Solo

This task was administered in order to see if the findings of Egner and Gruzelier (2003) were replicable, particularly the second experiment, which had a similar between-groups design to the current study. In summary, that study revealed alpha-theta NFT related within-group improvements in three out of four musicality measures: *Overall Musical Understanding, Stylistic Accuracy and Interpretative imagination*, and marginally significant improvements in *Overall Musical Performance*. The current analysis focussed on between-groups analyses as it was anticipated that all groups would improve on their repertoire solo performances through practice and task familiarity, although the significant within-group improvements detected previously provided useful methodological clues.

Data Screening One alpha-theta case received post intervention scores that were more than 3 standard deviations less than the mean of the participants' data and this case was removed from the analysis of instrumental performance.

A one-way ANOVA performed on the pre-intervention measures of performance revealed several significant group differences: Overall (F(2,19)=4.30, p=0.03); Overall Musicality (F(2,19)=3.67, p=0.05); Stylistic accuracy (F(2,19)=3.78, p=0.04); Imagination (F(2,19)=4.40, p=0.03); Emotional commitment (F(2,19)=4.39, p=0.03); Confidence(F(2,19)=4.67, p=0.02); Sense of performance (F(2,19)=4.0, p=0.04).

Post-hoc comparisons using the Tukey HSD test indicated that all of the above ANOVAS further revealed significant inter-group differences. The mean scores showed that controls didn't differ significantly on any measures, but alpha-theta group scores were significantly lower than those of the SMR group in every case: Overall: alpha-theta - SMR (M = -1.96, SE = 0.67) p=0.02; Overall Musicality: alpha-theta - SMR (M = -2.09, SE = 0.77) p=0.04; Stylistic accuracy: alpha-theta - SMR (M = -2.01, SE = 0.74) p=0.04; Imagination: alpha-theta - SMR (M = -2.22, SE = 0.76) p=0.02; Emotional commitment: alpha-theta - SMR (M = -2.24, SE = 0.76) p=0.02; Confidence: alpha-theta - SMR (M = -2.24, SE = 0.74) p=0.02; Sense of performance: alpha-theta - SMR (M = -2.31, SE = 0.83) p=0.03. Please see Figure 3.6

Ratings provided by our two panellists showed high levels of inter-rater consis-

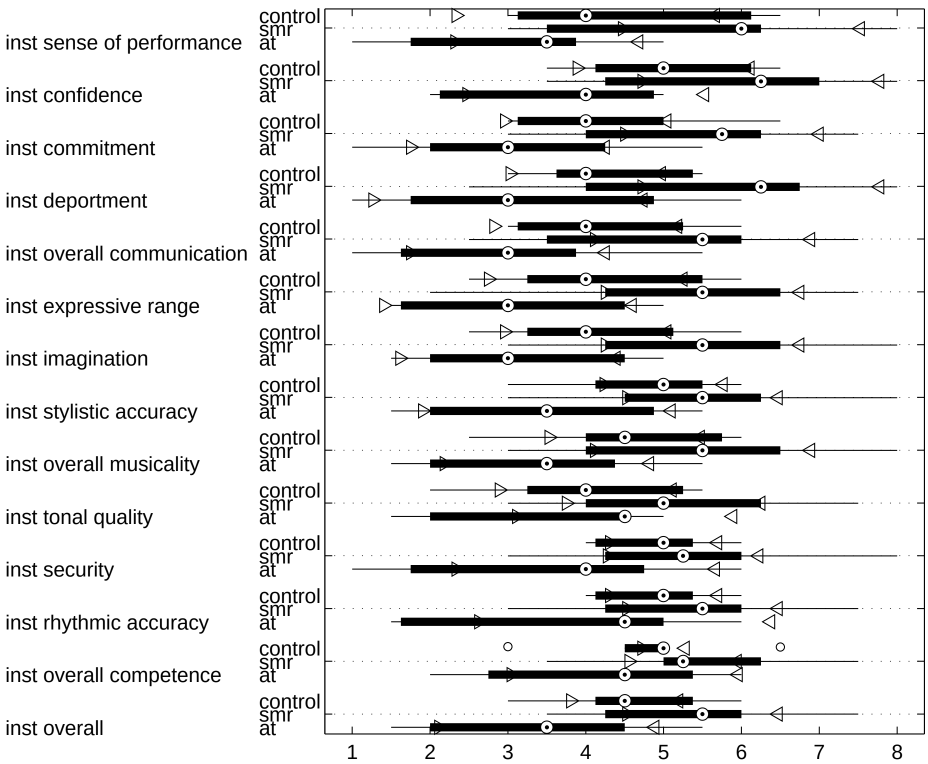


Figure 3.6: Boxplot showing between group differences in pre-intervention measures of Instrumental performance (Two medians are significantly different at the 5% significance level if their intervals do not overlap. Interval endpoints are the centres of the triangular markers.)

tency at $r=0.76$, $p<0.005$. The two sets of ratings were then combined into a single rater-average score for further analyses.

Creativity This task addressed Research questions 1 (Creativity) & 7 (is Egner and Gruzelier (2003) replicable?).

The means and standard deviations of baseline and change measures, as well as AN[C]OVA F-terms are included in Table 3.3 and visualised in Figure 3.7.

The rater-averaged performance scores were entered into univariate ANOVAs where performance measures did not differ at baseline, and ANCOVAs where they did. In ANCOVA, the pre-intervention scores acted as the covariate and the post-intervention score as the dependent variable; in ANOVA the pre/post repeated measures acted as levels 1-2 in a factor for that analysis.

The test results are shown in Table 3.3 and Figure 3.7. No test disclosed a differential effect of experimental group.

Table 3.3: Instrumental descriptive statistics

Measure	ALPHA-THETA (n=7) Pre	ALPHA-THETA (n=7) Change[1]	SMR (n=8) Pre	SMR (n=8) Change	CONTROL (n=7) Pre	CONTROL (n=7) Change	F-test (AN[C]OVA)
Overall	3.36 ± 1.55	0.48 ± 0.47	5.31 ± 1.31	0.07 ± 0.28	4.64 ± 0.99	0.05 ± 0.20	0.71[2]
Overall competence	4.14 ± 1.52	0.25 ± 0.33	5.50 ± 1.20	0.11 ± 0.31	4.79 ± 1.04	0.09 ± 0.16	0.13[3]
Rhythmic accuracy	3.64 ± 1.91	0.62 ± 0.73	5.25 ± 1.44	0.23 ± 0.56	4.86 ± 0.75	0.01 ± 0.26	0.97[3]
Security	3.43 ± 1.84	0.74 ± 0.99	5.25 ± 1.58	0.17 ± 0.52	4.86 ± 0.75	0.08 ± 0.29	0.62[3]
Tonal quality	3.43 ± 1.51	0.36 ± 0.35	5.12 ± 1.51	0.12 ± 0.41	4.07 ± 1.27	0.17 ± 0.16	0.55[3]
Overall musicality	3.29 ± 1.50	0.54 ± 0.40	5.38 ± 1.69	0.18 ± 0.55	4.57 ± 1.24	0.13 ± 0.36	0.09[2]
Stylistic accuracy	3.43 ± 1.62	0.52 ± 0.58	5.44 ± 1.55	0.09 ± 0.35	4.79 ± 1.04	0.03 ± 0.25	0.36[2]
Imagination	3.21 ± 1.44	0.39 ± 0.38	5.44 ± 1.64	0.06 ± 0.44	4.14 ± 1.25	0.22 ± 0.28	0.29[2]
Expressive range	3.14 ± 1.52	0.52 ± 0.49	5.25 ± 1.77	0.14 ± 0.55	4.21 ± 1.35	0.11 ± 0.22	1.26[3]
Overall communication	2.93 ± 1.57	0.52 ± 0.52	5.00 ± 1.71	0.13 ± 0.58	4.21 ± 1.19	0.14 ± 0.26	0.76[3]
Deportment	3.36 ± 1.86	0.50 ± 0.69	5.56 ± 1.88	0.14 ± 0.60	4.36 ± 0.99	0.13 ± 0.18	0.59[3]
Emotional commitment	3.07 ± 1.57	0.58 ± 0.51	5.31 ± 1.51	0.05 ± 0.39	4.29 ± 1.29	0.16 ± 0.25	0.23[2]
Confidence	3.57 ± 1.37	0.44 ± 0.38	5.81 ± 1.67	0.06 ± 0.46	5.00 ± 1.15	0.07 ± 0.17	2.21[3]
Sense of performance	3.00 ± 1.41	0.62 ± 0.60	5.31 ± 1.79	0.09 ± 0.57	4.50 ± 1.53	0.12 ± 0.26	0.28[2]

[1] $Change = \frac{(post-pre)}{pre}$

[2] ANCOVAs on group differences post-training, adjusting for differences pre-training: in all measures df(2,18) and p=NS

[3] ANOVAs on group × pre/post performance interaction: in all measures df(2,19) and p=NS

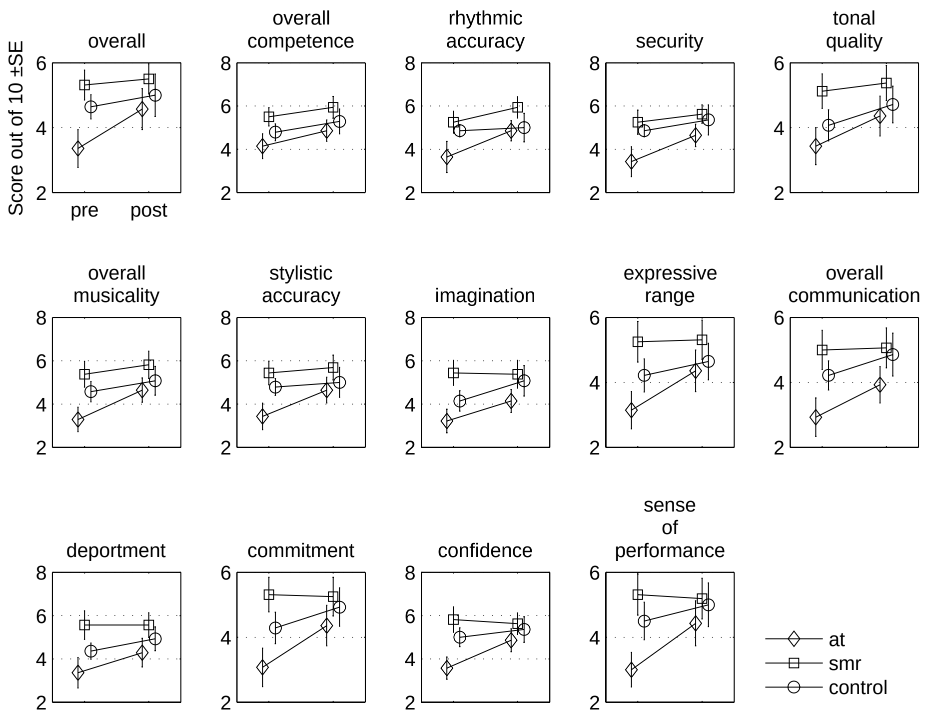


Figure 3.7: Group changes in music performance evaluation

As this part of the experiment replicated the second experiment in Egner and Gruzelier (2003), the within-group contrasts reported there are also shown here, although this is despite the fact that the alpha-theta group scored significantly less than SMR on baseline measures of performance, whereas Egner and Gruzelier (2003) reported that initial performance scores did not differ significantly. Bearing in mind their relatively low opening scores and the associated problem of their regression (upward) toward the mean on subsequent assessment (Bland and Altman, 1994), the alpha-theta group alone showed wide ranging and significant within-subjects improvements in performance (two-tailed t-tests, see Table 3.4). The improvements included two of the three musicality measures shown to be improved in the second experiment of Egner and Gruzelier (2003).

Table 3.4: Instrumental Solo — within-group changes
(two-tailed t-tests included as replication of Egner and Gruzelier (2003))

	ALPHA-THETA		SMR		CONTROL	
	t	p	t	p	t	p
Overall	2.89	0.03*	0.42	0.68	1.05	0.33
Overall competence	1.99	0.09	0.83	0.44	1.87	0.11
Rhythmic accuracy	3.23	0.02*	1.02	0.34	0.33	0.75
Security	2.19	0.07	0.59	0.57	1.02	0.35
Tonal quality	3.12	0.02*	0.48	0.65	2.46	0.05
Overall musicality	3.63	0.01*	0.51	0.63	0.98	0.37
Stylistic accuracy	2.56	0.04*	0.34	0.75	0.51	0.63
Interpretative imagination	2.52	0.05	0.00	1.00	2.41	0.05
Expressive range	2.79	0.03*	0.18	0.86	1.35	0.22
Overall communication	2.29	0.06	0.17	0.87	1.89	0.11
Deportment	1.88	0.11	0.00	1.00	1.62	0.16
Commitment	3.17	0.02*	-0.09	0.93	1.59	0.16
Confidence	4.87	0.00*	-0.27	0.80	1.11	0.31
Sense of performance	3.14	0.02*	-0.16	0.88	1.38	0.22
Degrees of Freedom	6		7		6	

*. Difference is significant at the .05 level

3.4.2.2 Stripsody

Data Screening The I.C.C. statistic measuring consistency between two panellists' ratings under a two-way random effects model showed a high level of inter rater reliability at r=0.94, p<0.005. Ratings were averaged for subsequent analysis.

A one-way ANOVA performed on the pre-intervention measures of performance revealed no significant group differences at baseline. Group score distributions are shown in Figure 3.8.

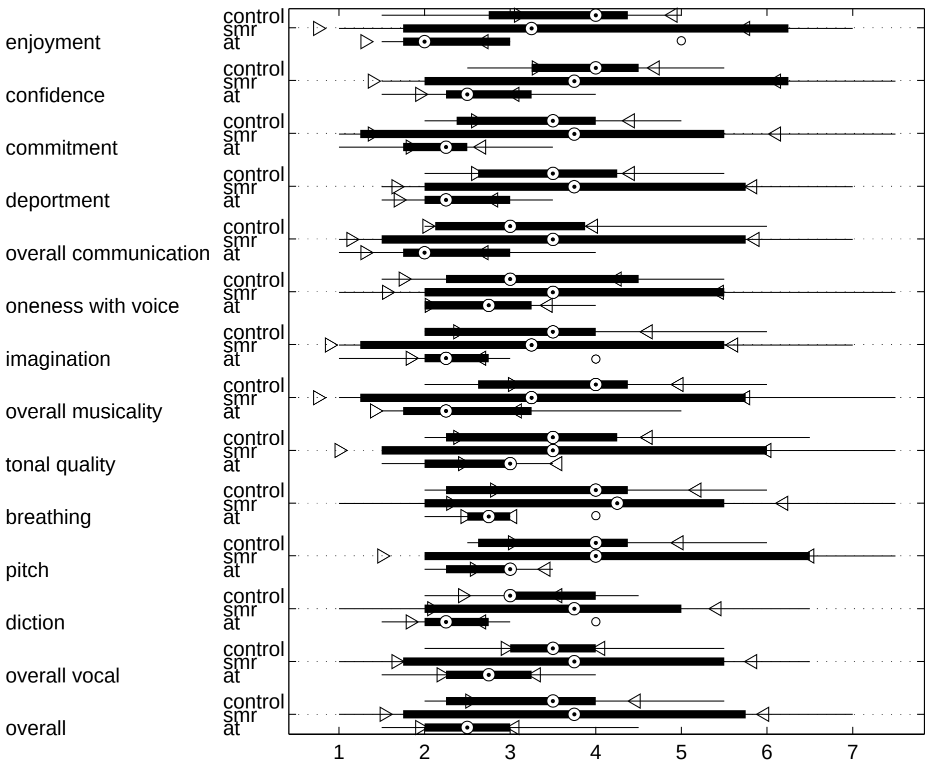


Figure 3.8: Boxplot showing between group differences in pre-intervention measures of Stripsody performance (Two medians are significantly different at the 5% significance level if their intervals do not overlap. Interval endpoints are the centres of the triangular markers.)

Creativity This task addressed RESEARCH QUESTION 1 (CREATIVITY).

The means and standard deviations, as well as ANOVA F-terms are included in Table 3.5 and visualised in Figure 3.9.

Across the test results, the ANOVA tests revealed a differential effect of experimental group on measures of 'Confidence'. A Tukey HSD post-hoc analysis did not reveal significant inter-group differences: alpha-theta - SMR (M = -0.5, SE = 0.80) p=NS; alpha-theta - control (M = -0.36, SE = 0.82) p=NS.

Table 3.5: Stripsody descriptive statistics

Measure	ALPHA-THETA (n=8) Pre	Change[1]	SMR (n=8) Pre	Change	CONTROL (n=7) Pre	Change	F-test (ANOVA[2])
Overall	2.62 ± 0.92	0.53 ± 0.75	3.81 ± 2.31	0.33 ± 1.13	3.43 ± 1.24	0.14 ± 0.58	1.28
Overall vocal	2.75 ± 0.80	0.35 ± 0.54	3.69 ± 2.09	0.41 ± 1.28	3.57 ± 1.10	0.13 ± 0.45	0.76
Diction	2.44 ± 0.78	0.47 ± 0.75	3.62 ± 1.87	0.32 ± 1.31	3.36 ± 0.85	0.11 ± 0.21	0.87
Pitch	2.75 ± 0.53	0.36 ± 0.54	4.31 ± 2.40	0.13 ± 0.81	3.79 ± 1.25	0.13 ± 0.44	1.02
Breathing	2.81 ± 0.59	0.35 ± 0.62	4.00 ± 2.24	0.46 ± 1.66	3.64 ± 1.44	0.14 ± 0.63	0.55
Tonal quality	2.62 ± 0.69	0.53 ± 0.87	3.88 ± 2.52	0.20 ± 0.91	3.57 ± 1.57	0.26 ± 0.65	0.95
Overall musicality	2.62 ± 1.19	0.62 ± 1.04	3.62 ± 2.56	0.58 ± 1.41	3.71 ± 1.35	-0.02 ± 0.60	1.17
Imagination	2.38 ± 0.88	0.59 ± 0.74	3.50 ± 2.39	0.49 ± 1.27	3.36 ± 1.49	0.26 ± 0.67	0.64
At one with voice	2.75 ± 0.76	0.47 ± 0.81	3.81 ± 2.34	0.31 ± 1.14	3.43 ± 1.46	0.30 ± 0.85	0.91
Overall communication	2.31 ± 1.00	0.68 ± 0.80	3.69 ± 2.42	0.20 ± 0.83	3.29 ± 1.41	-0.00 ± 0.48	2.37
Deportment	2.44 ± 0.68	0.46 ± 0.50	3.94 ± 2.16	0.04 ± 0.38	3.50 ± 1.19	-0.08 ± 0.39	3.16
Emotional commitment	2.19 ± 0.75	0.81 ± 0.77	3.69 ± 2.58	0.31 ± 0.74	3.43 ± 1.10	0.03 ± 0.52	3.16
Confidence	2.69 ± 0.80	0.64 ± 0.67	4.12 ± 2.39	0.04 ± 0.50	4.00 ± 1.00	-0.00 ± 0.37	3.73[3]
Enjoyment	2.50 ± 1.16	0.89 ± 1.00	3.81 ± 2.46	0.16 ± 0.79	3.57 ± 1.21	0.30 ± 0.78	2.73

[1] $Change = \frac{(post - pre)}{pre}$

[2] ANOVAs on group × pre/post performance interaction: in all measures df(2,20) and p=NS

[3] $p<0.05$

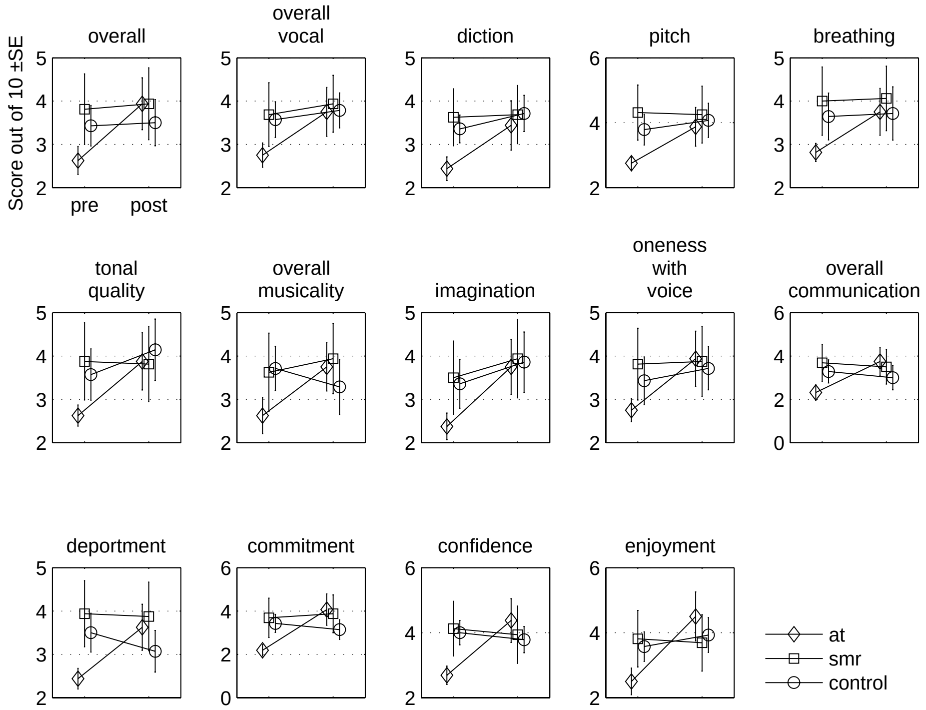


Figure 3.9: Group changes in music performance evaluation

3.4.2.3 Folk Song

Data Screening A one-way ANOVA revealed a significant difference between the groups on pre-intervention measures of Overall Vocal Competence (F(2,20)=3.74, p=0.04). Post-hoc Tukey HSD tests didn't reveal significant inter-group differences: Group score distributions are shown in Figure 3.10

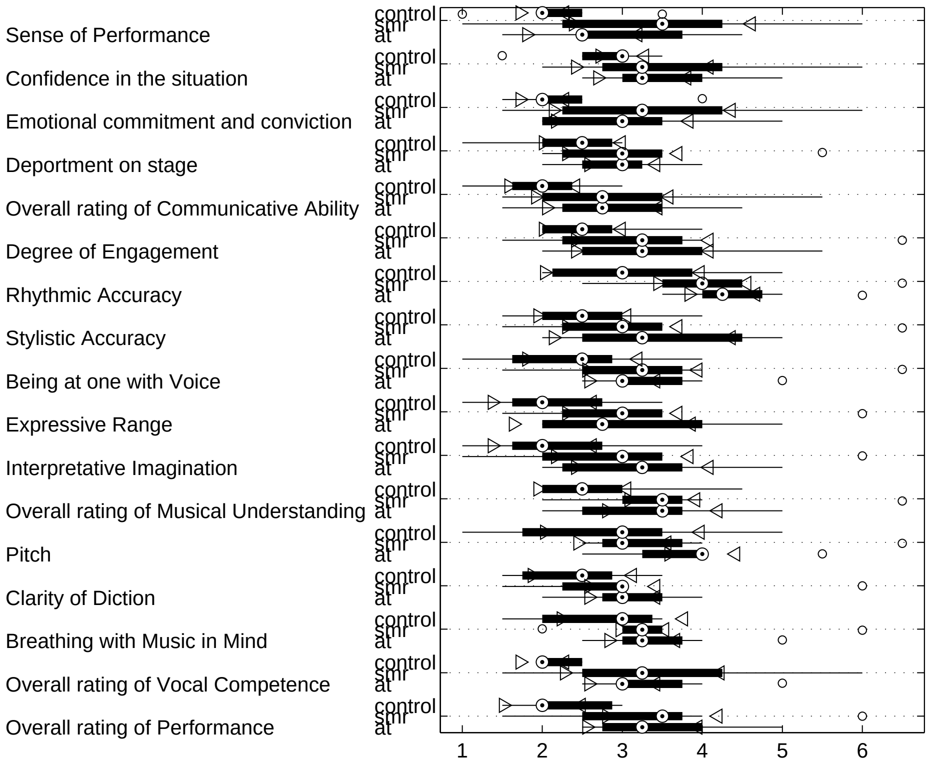


Figure 3.10: Boxplot showing between group differences in pre-intervention measures of Folk Song performance (Two medians are significantly different at the 5% significance level if their intervals do not overlap. Interval endpoints are the centres of the triangular markers.)

The mean ICC for panel ratings disclosed a moderate level of agreement at r=0.63, p<0.005. Although this was lower than in previous tests, it's strength was sufficient for mean ratings to be used in subsequent analyses.

Novice Performance This task addressed RESEARCH QUESTION 3 (NOVICE PERFORMANCE).

The means and standard deviations of baseline and change measures, as well as AN[C]OVA F-terms are included in Table 3.6 and visualised in Figure 3.11.

The ANOVA performed on measures of Pitch revealed a group difference. Post-hoc Tukey HSD measures revealed no inter-group differences: SMR - alpha-theta (M = 0.13, SE = 0.55) p=NS; SMR - control (M = 1.00, SE = 0.59) p=NS.

Table 3.6: Folk Song descriptive statistics

Measure	ALPHA-THETA (n=8) Pre	Change[1]	SMR (n=8) Pre	Change	CONTROL (n=7) Pre	Change	F-test (AN[C]OVA[2])
Overall	3.44 ± 0.90	0.06 ± 0.82	3.38 ± 1.36	0.31 ± 1.16	2.29 ± 0.57	0.21 ± 0.64	.26 [3]
Overall Vocal Competence	3.38 ± 0.79	0.13 ± 0.95	3.44 ± 1.40	0.06 ± 0.94	2.21 ± 0.27	0.36 ± 0.80	.52 [2]
Breathing with Music in Mind	3.44 ± 0.78	0.13 ± 0.95	3.44 ± 1.15	0.69 ± 0.96	2.64 ± 0.80	0.57 ± 0.53	0.89 [3]
Clarity of Diction	3.06 ± 0.62	0.31 ± 0.75	3.00 ± 1.34	0.69 ± 1.28	2.43 ± 0.73	0.21 ± 0.81	0.90 [3]
Pitch	3.81 ± 0.88	-0.13 ± 0.83	3.50 ± 1.31	0.75 ± 0.89	2.86 ± 1.35	-0.07 ± 1.06	4.23 [3], [4]
Overall Musical Understanding	3.31 ± 0.96	0.31 ± 0.37	3.63 ± 1.33	0.13 ± 0.92	2.71 ± 0.91	-0.07 ± 0.61	1.35 [3]
Interpretative imagination	3.19 ± 1.03	0.38 ± 0.44	3.00 ± 1.51	0.50 ± 1.56	2.21 ± 0.99	0.43 ± 1.10	.28 [3]
Expressive Range	3.06 ± 1.18	0.56 ± 0.82	3.13 ± 1.36	0.31 ± 1.31	2.14 ± 0.85	0.43 ± 0.84	.30 [3]
Being at one with Voice	3.38 ± 0.79	0.13 ± 0.64	3.38 ± 1.51	0.38 ± 1.19	2.36 ± 0.99	0.00 ± 0.91	.84 [3]
Stylistic Accuracy	3.44 ± 1.15	0.00 ± 0.85	3.19 ± 1.56	0.50 ± 1.25	2.57 ± 0.84	0.00 ± 0.87	1.11 [3]
Rhythmic Accuracy	4.44 ± 0.78	-0.13 ± 0.79	4.13 ± 1.16	0.63 ± 0.95	3.14 ± 1.11	0.21 ± 0.64	2.13 [3]
Degree of Engagement	3.38 ± 1.16	0.13 ± 0.83	3.31 ± 1.58	0.31 ± 1.25	2.57 ± 0.73	0.29 ± 1.04	0.31 [3]
Overall Communicative Ability	2.88 ± 0.99	0.00 ± 1.00	2.94 ± 1.29	0.31 ± 1.31	2.00 ± 0.65	0.29 ± 1.04	0.22 [3]
Deportment on stage	2.94 ± 0.62	0.31 ± 0.80	3.13 ± 1.13	0.19 ± 1.36	2.29 ± 0.70	0.14 ± 0.99	0.14 [3]
Emotional commitment	3.00 ± 1.07	0.69 ± 0.59	3.38 ± 1.46	0.06 ± 1.27	2.36 ± 0.80	0.29 ± 0.70	1.23 [3]
Confidence in the situation	3.50 ± 0.85	0.31 ± 0.80	3.56 ± 1.27	0.25 ± 0.96	2.71 ± 0.64	0.29 ± 0.86	0.29 [3]
Sense of Performance	2.94 ± 1.05	0.44 ± 1.05	3.38 ± 1.58	-0.06 ± 1.59	2.21 ± 0.76	0.36 ± 0.90	0.37 [3]

Continued on next page

Table 3.6 – continued from previous page

	ALPHA-THETA (n=8)		SMR (n=8)		CONTROL (n=7)		F-test
Measure	Pre	Change[1]	Pre	Change	Pre	Change	(AN[C]OVA[2])

[1] $Change = \frac{(post - pre)}{pre}$

[2] ANCOVAs on group differences post-training, adjusting for differences pre-training: in all measures df(2,18) and p=NS

[3] ANOVAs on group × pre/post performance interaction: in all measures df(2,19) and p=NS

[4] $p<0.05$

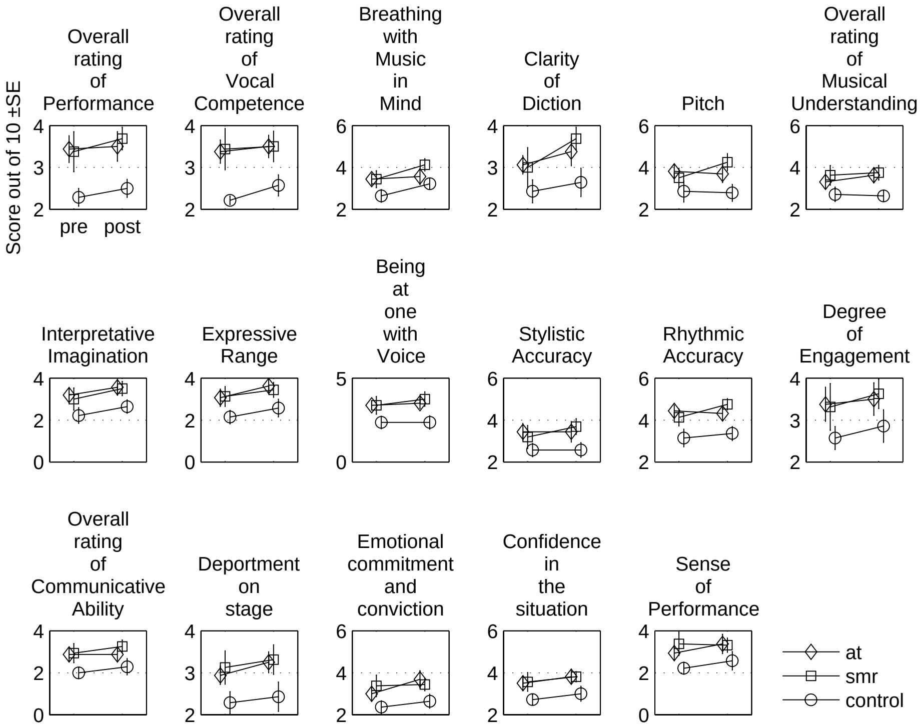


Figure 3.11: Group changes in music performance evaluation

3.4.2.4 Instrumental Improvisation

Data Screening The I.C.C. coefficient assessing agreement between raters was moderate at r=0.59, p<0.005. As in the folk performances (Section 3.4.2.3), moderate concordance between raters does raise the caution with which subsequent results should be interpreted. A Bland-Altman plot (Figure 3.12) of the agreement levels indicated that there was some disagreement between raters in one case, a post intervention performance from a member of the control group, with one panellist awarding high scores an average of >3STD higher than the mean rating for that participant. It was noted at the time of evaluation that this rater commented favourably on the communicativeness of this subject's post performance in which he looked directly into the camera whilst playing, and this is possibly the cause of rater disagreement. For these reasons this case was removed, and a consequent measure of the ICC coefficient disclosed high rater consistency at r=0.72, p<0.005. Subsequent analyses were based on mean ratings.

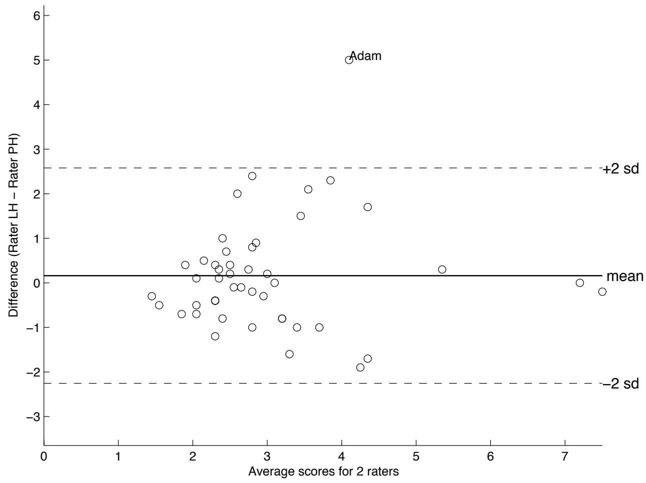


Figure 3.12: Bland-Altman plot of instrumental improvisation ratings.
Each dot represents the pooled average score for each performance among the grand total of 46 performances (including both pre and post). The labelled performance was, on average, scored 6.6/10 by rater-LH and 1.6/10 by rater-PH. The score of 6.6 was >2SD than the rater mean of 4.1 for that performance.

A one-way ANOVA performed on the pre-intervention measures of performance revealed no several significant group differences at baseline. Group score distributions are shown in Figure 3.13.

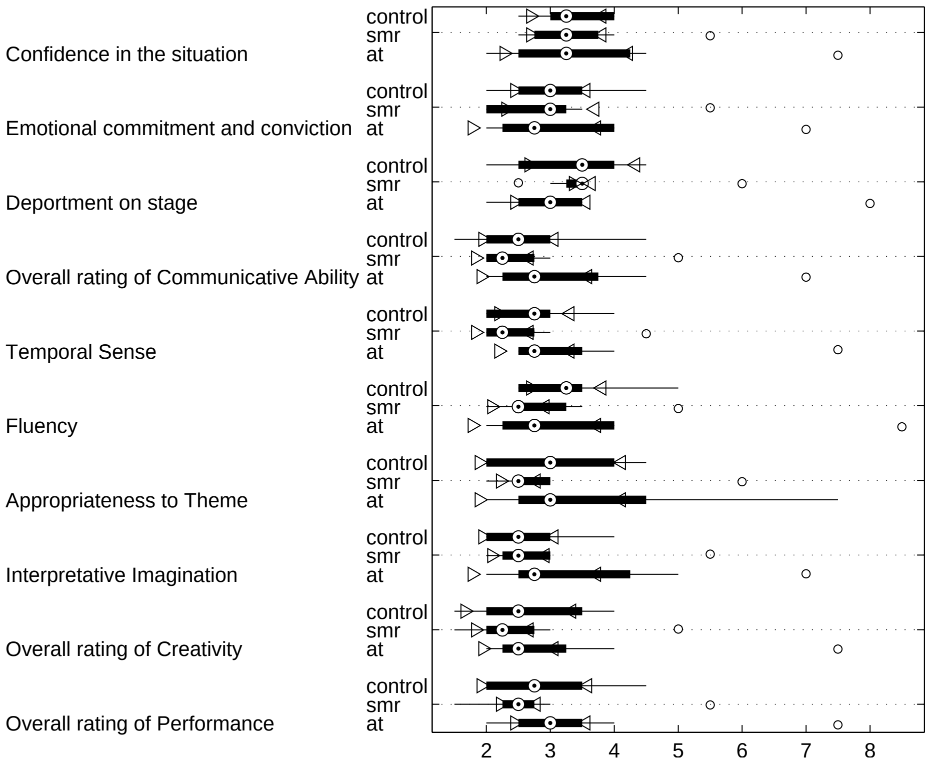


Figure 3.13: Boxplot showing between group differences in pre-intervention measures of Instrumental Improvisation(Two medians are significantly different at the 5% significance level if their intervals do not overlap. Interval endpoints are the centres of the triangular markers.)

Creativity This task addressed Research question 1 (Creativity).

The means and standard deviations of baseline and change measures, as well as anova F-terms are included in Table 3.7 and visualised in Figure 4.11.

As in the previous tasks, group differences were not shown to be significant.

Table 3.7: Instrumental improvisation descriptive statistics

Measure	ALPHA-THETA (n=8) Pre	Change[1]	SMR (n=8) Pre	Change	CONTROL (n=6) Pre	Change	F-test (ANCOVA[2])
Overall Performance	3.44 ± 1.74	0.09 ± 0.28	2.75 ± 1.20	0.10 ± 0.19	2.86 ± 0.90	0.14 ± 0.44	0.05
Overall Improvisational Creativity	3.19 ± 1.85	0.22 ± 0.31	2.56 ± 1.08	0.14 ± 0.27	2.57 ± 0.93	0.24 ± 0.44	0.47
Interpretative imagination	3.50 ± 1.69	0.04 ± 0.33	2.88 ± 1.13	-0.09 ± 0.22	2.57 ± 0.79	0.10 ± 0.31	0.63
Appropriateness to Theme	3.69 ± 1.81	-0.04 ± 0.20	3.00 ± 1.25	-0.14 ± 0.18	3.00 ± 1.00	-0.05 ± 0.40	0.79
Fluency	3.50 ± 2.14	0.10 ± 0.32	2.88 ± 0.92	-0.11 ± 0.19	3.36 ± 0.85	-0.16 ± 0.28	1.23
Temporal Sense	3.44 ± 1.72	-0.17 ± 0.15	2.56 ± 0.86	-0.12 ± 0.27	2.71 ± 0.70	-0.08 ± 0.35	0.56
Overall Communicative Ability	3.31 ± 1.69	0.06 ± 0.38	2.62 ± 1.03	-0.07 ± 0.25	2.57 ± 1.02	0.21 ± 0.40	0.48
Deportment on stage	3.50 ± 1.91	-0.10 ± 0.38	3.62 ± 1.03	-0.25 ± 0.14	3.21 ± 0.91	-0.11 ± 0.28	1.03
Emotional commitment	3.38 ± 1.66	0.07 ± 0.39	3.00 ± 1.16	-0.18 ± 0.25	3.07 ± 0.79	-0.12 ± 0.28	1.83
Confidence in the situation	3.69 ± 1.79	-0.02 ± 0.25	3.44 ± 0.98	-0.14 ± 0.24	3.36 ± 0.56	-0.12 ± 0.19	0.60

[1] $Change = \frac{(post - pre)}{pre}$

[3] ANOVAs on group × pre/post performance interaction: in all measures df(2,19) and p=NS

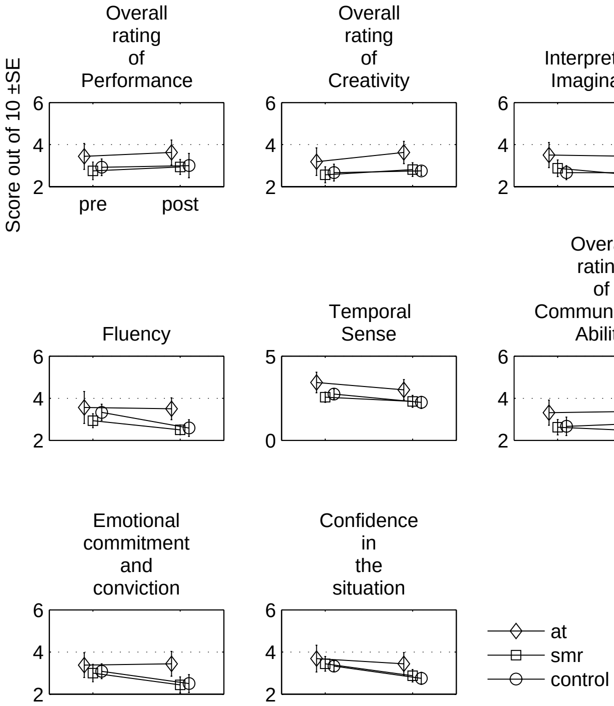


Figure 3.14: Group changes in music performance evaluation

3.4.3 Within-subjects relationship between changes in NFT-EEG and music performance

Within subjects ANCOVAS were performed to assess RESEARCH QUESTION 4 (EFFECT RELATION) as to whether changes in measures of music performance would be predicted by changes to EEG during training.

Table 3.9 includes all the results, and significant results are described by music task below. In both EEG and music measures, the index of change was calculated as latter data minus former data (e.g. second half of training minus former half), divided by former data. This approach measures late data in proportion to early data.

3.4.3.1 Instrumental Solo

As a replication of Egner and Gruzelier (2003), this study found no relationship between the 'slope of slopes' training measure[4] and performance changes. Non-significant negative correlations were observed in all measures, see Table 3.8.

Table 3.8: Correlation between training and music change replicating Egner and Gruzelier's (2003) statistical analysis

Measure	Training correlation
Overall	-0.20
Overall competence	-0.30
Rhythmic accuracy	-0.15
Security	-0.37
Tonal quality	-0.48
Overall musicality	-0.45
Stylistic accuracy	-0.30
Imagination	-0.21
Expressive range	-0.20
Overall communication	-0.29
Deportment	-0.08
Commitment	-0.24
Confidence	-0.33
Sense of performance	-0.42

[4] Egner and Gruzelier (2003) defined the relation between training and music by assessing post minus pre performance scores in relation to a training coefficient "... expressed by the slope of regression across sessions of the correlation between t/a amplitude ratios and the number of 3 min periods within each session"

Using the analysis of covariance applied in the remainder of this study and in Chapter 4, it was found that no musical measures of this task (either pre- or post-training) co-varied with within-session EEG ratios.

3.4.3.2 Stripsody

It was found that no pre- or post-training musical measures of this task co-varied with within-session EEG ratios.

3.4.3.3 Folk Song

It was found that the within-session SMR training ratio was a significant covariate of post-training 'Overall musical understanding,' 'Interpretative imagination,' 'Stylistic accuracy' and to a marginal extent 'Rhythmic accuracy.'

3.4.3.4 Instrumental Improvisation

It was found that no pre- or post-training musical measures of this task co-varied with within-session EEG ratios.

Table 3.9: Music covariance with within-session EEG (F statistic)

Performance	Measure	A-T pre	A-T post	SMR pre	SMR post
Instrumental[1]	Overall	0.15	0.49	0.23	3.15
	Overall Competence	0.32	0.06	0.01	2.80
	Rhythmic Accuracy	0.10	0.14	0.06	1.72
	Security	0.51	0.98	0.09	1.93
	Tonal Quality	0.04	0.19	0.01	1.31
	Overall Musicality	0.17	0.92	0.37	2.17
	Stylistic Accuracy	0.21	1.76	0.28	3.62
	Imagination	0.00	1.90	0.02	1.86
	Expressive Range	0.02	0.88	0.02	1.58
	Overall Communication	0.04	1.87	0.18	1.75
	Deportment	0.00	0.62	0.07	1.56
	Emotional Commitment	0.02	0.95	0.07	3.84
	Confidence	0.00	1.24	0.05	0.88
	Sense of Performance	0.03	1.02	0.17	1.56
Stripsody[2]	Overall	0.55	1.41	3.14	0.69
	Overall Vocal	2.36	1.10	2.88	0.32
	Diction	0.22	1.01	3.02	0.13
	Pitch	2.72	1.21	2.04	0.08
	Breathing	1.32	1.14	3.04	0.28
	Tonal Quality	4.52	0.37	2.51	0.43
	Imagination	2.20	0.58	2.02	0.58
	Oneness With Voice	0.62	1.51	2.44	0.62
	Overall Communication	0.43	0.98	2.12	1.33
	Deportment	1.02	2.95	1.43	2.02
	Overall Musicality	1.19	1.33	2.40	0.54
	Emotional commitment	0.71	0.42	1.79	1.94
	Confidence	0.45	1.23	1.92	2.15
	Enjoyment	0.32	1.28	2.61	1.64
Folk[2]	Overall Rating of Performance	2.44	0.51	1.19	2.71
	Overall Rating of Vocal Competence	1.97	0.32	0.59	2.11
	Breathing With Music in Mind	0.15	1.61	0.08	3.45
	Clarity of Diction	3.31	0.78	1.37	1.36
	Pitch	0.01	0.16	0.42	2.41

Continued on next page

Table 3.9 – continued from previous page

Performance	Measure	A-T pre	A-T post	SMR pre	SMR post
	Overall Rating of Musical Understanding	0.66	0.05	1.25	17.67**
	Interpretative Imagination	2.05	0.76	1.23	7.58*
	Expressive Range	1.72	0.38	1.46	4.39
	Oneness With Voice	1.97	0.16	0.93	3.89
	Stylistic Accuracy	0.23	0.08	1.85	10.56*
	Rhythmic Accuracy	0.15	0.42	0.64	5.72¨
	Degree of Engagement	0.38	1.08	1.64	3.47
	Overall Rating of Communicative Ability	2.48	1.03	1.14	4.39
	Deportment on Stage	1.64	0.64	1.50	0.26
	Emotional Commitment and Conviction	0.85	1.46	1.00	4.47
	Confidence in the Situation	3.35	2.63	0.65	0.55
	Sense of Performance	3.40	1.08	0.43	2.13
Improvisation[2]	Overall Performance	0.17	0.26	0.90	1.24
	Overall improvisational competence	0.32	0.17	3.15	2.38
	Interpretative Imagination	0.18	0.29	0.50	4.05
	Appropriateness to Theme	0.02	0.62	1.03	1.08
	Fluency	0.10	0.48	1.98	0.93
	Temporal Sense	0.47	0.52	2.16	1.13
	Overall Communicative Ability	0.04	0.23	1.91	1.91
	Deportment	0.09	0.04	0.84	1.04
	Emotional commitment	0.05	0.10	3.71	2.23
	Confidence in the Situation	0.09	0.36	2.97	2.55

[1] Degrees of freedom: alpha-theta (1, 5), SMR (1, 6)
[2] Degrees of freedom: alpha-theta (1, 6), SMR (1, 6)
** Covariance is significant at the 0.01 level.
* Covariance is significant at the 0.05 level.
¨ Covariance has a trend towards significance at the 0.06 level.

3.4.4 Music Results summary

The results of the Instrumental solo task confirmed RESEARCH QUESTION 7 (is (Egner and Gruzelier, 2003) replicable) as to whether measures of creativity would be improved in the alpha-theta theta group alone according to the within-group analyses replicated from the prior study; these included 'Overall musicality', 'Stylistic accuracy' and 'Expressive range'. Deportment co-varied with longitudinal t/a changes. This is qualified however by the understanding that alpha-theta participants received distinctly low scores to begin with, yet relatively equivalent scores post-intervention.

In ANOVA analyses of the Stripsody scores, Confidence disclosed significant group differences, being the first time a group × musical task interaction had been observed, although this was without post-hoc distinction. This addressed RESEARCH QUESTION 1. (CREATIVITY) in that a task involving the spontaneous processing of emotional content may have interacted with alpha-theta NFT reinforced hypnagogia.

The folk song task revealed group differences in evaluations of Pitch, although without supporting post-hoc disclosure. Post-intervention measures of 'Overall Musical Understanding,' 'Interpretative imagination' and 'Stylistic accuracy' all co-varied with within-session changes in the SMR training ratio.

In instrumental improvisation, no group differences emerged.

3.5 Discussion

3.5.1 Neurofeedback Training

3.5.1.1 Alpha-theta training

In the alpha-theta group, changes in the t/a ratio were observed in both the within- and across-session analyses, the changes were marginally significant ($p<0.053$) in the former comparison. This measure is considered the more robust estimator of NFT learning as it smoothes inter-session variability (Vernon et al., 2003).

In across-sessions and period × session interaction analyses, no significant changes were observed. This is comparable with the findings of prior alpha-theta studies (Moore et al. (2000), Boynton (2001), Egner et al. (2002), Egner and Gruzelier (2004a) and Raymond et al. (2005a)): none of which were able to detect across session training effects in the t/a ratio. Of the above studies, Egner and Gruzelier (2004a) did however detect an increase in absolute theta over the course of training, although the introduction of training ratios into the NFT methodology (Lubar and Shouse, 1976) was specifically designed to counteract the effect of non-training factors such as prior activity on absolute EEG measures, although the method was introduced for SMR training and sleep onset is characterised by rising theta and a combination of rising and then falling alpha. This calls into question the use of ratios which do not account for spectral differences Overall however, and as acknowledged by Vernon (2005), the aggregated within-session training effect serves as a more reliable measure of NFT learning ratios and a reliable measure of longitudinal learning has not been tested.

3.5.1.2 SMR training

In the within-session analysis, SMR training was not shown to invoke the explored changes in the promotion of SMR synchronisation against both theta and beta.

A comparable study by Vernon et al. (2003) found however that the training relationship (separated into SMR/theta and SMR/beta measures) changed reliably when collapsing measures across 8 × 15 minute sessions. The most immediate difference between that study and the present one is that Vernon's method measured beta in the 18–22 Hz band whereas the present study measured beta in the 22–30 Hz range precluding direct comparison. Despite the failure of the protocol to elicit targeted change in beta band, it is noteworthy that as with the sensorimotor rhythm, increases in beta band over the motor cortex occur as a function of cortical deactivation when halting movement (Pfurtscheller and Lopes da Silva, 1999). For this reason it is speculated that participants in the SMR group exhibited a tendency to elevate beta as a consequence of their efforts to inhibit the motor response, yet did not manage to achieve this by regulating the distinct SMR rhythm (the 12–15 Hz peak in frequency spectra), and instead modulated the broader beta frequency band (22–30 Hz), possibly for the reason that it occupies a larger part of the spectrum and thus provides greater scope for change. It is also possible that beta amplitudes, which rise with spontaneous cognitive activity (Laufs et al., 2003), may have risen as a function of changes in training strategy.

In the across-sessions analysis it was observed that the training ratio fell slightly over the course of intervention. The overall training ratio fell, as did the SMR/theta ratio, whilst the SMR/beta ratio increased. Between frequency dynamics were mediated to a larger extent by changes in theta and beta activity than SMR modulation.

Theta production during wakefulness has been implicated in the encoding of new information in working memory arising from oscillatory activity in a hippocampo-cortical loop that presents in frontal-midline areas (Buzsáki, 2002), and hippocampal theta is thought to reflect sensorimotor integration during the preparation of a motor response (Bland and Oddie, 2001). Despite the association between theta and sensorimotor integration, theta over the motor cortex is not as well understood as its frontal counterpart. To date theta activity in the motor region has been most directly explored through Repetitive Transcranial Magnetic Stimulation studies applying theta burst stimulation (Huang et al., 2005; Di Lazzaro et al., 2005). These studies have observed that the stimulation of theta cycling in motor areas depresses intracortical excitability, supporting the interpretation that motor theta is related to cortical deactivation, as seen in sleep, and in accordance with Lubar et al. (1995), who treated abnormally high theta in ADHD cases as evidence of low arousal. Given that frontal theta activity is related to the preparation of an action, whilst elicited motor theta is associated with the depression of cortical excitability, it is surmised that progressive theta/SMR increases seen across-training are more likely to have been predicted by cortical deactivation because participants responded to the training goal of maintaining motor stillness by promoting deactivation rather than regulation of the motor response. The slight falls in beta across the course of training also support the interpretation that deactivation occurred, and taken together the downward shift in spectral power over the course of training suggests a fall in vigilant arousal.

3.5.2 Music Performance

This section concentrates first on the replication (Egner and Gruzelier, 2003) part of the study, and continues by covering each of the experimental tasks newly introduced into the NFT methodology. Given the probing nature of this study, the effect of intervention across all measures is not evaluated, and focus is given to the apparent usability of each task as a reliable indicator of NFT related change.

3.5.2.1 Instrumental Solo

As with the replication precursor (Egner and Gruzelier, 2003), a post-intervention between-groups difference in instrumental performance was not disclosed. In the light of this is seems reasonable to assume that whilst this and previous exploration provided limited evidence for alpha-theta effects on performance, the level of experimental control required to isolate the effect is beyond the scope of the current research methodology.

There are several contributory factors that might have increased sampling error variance in this study, which in turn might blur protocol specific effects. Firstly the small sample size reduces the statistical power of the analyses used. There were also uncontrolled methodological factors that are likely to contribute to differences in ratings, with the highest amount of interference stemming from the open choice of music to be played, and the instrument to play it on. Although the current study retained this particular approach for consistency with prior work, Wapnick et al. (2004, 2005) documented the significant effect of a number of variables on audience evaluations including tempo, duration, style, and composer, which suggests that controlling for instrument and score might reduce sampling error variance in future attempts to isolate protocol specific effects.

The replication of Egner and Gruzelier (2003) in assessing within-subjects changes are discussed below, although with the caveat that a treatment effect may be blurred by the statistical phenomenon of regression to the mean as performance measures were significantly lower initially than post-intervention (Morton and Torgerson, 2005).

The *a priori* hypothesis that improvements in instrumental performance would replicate the findings of the second experiment in Egner and Gruzelier (2003) was confirmed in as far as between-groups differences were found in neither study, and within-group changes were seen in the alpha-theta group alone. A very similar marking scheme to that used in the previous work had been used here, and some exploratory within-group comparisons were compared to the Egner and Gruzelier (2003) study and showed that all the previously significant changes were replicated. However, in the current study, the alpha-theta group gained significantly lower scores on baseline measures of instrumental solo performance than the other groups and equivalent scores post-training, so the scope for improvement was greater than in other groups.

The current study extends the second experiment in Egner and Gruzelier (2003) by additionally disclosing the influence of the long term alpha-theta training covariate on within-subjects improvements in ratings of Deportment. The reason for this difference might be accounted for by the different analyses used; Egner and Gruzelier (2003) indexed NFT learning as across-session changes in within-session changes (a slope of slopes), whilst the current study used a early-late training comparative measure of learning (first 5 against final 5 sessions). This approach is consistent with the assertion that collapsing training data reduces sampling error variance caused by inter-session differences in uncontrolled factors that might modulate EEG (Vernon et al., 2003). Egner and Gruzelier's (2003) index had however disclosed a correlation between t/a and music change in the first experiment, in which alpha-theta training was given following a course of SMR and beta training, and so it is speculated that across-session t/a increases in Egner's first experiment may have been improved as a result of prior SMR NFT training. Scott et al. (2005) also used SMR training to optimise attentional performance prior to applying alpha-theta as a treatment for mixed chemical dependency withdrawal. Taken together, these reports suggest that the two protocols may interact.

The measure of 'Deportment on stage' itself is classed as a Communication variable, and if this were not a chance finding, it would suggest that the longitudinal change of sleep-onset EEG seen in training was positively related to this aspect of music performance. Considering that alpha-theta regulates sleep onset and was reported to influence associated mood measures (Raymond et al., 2005b), the self-control of physical aspects of performance might also be affected.

In combination, these findings did not significantly isolate protocol specific training effects, but rather replicated within-subjects improvements and added a single piece of evidence linking changes in EEG and perceived competence, indicating possible electrophysiological mediation. Extending the method to verify this form of mediation is covered in Chapter 5, which introduces a means of measuring music electrophysiology commensurate with NFT. Such an extension of the method provides the basis for testing the theoretical framework discussed in Section 1.5.2, in which the hypofrontal neurophysiologies of both sleep-onset and creative ideation are paralleled (Dietrich, 2003). Dietrich's hypothesis could be tested by measuring hypofrontality in both NFT and creative behaviour.

3.5.2.2 Stripsody

Post-intervention changes in ratings of 'Confidence' were shown to be significantly different between groups, yet post-hoc inter-group comparisons did not reveal distinct protocol differences. This measure was part of the 'Communication' category that was introduced into the study from the standard conservatory assessment measures (Taylor, 2005).

Of the four experimental tasks presented here, Stripsody and Folk song (see Section 3.5.2.3) were the only tasks that disclosed between-groups differences post-intervention, and even then on solitary measures out of many. This suggests chance outcomes, although in this task associated communication measures of 'Deportment on stage,' 'Emotional commitment' and 'Enjoyment on stage' all showed trends towards significance, so there are additional clues that this task may interact with the experimental intervention. Confidence changes were not shown to co-vary with training EEG.

On the basis that this is not a chance finding, the result suggests that the methodology has advanced through RESEARCH QUESTION 1 (CREATIVITY), by further isolating post NFT differences, and such an outcome invites further consideration.

As outlined in Section 3.3.5.2, the Stripsody task was selected to provide a controlled scope for spontaneous creativity, resulting in performances that afford both novel creative insight and empirical comparison. This attempt to control for some of the many variables impacting on music appraisal (Wapnick et al., 2004) does appear to have taken a step towards isolating protocol specific effects.

Confidence and alpha-theta have previously been investigated by Raymond et al. (2005b), who documented alpha-theta related improvements in this measure within the Profile of Mood States scale (Lorr et al., 1971). Raymond et al.'s (2005b) study also demonstrated post alpha-theta training increases in participants' feelings of being composed, agreeable and elevated, leading to the suggestion that combined mood improvements might underline the efficacy of alpha-theta NFT in task-related applications. In relation to this, a study by Petsche et al. (1997) found that increases in lower alpha amplitude (7.5–9 Hz) were related to elevated mood, which suggests that a downward shift in spectral power, as observed in the alpha-theta protocol, might have positive implications for mood via similar physiological mechanisms to creative behaviour. In addition it has been reported that mood measures of depression were reduced following music listening (Tornek et al., 2003), and in the current study significant confidence improvements were only observed in the alpha-theta group, suggesting that mood elevation occurred separately from music effects, implicating the t/a ratio as the main contributory factor in confidence differences.

In itself, performing confidently may not give rise to creative behaviour, but in a task such as this, which explicitly requires the performer to be spontaneous and produce fast responses during music creation, it is possible that the confidence to attempt new ideas may lead to innovation, and Phelan and Young (2003) reported suggestive evidence linking creative confidence to innovative behaviour in the workplace.

Furthermore, the stage fright literature (see Section 1.4.2.2) indicates that confidence is impaired by fear (Brotons, 1994), and so this result could be interpreted as an optimisation against performance anxiety.

3.5.2.3 Folk Songs

The folk song element of this study explored neurofeedback training effects in novice performance for the first time, and in line with research linking motor skill improvement with SMR training (Ros et al., 2009), this study explored whether NFT training would interact with sensory/motor components of performance as a result of SMR regulation.

A group difference in Pitch changes was observed, with the SMR group showing most improvement, however this change was not found to co-vary with changes in neurofeedback training ratios, which suggests that technical gains may not have been mediated by electrophysiological change. It is noteworthy that the other technical measures: 'Clarity of Diction,' 'Breathing with the music in mind,' or 'Overall vocal competence' did not exhibit similar positive changes following SMR training suggesting that technical gains were quite marginal, or perhaps that Pitch, as a relatively objective measure isolated motor skill changes most clearly.

Post-SMR scores of 'Overall Musical Understanding,' 'Interpretative imagination' and 'Stylistic accuracy' all co-varied with the within-session SMR training ratio. This suggests that Artistry may have changed as a function of SMR, but not to a marked extent. The idea that SMR training might influence perceived artistic qualities in performance can be interpreted as performance optimisation not in the anticipated technical sense, but in the sense that mitigating physiological arousal in stage fright interacts with emotional performance - possibly in the way that experienced performers are able to control stage fright in maintaining optimal arousal (Brotons, 1994).

3.5.2.4 Instrumental Improvisation

Looking at global changes across all performance measures, all participants received reduced scores as a function of time, and this was confirmed by repeated measures Multivariate ANOVA that showed a main effect of testing stage (F(10,10)=9.759, p=0.001). The fact that scores fell as a function of repeat testing can be interpreted based on the nature of the task. In the first performance participants were asked to choose from a list of descriptive scenes from which to improvise, and in the second performance to choose another from the same list. This leads to the speculation that participants might have had more difficulty in the second instance as their choice of source material was more restricted, and did not include their previous selection which may have been made on the basis of their ability to improvise with it. On this basis, it appears that the task became harder on the second attempt.

3.5.3 Summary of the study

As a constructive replication of the second experiment in Egner and Gruzelier (2003), the present study sought to determine whether post alpha-theta musicality improvements might be replicable in Instrumental solo performances. The results of the current study indicate that protocol specific improvements in Musicality may be replicable, although the evidence in favour was hampered by the low opening scores in the alpha-theta group (RESEARCH QUESTION 7).

Stripsody and Instrumental improvisation were included into the current study as they were speculated to isolate creativity related effects more specifically through their explicit inclusion of music creation behaviours. Post-intervention measures of confidence in the Stripsody task disclosed a significant different in group means. This finding, despite being the first example of a between-groups difference in the optimal performance NFT literature, did not support the explorations of the study as the improvements fell in the category of communication rather than artistry. This result was interpreted as being associated with the mood enhancing properties of the alpha-theta protocol as opposed to its role in modulating creativity, although it is notable that confidence in improvisation may offset stage-fright (Brotons, 1994), optimising spontaneous emotional processing (Research question 1).

The global reduction in improvisational quality was interpreted in terms of apparent methodological shortcomings of the experimental method, principally the use of a reduced choice of improvisational stimuli in the post-intervention measures.

Finally, the Folk song task was included to assess the novel question that SMR training would specifically optimise technical aspects of performance in a novice performance task (Research question 3) — and post-intervention measures did show significant variance of Pitch between group means, although without post-hoc distinction. The Folk task did however show several relations between SMR and Artistic variables, suggesting that such aspects of performance, potentially reduced by stage fight, may be supported through SMR training.

3.5.3.1 The following study

Given the results of the present study were able to address primary Research questions 1, 2, 3 & 4 to a limited extent, the addition of an additional population cohort into the current study was planned in order to raise statistical power.

An increased data capture was sought and a second group of participants recruited. In the implementation of the extended experiment, a methodological difference introduced a previously unobserved effect on music performance that altered the design of the study.

In this second cohort, post-training performances were recorded immediately following the final NFT session, whereas the participants in the current study waited at least one hour before performing music.

The transient after-effects of alpha-theta NFT appeared to lead to marked differences in post-training performance measures amongst participants who had emerged from a period of sleep-onset only minutes before.

Interestingly this raised a hitherto undocumented short-term effect of alpha-theta NFT, and the results of this altered study design are accordingly isolated and documented in Chapter 4.

4

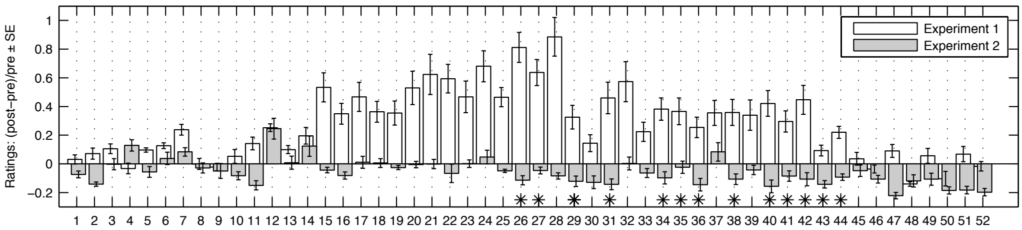
Experiment Two

4.1 Introduction

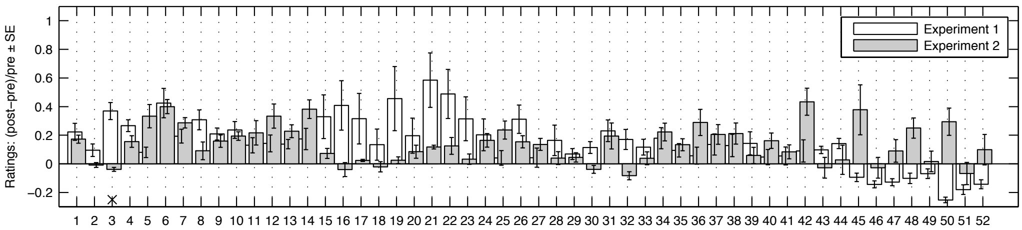
This study was originally set up as an extension to the study in Chapter 3, designed to raise the statistical power of the initial investigation of NFT and music creation tasks.

A methodological difference was introduced whereby post-training performances were recorded immediately following the final NFT session. During observation of music footage, it became apparent that alpha-theta participants were noticeably withdrawn in performances following their final alpha-theta session. This was seen as possible cause of observed performance impairments following alpha-theta NFT.

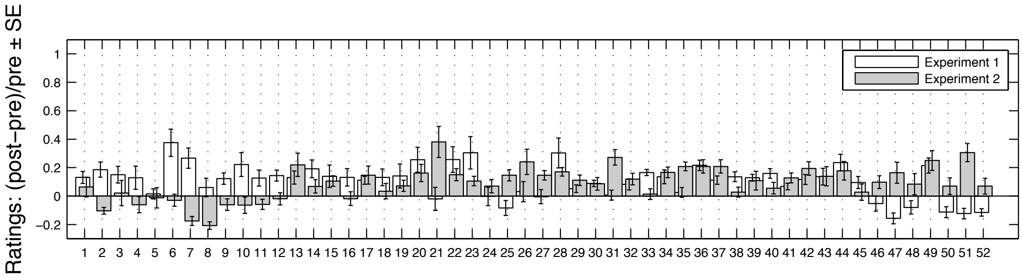
Exploratory independent groups comparisons between Experiments 1 & 2 showed that changes of performance ratings differed between the two sets of alpha-theta participants, but not those of control or SMR (in all but one measure). The differences are shown in Figure 4.1 and particularly affect the Stripsody and Instrumental solo performances. In Experiment 1, the latter task was found to disclose group differences in testing stage 1 however, and the post-NFT improvements in that task may have been attributable to regression-to-mean effects (Morton and Torgerson, 2005). The Stripsody task in Experiment 1 did not show such a difference, so the evidence of difference in changes between studies is more straightforward to compare. The data indicate that music changes in the alpha-theta group were predominantly negative in the second experiment, with 25% of them differing significantly from experiment one.



(a) alpha-theta



(b) SMR



(c) control

Figure 4.1: Significant differences are highlighted in the plots (× for SMR and * for alpha-theta). Variable names and significant test results are shown below:

Folk: 1– overall rating of performance, 2–overall rating of vocal competence, 3–clarity of diction× (t(8.07)=2.53, p=0.035), 4–pitch, 5–overall rating of musical understanding, 6–interpretative imagination, 7–expressive range, 8–stylistic accuracy, 9–rhythmic accuracy, 10–overall rating of communicative ability, 11–deportment on stage, 12–emotional commitment and conviction, 13–confidence in the situation, 14–sense of performance;

Stripsody: 15–overall, 16–overall vocal, 17–diction, 18–pitch, 19–breathing, 20–tonal, 21–overall musicality, 22–imagination, 23–oneness with voice, 24–overall communication, 25–deportment, 26–commitment* (t(7.54)=2.87, p=0.02), 27–confidence* (t(12)=2.27, p=0.04), 28–enjoyment;

Instrumental: 29–overall* (t(12)=2.94, p=0.01), 30–overall competence, 31–rhythmic accuracy* (t(7.67)=2.58, p=0.03), 32–security, 33–tonal quality* t(12)=2.69, p=0.02, 34–overall musicality* (t(12)=3.29, p=0.01), 35–stylistic accuracy* (t(12)=2.120, p=0.05), 36–imagination* (t(12)=2.83, p=0.02), 37–expressive range, 38–overall communication* (t(12)=2.85, p=0.02), 39–deportment, 40–commitment* (t(12)=3.20, p=0.3.20), 41–confidence* (t(12)=3.00, 0.01), 42–sense of performance* (t(12)=2.81, p=0.02);

Improv: 43–overall rating of performance* (t(12)=2.20, p=0.05), 44–overall rating of creativity* *t(12)=2.25, p=0.04, 45–interpretative imagination, 46–appropriateness to theme, 47–fluency, 48–temporal sense, 49–overall rating of communicative ability, 50–deportment on stage, 51–emotional commitment and conviction, 52–confidence in the situation.

4.2 Method

4.2.1 Participants

19 undergraduate music students from Goldsmiths University of London volunteered for participation (12 males, 7 females, mean age 24, ± 10.30). As in the previous cohort all who joined were instrumentalists with non-expert singing experience, and were assigned in the order of joining to one of three experimental groups: alpha-theta (n=7), SMR (n=6), controls (n=6). On completion of participation each subject received a payment of £20.

Participants played a variety of instruments, mostly but not exclusively in the classical tradition: 2 bassists; 1 clarinettist; 1 flautist; 3 guitarists; 7 pianists; 1 saxophonist; 1 tuba player; 3 violinists. One bassist played pop/rock, and the saxophonist played traditional jazz and classical. As with the previous participants, the prevailing musical orthodoxy was of playing music notation only, and improvisational skill had not been formally developed by any participants. Only the pop/rock musician was accustomed to the importance of jams, riffs and solos in the rock tradition.

4.2.2 Design

Prior to and following the intervention, participants in all groups performed the same battery of four musical tasks used in Chapter 3. The experimental intervention of either 10 NFT training sessions or a passive control period lasted for 72 (±25) days, with NFT sessions taking place every 8±3 days.

4.2.3 Neurofeedback, Music Performance and Statistical methods

Neurofeedback training provided was implemented according to procedures detailed in Section 3.3.3 and alpha-theta and SMR protocols detailed in Section 3.3.4. Music performance tasks were the same as those described in Section 3.3.5, however the post-performances did immediately follow the final training session, rendering them open to potential transient NFT effects, a key difference from the first cohort. Music performance ratings were conducted by the same two-member panel in the case of Stripsody and Folk-song performances, however in the case of Instrumental solos and improvisations, only one of the panel evaluated the performances, although given good prior agreement on assessment of these tasks, the use of single ratings was validated. The statistical methods used were previously introduced in Section 3.3.6.

4.3 Results

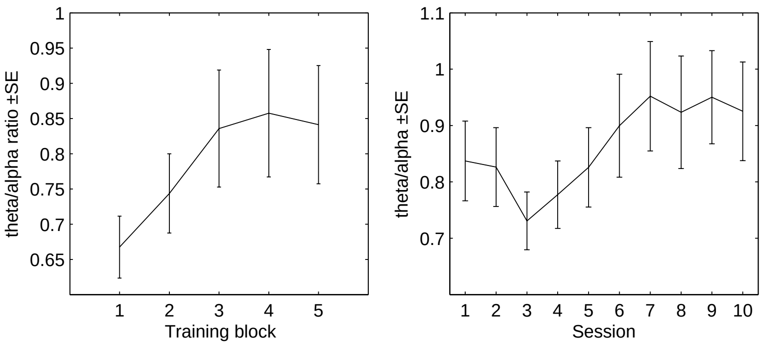
4.3.1 Neurofeedback training

For reasons stated in Section 3.3.6.1 the training ratio is used as the most reliable NFT learning index, as it is less sensitive to uncontrolled EEG modulators. However, absolute EEG component measures are included here to explore the factors underlying relative EEG changes.

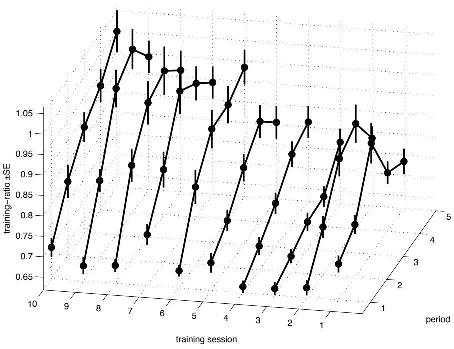
4.3.1.1 Alpha-theta neurofeedback training

According to the research questions of the experiment, alpha-theta NFT would modulate the theta-alpha ratio progressively both within- and across-sessions, plus these measures would interact (Research question 2). A repeated measures two-way (session × periods) ANOVA (with 10 × 5 levels respectively, sessions 1–10 and periods 1–5) disclosed marked changes across all measures:

- The within-session factor of the ANOVA revealed a significant effect of period on the t/a ratio (F(1.206, 7.236)=7.076, p=0.001), see Figure 4.2a
- The sessions factor of the ANOVA revealed a significant effect of session on the t/a ratio (F(9, 54)=2.301, p=0.029), see Figure 4.2b
- The session × period interaction showed a significant effect of session on period t/a ratios (F(36, 216)=1.517, p=0.038), see Figure 4.2c.



(a) theta/alpha ratio within a typical 15-minute session
(b) theta/alpha ratio across 10 sessions



(c) theta/alpha ratio: sessions × periods

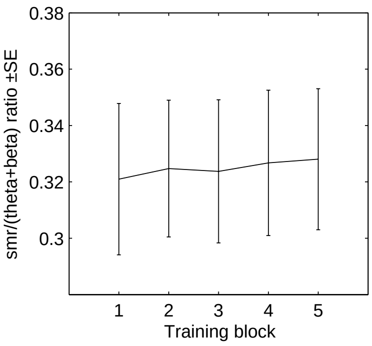
Figure 4.2: Theta/alpha ratios shown over the course of the average session, course and session × course relationship.

4.3.1.2 SMR neurofeedback training

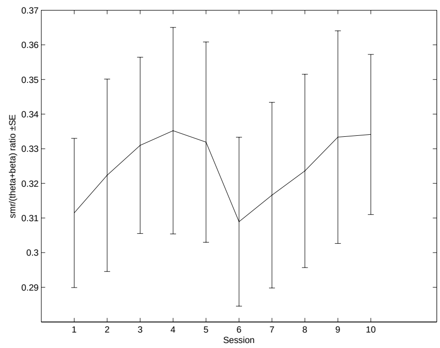
According to the research questions of the experiment, SMR NFT would raise the ratio of SMR to both theta and beta amplitudes progressively both within- and across-sessions, plus these measures would interact (RESEARCH QUESTION 2).

A repeated measures two-way (session × periods) ANOVA (with 10 × 5 levels respectively, sessions 1–10 and periods 1–5) disclosed marked changes in only the aggregated 'within-session' measure:

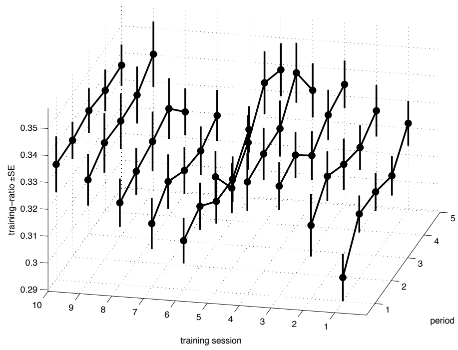
- The within-session factor of the ANOVA revealed a significant effect of period on the training ratio ($F(4, 20)=3.10$, $p=0.039$), see Figure 4.3a
- The sessions factor of the ANOVA revealed that there were no significant differences between sessions ($F(9, 45)=1.22$, p=NS), see Figure 4.3b
- The session × period interaction was examined for evidence of an effect of session on period t/a ratio. There was no significant interaction effect on the training ratio ($F(36, 180)=0.778$, p=NS), see Figure 4.3c.



(a) SMR/theta+beta ratio within a typical 15-minute session



(b) SMR/theta+beta ratio across 10 sessions



(c) SMR/theta+beta ratio: sessions × periods

Figure 4.3: SMR/(theta+beta) ratios shown over the course of the average session, course and session × course relationship.

4.3.2 Music Performance

4.3.2.1 Instrumental Solo

Data Screening Ratings were provided by one of the panellists from the prior study. Conservative 'single-measures' estimates of absolute rater agreement on prior instrumental data were computed — this approach is used in cases where high agreement between multiple raters on a subset of data is used as a precursor to continuing with one rater ('A-1' type, (Wong, 1981)). In instrumental ratings in the prior study, absolute agreement between the panel was high at r=0.73, p<0.0001, and thus the current set of ratings were interpreted as being representative of the panel's approach to marking this type of performance.

A one-way ANOVA on the pre-intervention measures of Instrumental performance revealed no differences between groups at baseline. Group score distributions are shown in Figure 4.4.

Creativity This task addressed RESEARCH QUESTION I (CREATIVITY).

The means and standard deviations of baseline and change measures, as well as ANOVA F-terms are included in Table 4.1 and visualised in Figure 4.5.

The ratings of performance were entered into repeated measures ANOVAS, with the pre-intervention scores as the covariate and the post-intervention score as the dependent variable. None of the tests showed a significant effect of experimental group.

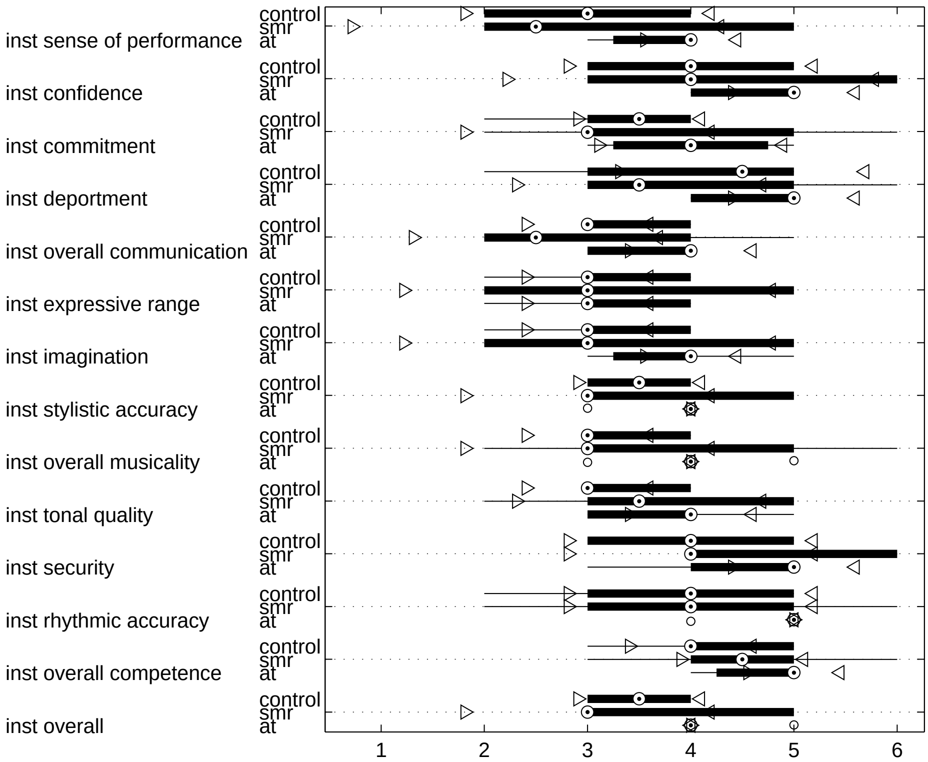


Figure 4.4: Boxplot showing between group differences in pre-intervention measures of Instrumental performance (Two medians are significantly different at the 5% significance level if their intervals do not overlap. Interval endpoints are the centres of the triangular markers.)

Table 4.1: Instrumental descriptive statistics

Measure	ALPHA-THETA (n=7) Pre	ALPHA-THETA (n=7) Change[1]	SMR (n=6) Pre	SMR (n=6) Change	CONTROL (n=6) Pre	CONTROL (n=6) Change	F-test (ANOVA[2])
Overall	4.14 ± 0.38	-0.12 ± 0.27	3.67 ± 1.03	0.04 ± 0.24	3.50 ± 0.55	0.11 ± 0.27	1.29
Overall competence	4.71 ± 0.49	-0.13 ± 0.33	4.50 ± 1.05	-0.04 ± 0.20	4.17 ± 0.75	0.09 ± 0.33	0.85
Rhythmic accuracy	4.86 ± 0.38	-0.14 ± 0.28	4.00 ± 1.41	0.19 ± 0.68	3.83 ± 1.17	0.27 ± 0.41	1.73
Security	4.43 ± 0.79	0.00 ± 0.33	4.67 ± 1.03	-0.08 ± 0.21	4.00 ± 0.89	0.12 ± 0.30	0.85
Tonal quality	3.71 ± 0.76	-0.06 ± 0.23	3.67 ± 1.21	0.04 ± 0.33	3.33 ± 0.52	0.01 ± 0.28	0.13
Overall musicality	4.00 ± 0.58	-0.10 ± 0.31	3.67 ± 1.51	0.22 ± 0.46	3.33 ± 0.52	0.17 ± 0.28	1.06
Stylistic accuracy	3.86 ± 0.38	-0.02 ± 0.32	3.67 ± 1.03	0.13 ± 0.31	3.50 ± 0.55	0.21 ± 0.23	1.00
Imagination	3.86 ± 0.69	-0.15 ± 0.33	3.33 ± 1.37	0.29 ± 0.68	3.17 ± 0.75	0.21 ± 0.35	1.42
Expressive range	3.29 ± 0.76	0.08 ± 0.48	3.33 ± 1.37	0.21 ± 0.51	3.17 ± 0.75	0.21 ± 0.35	0.25
Overall communication	3.57 ± 0.53	-0.11 ± 0.28	3.00 ± 1.26	0.21 ± 0.55	3.33 ± 0.52	0.03 ± 0.26	0.48
Deportment	4.57 ± 0.53	-0.04 ± 0.24	4.00 ± 1.26	0.06 ± 0.42	4.00 ± 1.26	0.11 ± 0.49	0.10
Commitment	4.00 ± 0.82	-0.16 ± 0.33	3.67 ± 1.51	0.16 ± 0.40	3.33 ± 0.82	0.06 ± 0.31	0.88
Confidence	4.57 ± 0.53	-0.09 ± 0.27	4.33 ± 1.37	0.08 ± 0.36	4.00 ± 0.89	0.13 ± 0.26	0.61
Sense of performance	3.71 ± 0.49	-0.11 ± 0.34	3.17 ± 1.47	0.43 ± 0.70	3.00 ± 0.89	0.19 ± 0.35	1.17

[1] $Change = \frac{(post - pre)}{pre}$

[2] df(2,16)

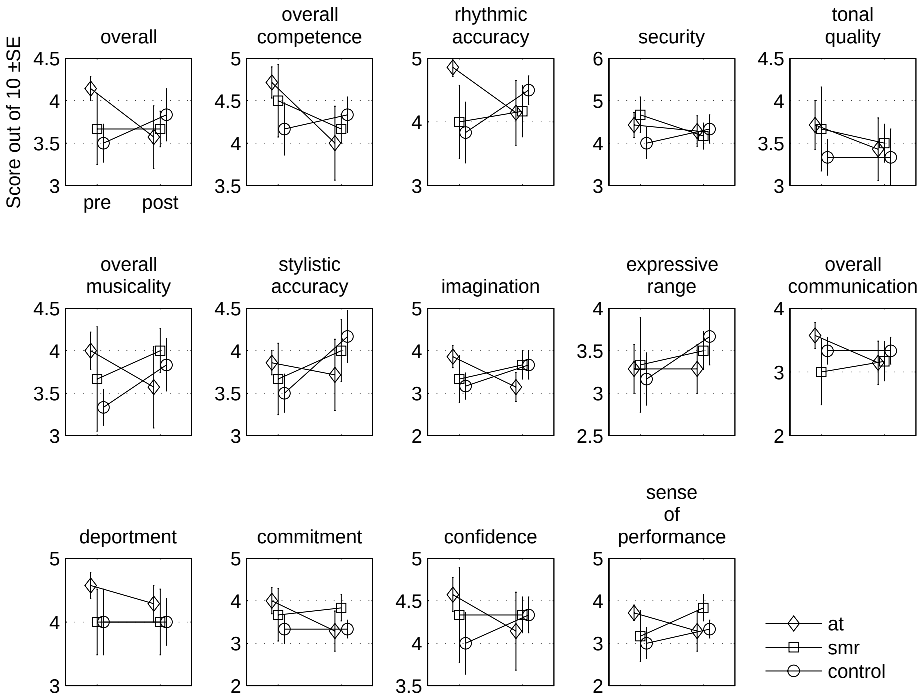


Figure 4.5: Group changes in music performance evaluation

As this part of the experiment ostensibly served as a replication of the second experiment in Egner and Gruzelier (2003), the within-group contrasts reported there are also shown here. Bearing in mind their relatively higher opening scores and the associated problem of their subsequent downward regression to the participant mean (See Figure 4.5), the alpha-theta group alone showed wide ranging within-subjects declines in performance (two-tailed t-tests, see Table 4.2). This is in contrast to the reports in Egner and Gruzelier (2003) and Chapter 3.

Table 4.2: Instrumental Solo — within-group changes
(two-tailed t-tests included as replication of Egner and Gruzelier (2003))

	ALPHA-THETA		SMR		CONTROL	
	t	p	t	p	t	p
Overall	-1.19	0.28	*w*=2	1.00	1.00	0.36
Overall competence	-1.46	0.20	*w*=1	0.62	*w*=0	1.00
Rhythmic accuracy	-1.37	0.22	0.00	1.00	*w*=0	0.12
Security	-0.31	0.77	-1.35	0.24	1.46	0.20
Tonal quality	-1.16	0.29	-0.60	0.58	-0.54	0.61
Overall musicality	-1.19	0.28	0.28	0.79	*w*=0	0.50
Stylistic accuracy	-0.68	0.52	0.35	0.74	1.46	0.20
Imagination	-1.37	0.22	0.21	0.84	*w*=0	0.25
Expressive range	0.00	1.00	0.00	1.00	*w*=0	0.25
Overall communication	-1.16	0.29	0.00	1.00	*w*=0	1.00
Deportment	-0.68	0.52	-0.24	0.82	0.35	0.74
Commitment	-1.69	0.14	0.00	1.00	-0.42	0.70
Confidence	-0.89	0.41	-0.25	0.81	*w*=0	0.25
Sense of performance	-0.89	0.41	0.65	0.54	*w*=0	0.25
Degrees of Freedom	6		5		5	

w=Wilcoxon sign test on data that did not satisfy assumptions of parametric t-tests.

4.3.2.2 Stripsody

Data Screening The I.C.C. statistic measuring consistency between two panellists' ratings under a two-way random effects model showed a high level of inter rater reliability at r=0.71, p<0.0001. Ratings were averaged for subsequent analysis.

A one-way ANOVA on the pre-intervention measures of performance revealed no differences between groups at baseline. Group score distributions are shown in Figure 4.6

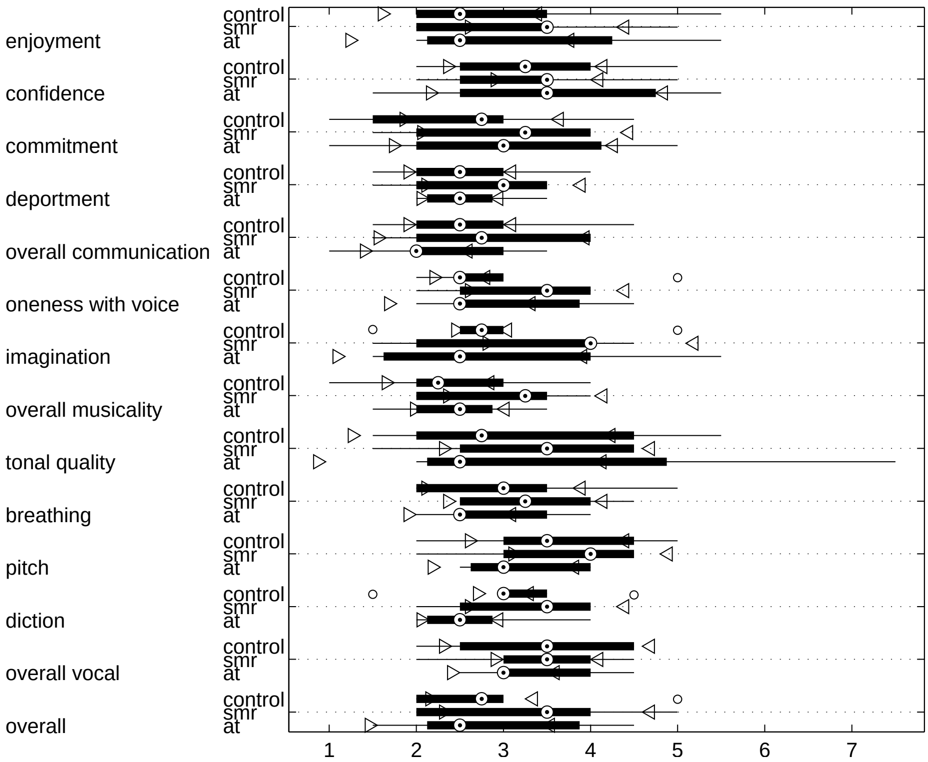


Figure 4.6: Boxplot showing between group differences in pre-intervention measures of Stripsody performance (Two medians are significantly different at the 5% significance level if their intervals do not overlap. Interval endpoints are the centres of the triangular markers.)

Creativity This task addressed RESEARCH QUESTION I (CREATIVITY).

The means and standard deviations of baseline and change measures, as well as ANOVA F-terms are included in Table 4.3 and visualised in Figure 4.7.

None of the tests showed between-group differences.

Table 4.3: Stripsody descriptive statistics

	ALPHA-THETA (n=7)		SMR (n=6)		CONTROL (n=6)		F-test
Measure	Pre	Change[1]	Pre	Change	Pre	Change	(ANOVA[2])
Overall	2.93 ± 1.10	-0.04 ± 0.14	3.33 ± 1.17	0.07 ± 0.26	2.92 ± 1.11	0.11 ± 0.28	0.66
Overall vocal	3.43 ± 0.73	-0.08 ± 0.19	3.42 ± 0.86	-0.04 ± 0.36	3.42 ± 1.02	-0.02 ± 0.36	0.01
Diction	2.64 ± 0.69	0.01 ± 0.31	3.25 ± 0.82	0.02 ± 0.06	3.08 ± 0.97	0.15 ± 0.47	0.18
Pitch	3.29 ± 0.70	0.01 ± 0.23	3.67 ± 0.98	-0.02 ± 0.27	3.58 ± 1.07	0.03 ± 0.40	0.23
Breathing	2.93 ± 0.73	-0.03 ± 0.11	3.33 ± 0.82	0.02 ± 0.18	3.08 ± 1.11	0.07 ± 0.29	0.03
Tonal spectrum	3.71 ± 2.06	-0.01 ± 0.17	3.33 ± 1.17	0.08 ± 0.34	3.17 ± 1.54	0.16 ± 0.45	0.00
Overall musicality	2.43 ± 0.67	-0.00 ± 0.24	3.00 ± 0.84	0.12 ± 0.10	2.42 ± 1.02	0.38 ± 0.81	1.25
Imagination	3.00 ± 1.53	-0.07 ± 0.47	3.33 ± 1.25	0.12 ± 0.43	2.92 ± 1.16	0.15 ± 0.32	1.42
Oneness with voice	3.07 ± 0.93	0.00 ± 0.19	3.25 ± 0.82	0.03 ± 0.27	2.92 ± 1.07	0.11 ± 0.25	0.23
Overall communication	2.36 ± 0.85	0.05 ± 0.36	2.83 ± 1.03	0.16 ± 0.35	2.67 ± 1.08	0.07 ± 0.35	0.22
Deportment	2.57 ± 0.53	-0.05 ± 0.09	2.75 ± 0.82	0.24 ± 0.47	2.58 ± 0.92	0.15 ± 0.29	1.42
Commitment	2.93 ± 1.43	-0.11 ± 0.24	3.00 ± 1.05	0.15 ± 0.31	2.58 ± 1.24	0.24 ± 0.66	1.02
Confidence	3.50 ± 1.44	-0.05 ± 0.18	3.33 ± 1.03	0.14 ± 0.31	3.33 ± 1.08	0.15 ± 0.25	2.61
Enjoyment	3.21 ± 1.35	-0.08 ± 0.17	3.25 ± 1.13	0.04 ± 0.34	3.00 ± 1.38	0.17 ± 0.22	1.63

[1] $Change = \frac{(post-pre)}{pre}$

[2] df(2,16)

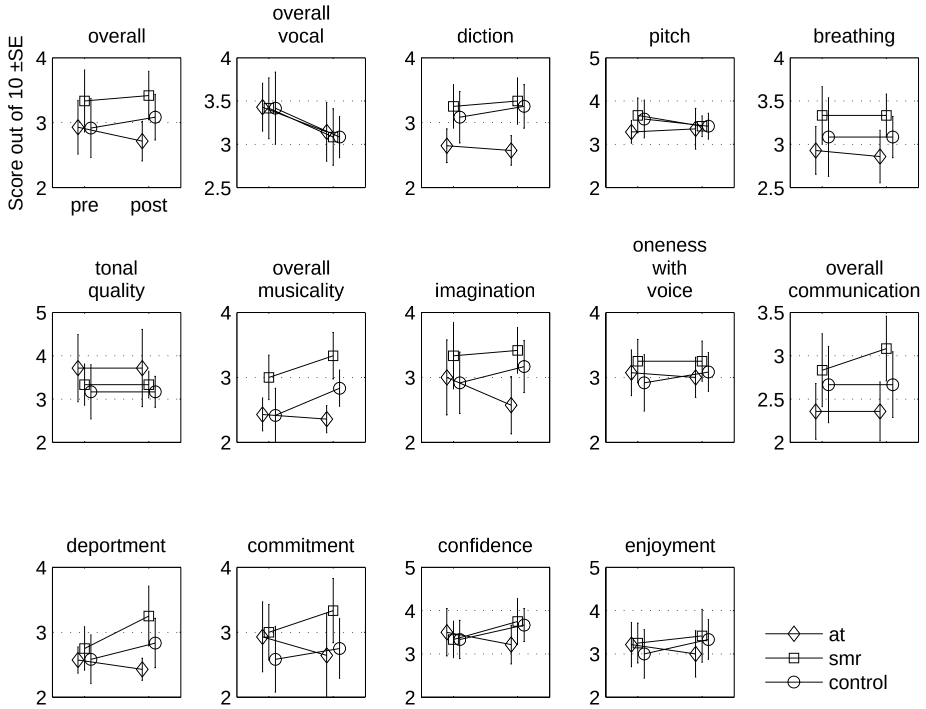


Figure 4.7: Group changes in music performance evaluation

4.3.2.3 Folk Song

Data Screening The I.C.C. statistic measuring consistency between two panellists' ratings under a two-way random effects model showed a moderate level of inter rater reliability at r=0.63, p<0.0001. Ratings were averaged for subsequent analysis.

A one-way ANOVA on the pre-intervention measures of performance revealed no differences between groups at baseline. Group score distributions are shown in Figure 4.8

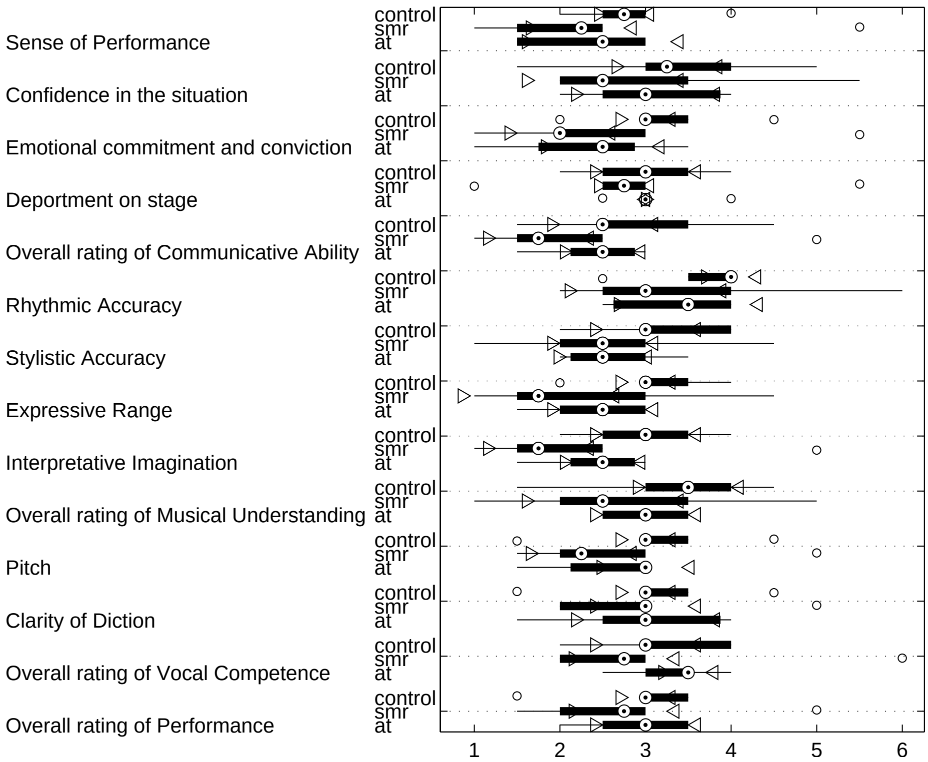


Figure 4.8: Boxplot showing between group differences in pre-intervention measures of Folk Song performance (Two medians are significantly different at the 5% significance level if their intervals do not overlap. Interval endpoints are the centres of the triangular markers.)

Novice Performance This task addressed RESEARCH QUESTION 3 (NOVICE PERFORMANCE).

The means and standard deviations of baseline and change measures, as well as ANOVA F-terms are included in Table 4.4 and visualised in Figure 4.9.

The initial use of ANOVA revealed a group difference in measures of 'Expressive range' ($F(2, 16)=5.80$, $p<0.05$). Post-hoc comparisons however showed no inter-group differences SMR - alpha-theta (M = 0, SE = 0.49) p=NS; SMR - control (M = -0.33, SE = 0.57) p=NS.

Table 4.4: Folk Song descriptive statistics

Measure	alpha-theta (n=7) Pre	Change[1]	smr (n=6) Pre	Change	control (n=6) Pre	Change	F-test (ANOVA[2])
Overall Performance	2.93 ± 0.61	-0.07 ± 0.18	2.83 ± 1.21	0.17 ± 0.21	2.92 ± 0.74	0.06 ± 0.52	1.50
Overall Vocal Competence	3.29 ± 0.49	-0.14 ± 0.11	3.08 ± 1.50	-0.01 ± 0.12	3.17 ± 0.75	-0.10 ± 0.18	1.67
Clarity of Diction	3.00 ± 0.91	-0.00 ± 0.29	3.00 ± 1.10	-0.04 ± 0.11	3.08 ± 0.97	0.02 ± 0.66	0.11
Pitch	2.57 ± 0.61	0.13 ± 0.29	2.67 ± 1.25	0.16 ± 0.30	3.08 ± 0.97	-0.06 ± 0.42	1.76
Overall Musical Understanding	3.00 ± 0.50	-0.06 ± 0.28	2.75 ± 1.37	0.33 ± 0.61	3.33 ± 1.03	-0.01 ± 0.53	1.48
Interpretative Imagination	2.43 ± 0.53	0.04 ± 0.32	2.25 ± 1.44	0.40 ± 0.37	3.00 ± 0.77	-0.03 ± 0.31	2.41
Expressive Range	2.43 ± 0.61	0.08 ± 0.22	2.25 ± 1.29	0.29 ± 0.27	3.08 ± 0.66	-0.18 ± 0.23	5.80[3]
Stylistic Accuracy	2.64 ± 0.56	-0.03 ± 0.26	2.58 ± 1.16	0.09 ± 0.46	3.17 ± 0.75	-0.21 ± 0.20	1.93
Rhythmic Accuracy	3.36 ± 0.69	-0.05 ± 0.39	3.42 ± 1.43	0.16 ± 0.32	3.67 ± 0.61	-0.06 ± 0.30	0.76
Overall Communicative Ability	2.43 ± 0.53	-0.08 ± 0.21	2.25 ± 1.44	0.19 ± 0.22	2.83 ± 1.03	-0.06 ± 0.42	1.73
Deportment on stage	3.07 ± 0.45	-0.15 ± 0.24	2.92 ± 1.46	0.22 ± 0.63	3.00 ± 0.71	-0.06 ± 0.27	1.41
Emotional commitment	2.36 ± 0.85	0.24 ± 0.54	2.58 ± 1.56	0.33 ± 0.63	3.17 ± 0.82	-0.02 ± 0.32	0.71
Confidence in the situation	3.07 ± 0.79	0.01 ± 0.34	3.00 ± 1.38	0.23 ± 0.33	3.33 ± 1.17	0.22 ± 0.61	0.64
Sense of Performance	2.29 ± 0.76	0.12 ± 0.53	2.50 ± 1.58	0.38 ± 0.48	2.83 ± 0.68	0.07 ± 0.35	0.70

[1] $Change = \frac{(post-pre)}{pre}$

[2] df(2,16)

[3] $p<0.05$

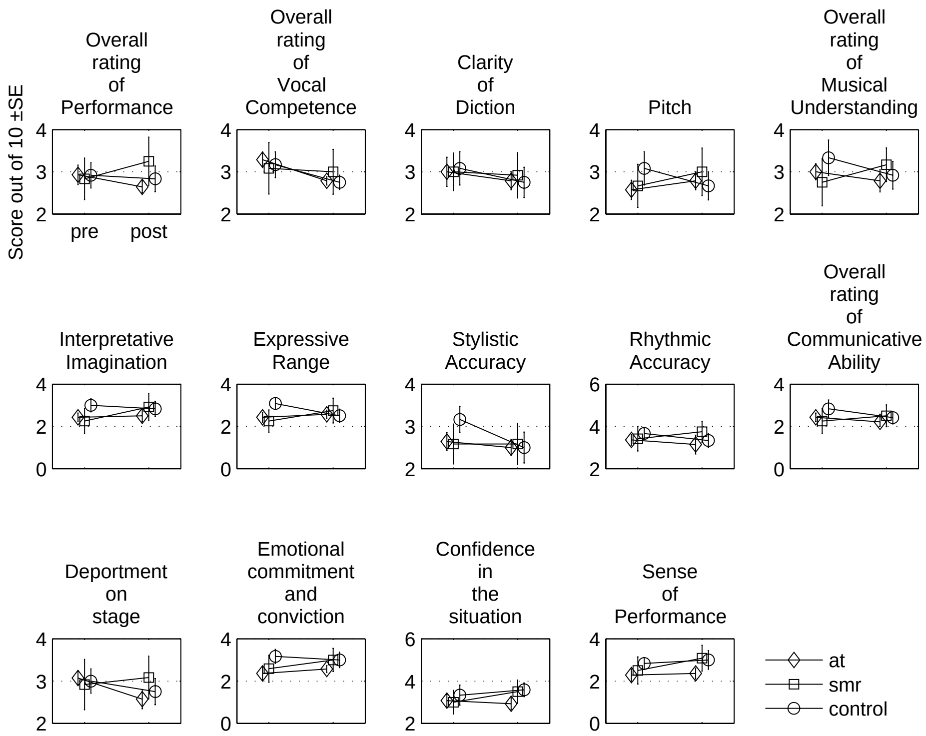


Figure 4.9: Group changes in music performance evaluation

4.3.2.4 Instrumental Improvisation

Data Screening Ratings were provided by one of the panellists from the prior study. In instrumental ratings in the prior study, absolute agreement between the panel was moderate at r=0.59, p<0.0001, and the current set of ratings were interpreted as being representative of the panel's approach to marking this type of performance.

A one-way ANOVA on the pre-intervention measures of performance revealed no differences between groups at baseline. Group score distributions are shown in Figure 4.10

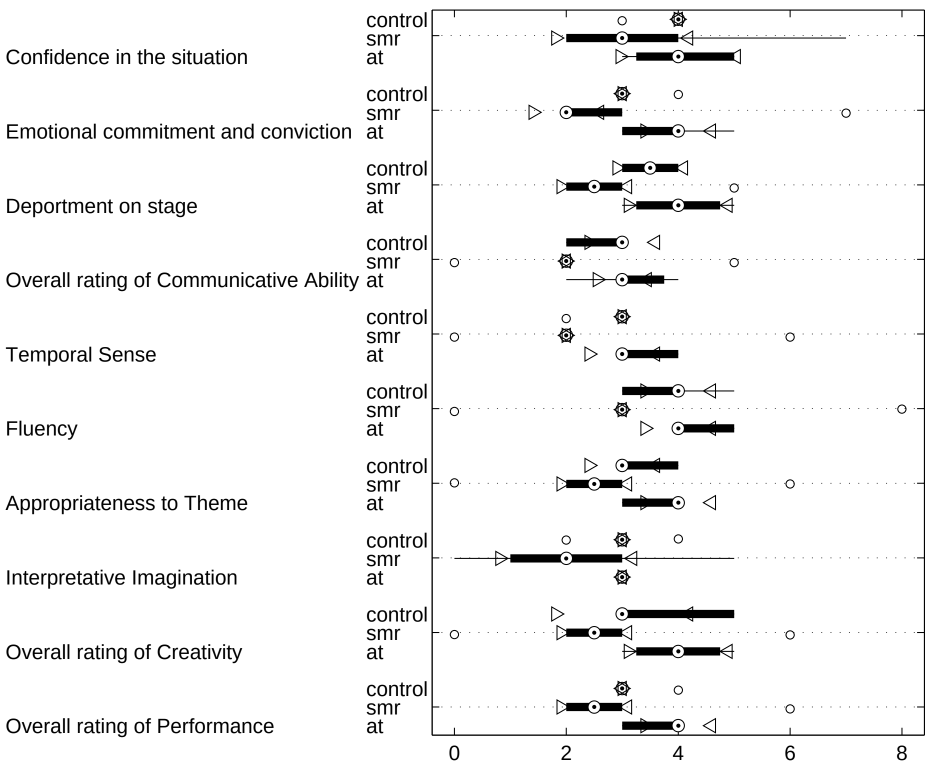


Figure 4.10: Boxplot showing between group differences in pre-intervention measures of Instrumental Improvisation(Two medians are significantly different at the 5% significance level if their intervals do not overlap. Interval endpoints are the centres of the triangular markers.)

Creativity This task addressed RESEARCH QUESTION 1 (CREATIVITY).

The means and standard deviations of baseline and change measures, as well as ANOVA F-terms are included in Table 4.5 and visualised in Figure 4.11.

A marginal group difference in scores of 'Emotional commitment' was found by ANOVA tests.

Table 4.5: Instrumental improvisation descriptive statistics

	ALPHA-THETA (n=7)		SMR (n=6)		CONTROL (n=6)		F-test
Measure	Pre	Change[1]	Pre	Change	Pre	Change	(ANOVA[2])
Overall Performance	3.57 ± 0.53	-0.14 ± 0.20	3.00 ± 1.55	-0.03 ± 0.54	3.17 ± 0.41	0.14 ± 0.50	1.13
Overall Improvisational Competence	4.14 ± 0.69	-0.13 ± 0.17	3.00 ± 1.55	0.03 ± 0.76	4.00 ± 0.89	0.07 ± 0.45	0.43
Interpretative Imagination	3.00 ± 0.00	-0.05 ± 0.30	2.50 ± 1.38	0.38 ± 1.30	3.00 ± 0.63	0.03 ± 0.43	0.03
Appropriateness to Theme	3.57 ± 0.53	-0.11 ± 0.20	2.83 ± 1.72	-0.03 ± 0.54	3.33 ± 0.52	0.10 ± 0.34	0.93
Fluency	4.43 ± 0.53	-0.22 ± 0.17	3.67 ± 2.16	0.11 ± 0.55	3.83 ± 0.75	0.16 ± 0.55	0.79
Temporal Sense	3.43 ± 0.53	-0.12 ± 0.32	2.67 ± 1.63	0.25 ± 0.52	2.83 ± 0.41	0.08 ± 0.56	0.29
Overall Communicative Ability	3.14 ± 0.69	-0.11 ± 0.31	2.50 ± 1.22	0.02 ± 0.53	2.67 ± 0.52	0.25 ± 0.51	0.97
Deportment on stage	4.14 ± 0.69	-0.22 ± 0.17	2.83 ± 1.17	0.29 ± 0.71	3.83 ± 0.41	-0.01 ± 0.45	0.83
Emotional commitment	3.71 ± 0.76	-0.18 ± 0.20	3.00 ± 2.00	-0.07 ± 0.58	3.17 ± 0.41	0.31 ± 0.48	2.28
Confidence in the situation	4.14 ± 0.90	-0.20 ± 0.19	3.50 ± 1.87	0.10 ± 0.79	3.83 ± 0.41	0.07 ± 0.41	0.91

[1] $Change = \frac{(post - pre)}{pre}$

[2] df(2,16)

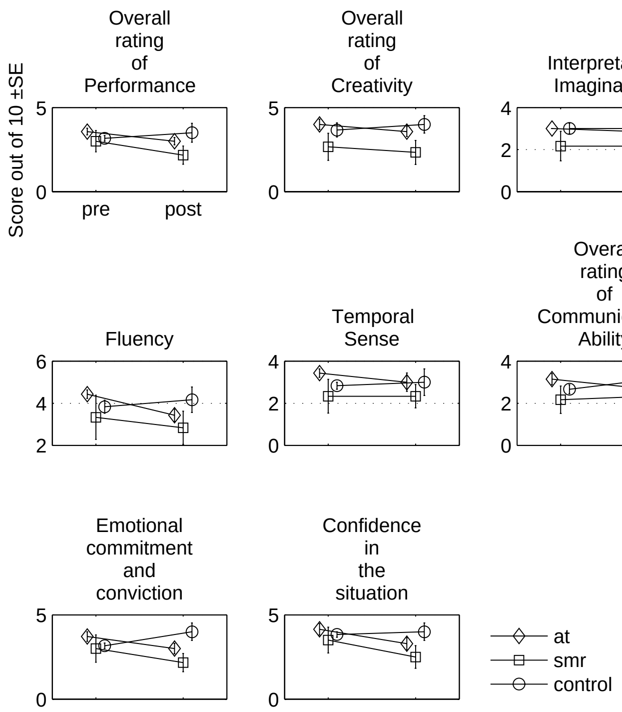


Figure 4.11: Group changes in music performance evaluation

4.3.3 Within-subjects relationship between changes in NFT-EEG and music performance

Within subjects ANCOVAS were performed to assess the research question as to whether changes in measures of music performance would be predicted by changes to EEG during training (RESEARCH QUESTION 4).

Table 4.7 includes all the results, and significant results are described by music task below. In both EEG and music measures, the index of change was calculated as latter data minus former data (e.g. second half of training minus former half), divided by former data. This approach measures late data in proportion to early data.

4.3.3.1 Instrumental Solo

It was found that no pre- or post-training musical measures of this task co-varied with within-session EEG ratios.

This task, which replicates the task in Egner and Gruzelier (2003) is also analysed using the approach adopted there (see Section 3.3.6.3). The training coefficients all correlated negatively and non-significantly (see Table 4.6).

Table 4.6: Correlation between training and music change replicating Egner and Gruzelier's (2003) statistical analysis

Measure	Training correlation
Overall	-0.71
Overall competence	-0.28
Rhythmic accuracy	-0.55
Security	-0.51
Tonal quality	-0.47
Overall musicality	-0.72
Stylistic accuracy	-0.72
Imagination	-0.87
Expressive range	-0.63
Overall communication	-0.78
Deportment	-0.59
Commitment	-0.92
Confidence	-0.74
Sense of performance	-0.76

4.3.3.2 Stripsody

The within-session SMR ratio was a covariate of pre-training 'Overall musicality' and 'Confidence' measures, plus post-training 'Overall communication.' To a marginal extent, it was a covariate of post-training 'Breathing' and 'Emotional commitment.'

4.3.3.3 Folk Song

It was found that no pre- or post-training musical measures of this task co-varied with within-session EEG ratios.

4.3.3.4 Instrumental Improvisation

The within-session alpha-theta ratio was a covariate of post-training 'Overall Improvisational Competence,' 'Fluency' and 'Overall Communicative Ability.'

Table 4.7: Music covariance with within-session EEG (F statistic)

Performance	Measure	alpha-theta pre	alpha-theta post	SMR pre	SMR post
Instrumental	Overall	2.95	0.01	0.18	0.18
	Overall Competence	1.61	0.15	1.07	3.53
	Rhythmic Accuracy	0.34	0.04	0.22	0.35
	Security	0.05	0.02	0.18	0.58
	Tonal Quality	0.12	0.10	0.57	0.32
	Overall Musicality	1.23	0.89	0.02	0.05
	Stylistic Accuracy	0.14	1.41	0.18	0.07
	Imagination	0.44	0.45	0.43	0.28
	Expressive Range	0.07	0.82	0.43	0.32
	Overall Communication	0.00	0.45	0.00	0.73
	Deportment	0.00	0.14	0.52	0.00
	Emotional commitment	1.06	0.76	0.02	0.18
	Confidence	0.94	0.58	0.10	0.34
	Sense of Performance	0.02	0.76	0.05	0.16
Stripsody	Overall	0.00	0.08	3.55	4.52
	Overall Vocal	0.10	0.80	1.11	0.93
	Diction	1.12	0.02	2.47	3.29
	Pitch	0.07	0.00	2.96	3.55
	Breathing	0.59	0.03	2.13	6.85··
	Tonal Quality	0.01	0.03	2.19	2.76
	Overall Musicality	0.37	0.91	8.90*	3.29
	Imagination	0.16	0.10	4.46	1.11
	Oneness With Voice	0.37	0.89	2.47	3.25
	Overall Communication	0.04	0.25	1.11	9.97*
	Deportment	0.17	0.06	2.47	3.56
	Emotional commitment	0.01	0.05	3.13	6.85··
	Confidence	0.02	0.05	8.73*	2.24
	Enjoyment	0.05	0.01	6.26	3.10
Folk	Overall Performance	0.62	0.10	0.57	0.95
	Overall Vocal Competence	2.71	1.08	0.23	0.63
	Clarity of Diction	0.60	0.44	0.38	0.30

Continued on next page

Table 4.7 – continued from previous page

Performance	Measure	alpha-theta pre	alpha-theta post	SMR pre	SMR post
	Pitch	0.23	0.75	0.03	0.16
	Overall Rating of Musical Understanding	0.00	0.06	0.08	0.11
	Interpretative Imagination	0.62	0.00	0.44	0.28
	Expressive Range	0.00	0.08	0.14	0.25
	Stylistic Accuracy	0.00	0.11	0.18	0.37
	Rhythmic Accuracy	0.01	0.15	0.12	0.49
	Overall Communicative Ability	0.62	0.09	0.44	0.38
	Deportment on Stage	3.92	0.01	0.69	1.03
	Emotional Commitment	0.62	0.25	0.21	0.76
	Confidence in the Situation	0.76	0.00	1.36	0.76
	Sense of Performance	0.47	0.13	0.64	0.65
Improvisation	Overall Performance	0.20	1.23	1.75	0.46
	Overall Improvisational Competence	2.80	19.23**	1.75	0.72
	Interpretative Imagination	0.00	0.36	1.36	0.46
	Appropriateness to Theme	0.20	2.80	0.34	0.83
	Fluency	0.38	7.23*	0.99	0.89
	Temporal Sense	0.38	2.55	0.73	0.02
	Overall Communicative Ability	0.05	12.40*	0.73	0.00
	Deportment on Stage	0.39	2.95	2.19	0.11
	Emotional Commitment	0.26	0.07	1.60	0.83
	Confidence in the Situation	0.06	0.08	1.67	0.04

[1] Degrees of freedom: alpha-theta (1, 5), SMR (1, 6)
[2] Degrees of freedom: alpha-theta (1, 6), SMR (1, 6)
** Covariance is significant at the 0.01 level.
* Covariance is significant at the 0.05 level.
¨ Covariance has a trend towards significance at the 0.06 level.

4.3.4 Music Results summary

The results of the Instrumental solo task did not confirm the possibility that measures of creativity would be improved in the alpha-theta theta group alone; and did not support the findings of the first experiment, or (Egner and Gruzelier, 2003). No significant changes in performance were observed, or training/performance covariance.

In post-intervention performances of the Stripsody the group difference in 'Confidence' was not reproduced from the study in Chapter 3. Within-session SMR changes predicted pre-training 'Overall musicality' and 'Confidence' measures, plus post-training 'Overall communication,' and a marginal extent, post-training 'Breathing' and 'Emotional commitment.'

The Folk song results revealed that the change in 'Expressive range' was significant between groups, although without follow-on post-hoc confirmation. No training/performance covariances were observed.

Improvisation results showed no group differences in performance change, whilst within-session t/a ratio changes predicted declining performance scores in 'Overall Improvisational Competence,' 'Fluency' and 'Overall Communicative Ability.'

4.4 Discussion

4.4.1 Neurofeedback Training

4.4.1.1 Alpha-theta training

The training results are similar to those in comparable experiments in Chapter 3 and in Egner and Gruzelier (2004a): t/a ratios clearly changed on within-session measures. They also changed definitively across 10 training sessions and in the session × period interaction, demonstrating cumulative within-session changes over the course of training.

Given an experimental control, such as the use of mock feedback (Egner et al., 2002) or relaxation (Boynton, 2001), this evidence could be interpreted as NFT assisted regulation of hypnagogic EEG (Green et al., 1974; Peniston and Kulkosky, 1999). The current results, whilst promising, do not show that changes occurred over-and-above what happens in normal sleep onset.

Compared to the data in Chapter 3 and (Egner and Gruzelier, 2004a), this study shows longitudinal training effects: session values increased significantly, suggesting that 10 sessions is sufficient to invoke the targeted change in EEG.

Within-session changes also increased significantly over time, providing additional evidence of a learning curve, and being the possible mediator of the across-sessions gains. Again, this suggests that with each session, the participants became increasingly adept at moving towards hypnagogia.

Possibly as a result of this accelerated sleep onset, this study found some evidence of a transition beyond SLEEP STAGE I, as within-session measures showed that in the final three minutes of training, both theta *and* alpha began to increase. This change from falling to rising alpha could signal the presence of SLEEP STAGE II physiology as characterised by De Gennaro et al.'s (2001) spectral analysis of sleep onset (see Figure 4.12).

In practice however, sleep stage classification does not use spectral band power but visual waveform analysis by a panel (Rechtschaffen and Kales, 1968) and with reference to signal characteristics shown in Figure 4.13. Additionally, sleep EEG is not recorded solely from the Pz-A1 scalp difference, so again this data does not provide the basis for sleep scoring.

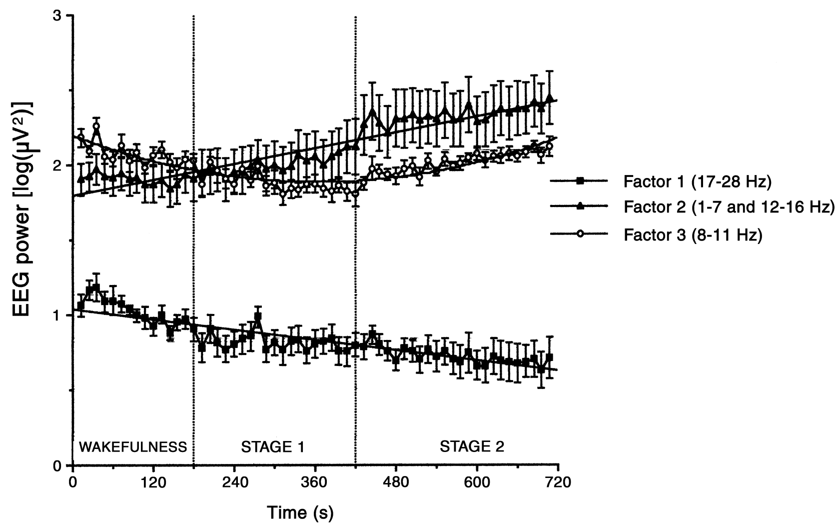


Figure 4.12: De Gennaro et al.'s (2001) spectral analysis of scalp-wide EEG during sleep onset - Note that alpha (8-11 Hz) begins to rise during STAGE II initiation, and theta (merged with SMR "sleep spindle" EEG) rises throughout.

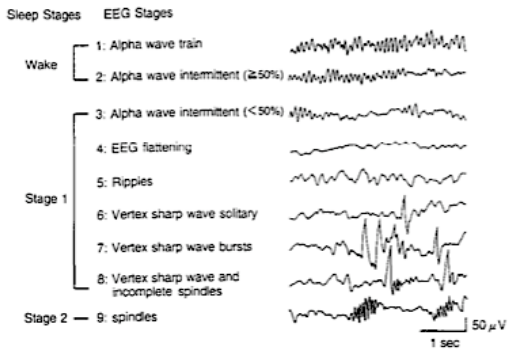


FIG. 1. Typical electroencephalogram (EEG) patterns during the hypnagogic state [following Hori et al. (18)]. EEG stage 1, alpha wave train; EEG stage 2, alpha wave intermittent A ($\alpha \geq 50\%$); EEG stage 3, alpha wave intermittent B ($\alpha < 50\%$); EEG stage 4, EEG flattening; EEG stage 5, ripples; EEG stage 6, vertex sharp wave solitary; EEG stage 7, vertex sharp-wave train or burst; EEG stage 8, vertex sharp wave and incomplete spindle; EEG stage 9, spindles.

Figure 4.13: Morikawa et al.'s (1997) characterisation of the visual properties of hypnagogic EEG.

Nonetheless, if the participants did both enter and exit SLEEP STAGE I within the final 3 minutes of a session, this would suggest that this stage lasted no more than 3-minutes, agreeing with time-scales documented in Morikawa et al. (1997). Given that significant t/a ratio increases are taking place in 15-minute sessions, and that SLEEP STAGE I is possibly completing its cycle within that time-scale, it is surmised that the session duration is fit for the purposes of attaining hypnagogic EEG, i.e. the first stage of sleep onset Tanaka et al. (2000). Despite this Peniston and Kulkosky's (1991) proposed application of NFT was to sustain hypnagogia, in which case longer training sessions would be required to determine the ability of NFT to extend SLEEP STAGE I beyond the average 3 minutes.

4.4.1.2 SMR training

In SMR training, a typical session saw the training ratio increase to a small but significant degree. This discloses targeted effects to a greater extent than Experiment 1, which found no evidence of EEG change, yet the actual difference in EEG is very small.

As with Experiment 1, across-session analyses showed no training effects, and the lack of clear longitudinal change is striking. However Gruzelier et al. (2010) reported SMR/(theta+beta) differences underpinned by an ascending linear trend across 6 sessions, although as with the Vernon et al. (2003) study, the beta range used (15–21 Hz) was distinct from that used here (22–30 Hz). The comparative efficacy of training lower beta ranges suggests this is more feasible in healthy subjects.

A recent single-session study found that SMR training did not lead to changes in SMR (Ros et al., 2010). Many other studies do not document training data, although Egner et al. (2004) found SMR training to be somewhat associated with reduced post-training SMR activity in resting EEG measures. In the clinical literature, SMR protocols have demonstrated changes in EEG (resting measures), for example Gevensleben et al. (2009b) documented post-training decreases of theta activity at central-midline and parietal-midline electrodes, indicating that theta inhibition was successfully applied.

Overall, it seems that this SMR protocol was sub-optimal, particularly in relation to reducing beta. A possible explanation for the relative success of the protocol applied in Vernon et al. (2003) and Gruzelier et al. (2010) might lie in protocol differences. The current studies attempted to inhibit beta in the 22–30 Hz range, whereas the other studies used much lower ranges. Considering that beta is thought to reflect changes in cognitive operations Laufs et al. (2003), using a higher and wider band for measuring beta might allow broader scope for interference from diffuse neural processes occurring during the course of training. Interestingly, once apparent fluctuations in the interaction between sessions and periods were controlled for, rising trends in SMR/beta values were observed. This might suggest that once EEG fluctuations are taken into account, healthy participants could be shown to be able to modulate the higher beta band in training. Another factor that might impact the training response is the frequency of training, in Vernon et al. (2003) participants attended twice-weekly, and in Gruzelier et al. (2010) 7–10 sessions were given over a 6 week period with no more than one session per day, Ros et al. (2009) found that SMR trainees in whom the SMR/theta ratio fell in training had a larger intersession interval of over one week, implying that the longer the intersession interval, the more the SMR/theta ratio fell across-sessions. In the current study the intersession interval was 8 days on average, which might potentially account for why the training response in the current study was slower than in Gruzelier et al. (2010), in which sessions took place >1 times per week on average.

4.4.2 Music Performance

An important consideration in interpreting the results of the current experiment is that the final session of neurofeedback training was administered immediately prior to the post-training performances, which began within 10 minutes of the end of training. In a recent paper Ros et al. (2010) demonstrated that transient neurofeedback effects were observable 20 minutes after training ended, and the current results can be considered in the light of this. In alpha-theta training, as well as featuring the possible transient effects of t/a ratio reinforcement, participant performances are considered as taking place in a post-nap 'hypnopompic' condition. The literature on post-nap performance is divided in its conclusions. Whilst longer naps (>30-minutes) stopped during slow wave sleep are commonly associated with sleep inertia and impaired performance (Hofer-Tinguely et al., 2005), shorter naps (<30-minutes) can maintain daytime arousal (seen in reduced wakeful alpha EEG), and possibly optimises cognitive performance levels (Hayashi et al., 1999a,b). The timing of daytime sleep has a differential effect on performance, with early afternoon being the most advantageous time for performance improvements. Sleep habits also have an effect; people who regularly nap benefit from a short sleep, whilst non-habitual nappers can experience performance impairments on motor tasks (Milner et al., 2006).

Relating the above points to the current study, the session length of 15-minutes meant that sleep inertia was unlikely after alpha-theta, and spectral analysis of the final session confirmed that whilst sleep-onset probably began in the final three minutes of training, it was unlikely that slow wave sleep occurred (Hofer-Tinguely et al., 2005). The average time-of-day of the final session was 13:59:54 ± 01:34:54, and so was optimal in terms of sleep-effects in maintaining daytime performance levels (Hayashi et al., 1999b). The daytime sleeping habits of participants were not recorded. Overall, and despite the possibly beneficial effects of a short nap of approximately 3 minutes, post-alpha-theta training benefits seen in Chapter 3 and (Egner and Gruzelier, 2003) were not replicated in this study, and are interpreted as being negated by either transient alpha-theta or post-nap effects.

The immediate after effects of SMR NFT have been previously investigated by Ros et al. (2010) in a study evaluating cortico-motor activity following a single NFT session, although training contingencies were not achieved by the participants, and no post-training effects were observed. In the current study, the final session of SMR training was not found to disclose a differential effect of training period on SMR/theta ($F(4, 28)=0.479$, p=NS) or SMR/beta ($F(4, 28)=0.986$, p=NS) and no trends for change were in evidence.

4.4.2.1 Instrumental Solo

No between groups differences were observed in post-intervention performance measures. Within-subjects improvements seen in alpha-theta participants in Chapter 3 and Egner and Gruzelier (2003) were not replicated in this study. No effect relation between training and performance was disclose, and a non-significant decline in music evaluation was observed across all measures.

Whilst EEG measures of training showed distinct changes in the t/a ratio, the expected music improvements following alpha-theta was reversed, albeit non-significantly. Given that post-intervention performances took place immediately following the final training session, this raises the question as to whether alpha-theta training conducted prior to performance might actually have a detrimental effect.

In the light of the sleep literature, specifically the finding that motor performance in those unaccustomed to sleeping in the day is impaired by a short sleep (Milner et al., 2006), this reversal of prior results is interpreted as evidence that music performance improvements following alpha-theta NFT are observed generally, but not transiently, where the reverse may be observed. Despite this afternoon naps have also been found to optimise procedural motor memory (Backhaus and Junghanns, 2006), which in turn might be expected to benefit music performance - so a logical next step for this research might be too look at how training EEG and performance EEG interrelate between regulated sleep physiology and creative behaviour scenarios. If alpha-theta NFT changes physiological processes underlying creativity more generally, and these changes mediate improvements in music performance, additional measures of music physiology may then be able to reveal commonalities between training and performance, and whether they occur generally. As a consequence, the experiment in Chapter 5 begins to address the question of measuring task-related physiology in music performance in a way that compares with NFT EEG.

4.4.2.2 Stripsody

No between-groups differences were seen, unlike in Chapter 3.

Considering the possibility that post-nap conditions may have impaired performance in alpha-theta participants, as has been seen in a sleep study (Milner et al., 2006), it may be the case that motor slowing impacts negatively on the ability to generate free response motor sequences in primary motor cortex (Bengtsson et al., 2007), or to manifest them in corticomotor projections. Psychometric measures of creativity (the Remote Associates Test (Mednick and Mednick, 1967a) and the Torrance Tests of Creative Thinking (Torrance, 1974)) have recently been shown to increase after hour-long naps containing REM sleep or full-night sleep containing more slow-wave sleep (Cai et al., 2009). This suggests that whilst sleep physiology may affect creative cognition, sleep-impaired motor performance may limit music creation behaviour.

This result may support Brennan's (1982) view that motor creativity is a distinct phenomenon. The analyses of covariance showed that within-session changes in the t/a ratio predicted changes in the 'At on with voice' measure, a musicality scale, and in the current study part of the analogue for creativity. Nonetheless, as one association amongst a possible fourteen, this result has to be interpreted as a possible chance association. Given the degree of caution, this relation provides tentative support for the relationship between NFT dynamics and creativity.

In the SMR group, the within-session SMR ratio was a covariate of pre-training 'Overall musicality' and 'Confidence' measures, plus post-training 'Overall communication.' To a marginal extent, it was a covariate of 'Breathing' and 'Emotional commitment.' The pre-training associations suggest that aspects of performance relate naturally to EEG measures, although this is not reproduced in the post-training task, appears to lack reliability. Post-training covariance was only distinct in the 'Overall communication' measure, with marginal support in the 'Emotional commitment' category. Together these suggest that SMR training prior to performance optimises the presentational aspects of performance, indicating a possible mitigation of stage fright and improvement of engagement. This kind of result would require replication however to rule out the possibility of chance effects.

Arousal in performance was unmeasured in this study, and the use of subjective reports in Egner and Gruzelier (2003) did not show any effect of pre-performance arousal (anxiety) on musical tasks, so the experiment in Chapter 5 introduces the use of EEG monitoring into the methodology to provide a basis for measuring arousal electrophysiologically.

4.4.2.3 Folk Songs

Analyses of post-intervention changes revealed 'Expressive range' showed group differences across the intervention, but without follow-on post-hoc differences. No training/music covariances were observed.

In relation to the novice performance question investigating possible post-SMR technical improvements, this result provides limited support. 'Expressive range' assesses artistic as opposed to technical aspects of performance, and if SMR did interact with artistry, it was not anticipated.

If this association were found to hold in related studies, this would suggest that there may be a role for SMR NFT in optimising arousal prior to performance, as discussed in Section 4.4.2.2. This bears some relation to the proposal that arousal increases benefit performance up to an optimal point, above which impairment becomes observable (Steptoe, 1982). This possible SMR-arousal optimisation was not seen in Chapter 3 or Egner and Gruzelier (2003), although SMR training was positively associated with improvements in 'perceptual sensitivity' and reduced false hits in a Go-NoGo task (Egner and Gruzelier, 2001, 2004b). This might suggest that wider aspects of music performance could benefit from attentional optimisation due to reduced error incidence in task performance. Some further support for this interpretation is seen in Ros et al. (2009) where technical improvements in micro-surgery were found following SMR NFT. The alpha-theta group was found to have decreased in overall ratings of overall vocal competence and this result is interpreted as being possibly due to post-nap motor impairment, as in the prior tasks.

4.4.2.4 Instrumental Improvisation

This task revealed a predictive association between within-session t/a changes and post-training measures of 'Overall Improvisational Competence,' 'Fluency' and 'Communicative Ability'. Given that these measures fell after training, it may have been the case that performers who could most regulate sleep onset may have also been able to manage sleep offset too, and thus mitigate post-sleep impairment effects. If this had happened, Technical, Artistic and Presentational measures may have disclosed parallels with sleep physiology.

4.4.3 Summary of the study

The neurofeedback results showed much greater evidence of targeted EEG change compared to Chapter 3. Alpha-theta training changed within, between and within × between session t/a ratios; SMR training changed within-session training ratios. In alpha-theta analyses it was concluded that the 15-minute length of sessions was fit for the purpose of invoking and possibly sustaining hypnagogic EEG as there was suggestive evidence that SLEEP STAGE I completed its cycle in these data (RESEARCH QUESTION 2).

The music results were quite different from those in Chapter 3, and this was interpreted in terms of the timing of post-intervention performances, which immediately followed final NFT sessions, rendering them open to possible transient after effects of NFT. This difference apparently counteracted the improved scores seen after the previous alpha-theta intervention, and this was interpreted in terms of possible motor impairments following a period of sleep-onset. RESEARCH QUESTION I was challenged by the possibility that in the short-term, hypnagogia could impair spontaneous processing of emotional content expressed as physical performance.

The SMR results were however slightly more promising, with the novice performance task (Folk song) disclosing the only significant ANOVA in measures of 'Expressive range'. This change was not distinguished by post-hoc analysis, and addressed RESEARCH QUESTION 3 (NOVICE PERFORMANCE) to a very limited extent.

Several instances of music score changes co-varying with training changes were observed, although these were isolated amongst measures and did not tie-in with distinct changes to performance scores.

Overall the absence of effects and the difference with the previous cohort was most striking, and the study was interpreted in the light of possible transient effects of NFT.

4.4.3.1 The following study

The changes seen in this study did not replicate those seen previously, and a subsequent study was designed to further explore the effects of post-sleep physiology on music performance, and to investigate the possible relationship between arousal and perceived performance quality hinted at in the current results.

To carry out this type of analysis the next experiment employed task-related EEG measures of music performance using neurofeedback EEG methods, and in so doing sought to begin the examination of electrophysiological mediators of NFT effects on behaviour.

" *... before I play, particularly if I am playing solo, I like to sleep, to sleep almost up to the time of playing, just for half an hour or even ten minutes ... that is pretty near the perfect preparation as far as I am concerned ... while that might interfere with technical things, it's better."*

Derek Bailey[1]

5 Experiment Three

5.1 Introduction

In the neurofeedback literature, it has been demonstrated that time-sensitive task/event-oriented EEG measures are effective at revealing the effects of NFT on performance. This has been demonstrated in processes such as attentional performance (Arns et al., 2009) and learning (Keizer et al., 2010a). In the music studies described in the previous two chapters, a combination of between-groups and correlational evidence has been revealed suggesting that music performance behaviour co-varies with the electrophysiological response to NFT, but the mediation of this possible relationship remains unexplored.

This study introduces a method that would enable direct comparison between electrophysiological measures of NFT and music performance. There are nonetheless practical limitations on the recording of EEG during task performance, particularly tasks involving movement which causes electromyographic (EMG) interference within the EEG signal. Despite this, it has been possible to make EEG measures of task-performance in two ways:

- EEG is recorded during periods of low movement, such as immediately prior to and following shooting e.g. Doppelmayr et al. (2008)
- EEG is recorded in tasks that involve little movement close to the EEG electrodes such as ergometer cycling e.g. (Nybo and Nielsen, 2001; Grego et al., 2004;

[1]During an interview in 1996, free improviser Derek Bailey described the influence of sleep on his performance `http://efi.group.shef.ac.uk/fulltext/mbailin2.html`

Pontifex and Hillman, 2007).

In these studies, researchers have used neuroelectric measures to obtain a profile of spectral and/or event related EEG recorded during task performance.

In the study of music, the EEG recording method has also been applied to piano performance in experiments that investigated co-activation between auditory and motor areas of the brain by measuring event-related EEG (Bangert and Altenmüller, 2003; Ruiz et al., 2009a) and spectral EEG (Ruiz et al., 2009b). In all of the above studies, the EEG recordings were made using procedures similar to those used in neurofeedback, although EEG artefact rejection was conducted with either electro-oculogram (EOG) detection or wavelet enhanced independent component analysis (ICA) methods. In contrast, neurofeedback applications require realtime signal feedback which the aforementioned methods do not currently provide, and so use an e.g. >60–100 microvolt amplitude filter to remove electrical activity in a range that includes average EMG amplitudes (EEGer Neurofeedback Software, 2005). This approach does however also lead to the discarding of some EEG data too.

In relation to the current investigations of creative behaviour, task-related neurophysiological analysis of piano performance has recently been incorporated into the fMRI literature, notably in experiments investigating the neural correlates of improvisation. Bengtsson et al. (2007) documented a higher BOLD signal in improvisation compared to a memorised reproduction of prior improvisation for the right dorsolateral prefrontal cortex (DL-PFC) and pre-supplementary motor area. Limb and Braun (2008) conducted a jazz-blues study comparing improvised accompaniment to memorised accompaniment, finding widespread deactivation in almost all areas of the prefrontal cortex, except for selective activation of the frontal polar cortex (BA 10) and activations in neocortical sensorimotor areas, anterior cingulate cortex ACC and right lateral cerebellar hemisphere — activations during improvisation were matched by deactivations during the control task (playback of pre-learned 12 bar blues). Berkowitz and Ansari (2008) compared improvisation to scored performance, finding relative BOLD increases for both melodic and rhythmic improvisation in premotor areas, posterior ACC, inferior frontal gyrus, left sensorimotor cortex, some parietal areas, and the cerebellum. Berkowitz and Ansari (2010) repeated the previous method, comparing highly trained and novice musicians, and finding relative deactivation of the right temporoparietal junction in experts.

The differences in the above results have been interpreted in the light of the transient hypofrontality hypothesis, that is the fleeting deactivation of selective attention processes in working memory control (Dietrich and Kanso, 2010). It was contended that the design of Limb and Braun's (2008) study alone provided scope for previously memorised (implicitly stored) motor sequences to be triggered spontaneously; with metacognition downplayed, participants could produce more intuitive musical responses. The other fMRI studies engaged attentional and working memory functions, as improvising participants were asked to retain internal representations of music or non-standard keyboards during task execution, and as a result activated higher order control mechanisms that Limb and Braun's (2008) jazz-blues improvisations were shown to deactivate.

Given that hypofrontality during music improvisation could, due to its neocortical associations, also be observed from surface EEG measures, and that creativity related hypofrontality has been observed during the performance of Christensen et al.'s (1960b) 'Alternate uses' creativity task (Fink et al., 2006), an experimental rationale for testing improvisational hypofrontality in an EEG study presents itself. An EEG methodology such as this could in turn be used to draw closer comparisons between electrophysiology in both NFT *and* music performance, potentially illuminating intermediary processes. Accordingly, the objective of the current study was to examine several different types of piano performance, as a preliminary step in identifying where hypofrontality occurs in music creation, as a precursor to designing future optimal performance studies of NFT.

The generated research question is that electrophysiological measures of music creation (improvisation) will differ from a control task (rendition), with improvisations being characterised by greater hypofrontality (measured as frontal alpha synchronisation) — this addresses (Research question 6 (Improvisation as creativity)).

The functional significance of frontal alpha synchronisation during creative tasks is the subject of some debate, a more traditional view maintains that alpha activity represents cortical idling in unused areas during activation of specific neuronal networks implicated. An example of this might be the sensation of 'Muscle memory' in which frontal areas deactivate whilst a specific motor circuit operates between the basal ganglia, the supplementary motor cortex, the motor thalamus and the hippocampus (Dietrich, 2004b). Alternatively, cortical alpha may reflect a top-down, executive process that selectively inhibits stimulus driven attention from disturbing the content of working memory. Pressing (1988) proposed that improvisation incorporated higher cognitive feed-forward editing to "set the design of motor programs" and monitor efferent activity to enhance processing speed and accuracy — such a process would require not just activation in motor circuits, but also in those incorporating cognitive control. This perspective has received some support from a recent EEG study comparing professional to novice dancers Fink et al. (2009). The authors associated dance expertise with greater alpha synchronisation in the parietotemporal cortex during imagined dance improvisation, especially in the right hemisphere. It was surmised that dancers disclose a specialised process whereby stimulus driven attention is inhibited in order to block visual input — this difference was not observed in EEG measures of the imagined performance of a waltz, suggesting that it is specific to creative behaviour. A subsequent fMRI study comparing expert and non-expert musicians also supported this perspective; Berkowitz and Ansari (2010) demonstrated that expert musicians selectively inhibit the right temporoparietal junction in order to inhibit stimulus driven attention. The authors also identified weaker evidence of activations in the ACC as a possible indication that inhibition emanates from an area implicated in cognitive control.

To this end, a secondary improvisation research question was also introduced: improvisation would contain relatively higher parietal inhibition (Pz alpha) than the rendition of a musical score — addressing RESEARCH QUESTION 5 (HYPNAGOGIA & IMPROVISATION EEG).

In addition to testing EEG methods in which NFT effect mediation might be investigated, the current study drew up supplementary research questions relating to RESEARCH QUESTION 1 (CREATIVITY) — raised by the apparently negative after-effect of alpha-theta NFT on spontaneous processing in music performance seen in Chapter 4.

The failed replication was interpreted in the light of the fact that participants in the second experiment carried out post-training tasks immediately following their final NFT session, and this was interpreted as possible evidence that the alpha-theta participants experienced post-nap response-slowing (Milner et al., 2006), which had hindered music performance. In contrast, the research on cognitive performance suggests that napping is beneficial to subsequent cognition (Lovato and Lack, 2010), and so this study set out to assess whether napping might simultaneously impair and enhance motor and cognitive performance respectively, specifically in relation to the hypofrontality framework explored in this thesis.

This trial did not however employ an alpha-theta intervention, but rather sought confirmation of some of the issues in current sleep research regarding post-nap performance as a preliminary step in devising a methodology for comparing transient NFT and sleep-offset effects. This in turn is related to the overall investigative approach of this thesis in addressing the possible mediating role of hypofrontality in both sleep transition and creativity. To this end, the current study was designed to compare frontal inhibitory activity in napping and wakefulness to ascertain whether napping is characterised by hypofrontality, in line with Muzur et al.'s (2002) contention that NREM sleep down-regulates the DLPFC, leading to executive deficiencies that 'deprive dream mentation of logical reasoning capacities.'

The generated research question here is that napping would contain more frontal inhibitory activity than wakeful rest — this relates to RESEARCH QUESTION I (CREATIVITY) and its interest in the relation between hypnagogia and spontaneous emotional processing in the short-term.

The rest type chosen in the current study was watching a 30-minute silent movie: Charlie Chaplin's "A Night Out" (1915). This type of waking activity was selected as a no-nap control as it placed participants in a common condition in which they remained motionless whilst encountering the same 'visual environment' (Smith and Gevins, 2004). The effects of watching silent-movie footage on neural function are not entirely clear however; on the one hand it is thought that movie-watching *is* accompanied by hypofrontality, possibly as a result of reduced self-awareness when the viewer becomes immersed in the narrative (Hasson et al., 2004), but on the other hand some footage, for example advertisements, attenuate frontal alpha EEG activity in line with processing demands raised by the orienting-response or episodic memory encoding (Smith and Gevins, 2004). Overall, it was not entirely clear in advance what the difference between nap and silent movie watching might be when measured in the EEG, although it was nonetheless anticipated that hypofrontality would be in greater evidence during napping due to the difference between sleep and wakefulness.

In terms of motor performance, the discussion of the results in Chapter 4 posited that post-nap motor impairments mitigated against post-alpha-theta musical improvements seen in previous studies (Chapter 3, and Egner and Gruzelier (2003)).

In response, the research question here is that measures of (a) motor activity and consequently (b) musical processing would be reduced following a nap in comparison to a period of wakeful rest — this approach assesses RESEARCH QUESTION 1 (CREATIVITY) as a product of hypnagogia's after-effects during sleep-offset. The identification of post-nap response-slowing in the music performance data was sought in terms of the amount and velocity of piano notes played, which were predicted to be reduced due to transient motor impairment, and the duration of notes which were predicted to be longer immediately following napping.

Despite the possible negative impacts of sleep-offset on motor aspects of music performance, cognitive performance has been found to be improved by daytime napping (Takahashi and Arito, 2000; Brooks and Lack, 2006). This is possibly as a result of the restorative effects of napping on daytime arousal levels, expressed as reduced alpha band EEG (Hayashi et al., 1999a,b). Alternatively post-nap cognitive improvements have been described as the "rapid dissipation of inhibition in the 'wake-active' cells associated with the 'sleep-switch' mechanism" (Lovato and Lack, 2010). Considering that napping may simultaneously impair and enhance motor and cognitive performance respectively, the current experiment included the study of post-nap cognition, particularly in frontal function relating to the investigation of hypofrontality.

The generated research question in response to this is that measures of frontal cognitive function will be enhanced following nap compared to wakeful-rest — addressing RESEARCH QUESTION 1 (CREATIVITY). A cognitive test associated with the function of the prefrontal cortex, specifically the DLPFC (Cabeza and Nyberg, 2000) is the Wisconsin card sorting test (WCST) (Berg, 1948), a measure of "top-down" processing in which behaviour must be controlled not in terms of implicitly stored responses to incoming sensory information, but according to explicitly held intentions (Miller and Cohen, 2001). The test works by providing subjects with cards to sort according to a rule (colour, shape, quantity), however the rule changes periodically and without notice, at which point the participant must infer the new rule, requiring a non stimulus-driven executive response. The electrophysiological correlates of WCST performance include greater alpha power during prior rest, and reduced left-frontal alpha power during task performance (Ciçek and Nalçaci, 2001), as well as increased parietal alpha (Ciçek and Nalçaci, 2001; González-Hernández et al., 2002).

The associated research question generated in response to this is that measures of frontal alpha made during WCST execution will be reduced in comparison to those made after wakeful-rest, and these will correlate with cognitive performance. This addresses RESEARCH QUESTION I (CREATIVITY) in the relation between hypnagogia and the role of frontal hypofunction in spontaneous processing of emotional content.

To address the EEG, motor, creativity, and cognitive research questions introduced above, the current experiment was implemented as two studies. Firstly, a repeated-measures design compared improvisation and rendition tasks for evidence of neural and creative differences. Secondly, a between-groups design compared nap and wakeful rest physiologies, plus their after-effects on motor and creative aspects of music performance, and frontal cognitive processing. The design of the study is detailed in Section 5.2.5.

5.2 Methods

5.2.1 Participants

Twelve healthy pianists participated in the study. All of them had been musically trained and been playing the piano for more than 10 years. Their ages ranged from 20 to 29 years old (mean 24.33 ± 2.90), and 3 of them were male, 9 of them female. Of the twelve, two had prior experience of improvising. One had previously worked as a church organist and had extensive experience of improvising at weddings, funerals and other ceremonies wherein the use of improvisation allowed the player to thematically extend or curtail a piece of music based on the running-time of the ceremony. The other improvising participant had a long-term hobby of practising but not performing jazz improvisation. Both of these individuals were familiar with the melodic template approach to improvisation, that is the 'variation-on-a-theme' style. All the other participants played in the classical tradition, and were unaccustomed to improvising.

5.2.2 Contributors

Felicia Cheng collaborated on the design and application of the experimental protocol, and composed the melodic stimuli used the melody and score tasks (shown in Section 5.2.4). Other contributors were Shama Rahman, Tom Perchard, John Burton, Mat Kaner, Tomas Ros and John Gruzelier who discussed the use of improvisational stimuli and the design of the study. In particular, Tom Perchard, an expert on free improvisation, suggested the use of the book (Stevens, 1985) which contained the 'Scribble' task (see Section 5.2.4), and Shama Rahman described the use of melodic templates in experimental design.

5.2.3 Equipment and Assessments

The study recorded EEG, MIDI piano data (plus subsequent evaluations of their creativity), and cognitive performance. The set-up of EEG and MIDI recording equipment is shown in Figure 5.1, at the end of the music performances, the piano keyboard was replaced with a computer keyboard to measure key press responses in the WCST.

Figure 5.1: Photo of the experimental setup
showing the EEG amplifier connected wirelessly to a laptop, and MIDI keyboard
connected to a computer which also showed the experimental stimuli

5.2.3.1 EEG

EEG measurements were made with a Nexus 4 amplifier connected wirelessly to a laptop running the Biotrace 2009a software (both made by Mind Media B.V.). Recording electrodes were placed at Fz and Pz, referenced to the right and left mastoids respectively, with the ground electrode at Cz. The Alpha (8–11 Hz) EEG band was extracted via online FFT transformations.

The current study measured frontal/parietal inhibition as alpha band EEG recorded at Fz/Pz. There are however several limitations of this approach. Firstly the spatial resolution of the EEG is poor, a single scalp electrode detects potential changes in surface neurons across an area of $10cm^2$, efforts to improve the resolution of the breadth and depth of EEG measures require a larger amount of electrodes (between 25 and 128 for example (Pascual-Marqui, 2002)), from which higher resolution EEG source localisation can be calculated. The second problem associated with using single electrode measures is that of artefact removal; again, methods for detecting and removing non-EEG data components from the recording require the use of multiple electrodes to enable the extraction of characteristic features composing the recorded signal (Delorme and Makeig, 2004).

Considering these points means that the specific association of an Fz/Pz EEG signal to prefrontal/parietal function is limited. Fz recordings are for example likely to be affected by neuronal assemblies extending beyond surface neurons in the Dorsolateral prefrontal cortex (to which Fz is closest) into the premotor and primary motor areas. Whilst the Dorsolateral prefrontal cortex is de-activated during improvisation, motor cortices are both activated and inhibited (Limb and Braun, 2008), which could subsequently affect evidence of prefrontal alpha synchronisation by incorporating synchronisation/desynchronisation of alpha EEG in motor areas (Klimesch et al., 2007). Moreover, the signal-to-noise ratio problem is crudely addressed in the current study; by rejecting datapoints based on raw EEG amplitudes above a fixed level, and band amplitudes outside a standardised dispersion of values. Whilst this means that some noise is rejected, some signal is too, and furthermore only high amplitude noise components are detected. This basic EEG methodology was nevertheless adopted for consistency with the methods used in NFT itself, in which t/a ratio changes at Fz have been observed over 10 sessions (Egner and Gruzelier, 2004a), indicating that it may be possible to detect changes in prefrontal EEG using this methodology.

5.2.3.2 Motor Performance

Piano performances were recorded as MIDI files using a digital piano wired to a laptop running the MidiSwing sequencer software (Version 0.3.5b).

Various MIDI parameters of piano performance were used to probe for evidence of 'response-slowing' following napping (Milner et al., 2006). For each performance, the following measures were extracted: (a) the number of notes played; (b) the mean velocity of notes played; (c) the number of notes played in different duration ranges (units of one beat). These experimental measures were extracted from the midi recordings using the MATLAB midi toolbox (Eerola and Toiviainen, 2004).

5.2.3.3 Creativity

The operational definition of creativity in this experiment was formed according to two criteria:

- The type of neural process being explored, defined in Section 1.5.1 as *'spontaneous processing of emotional content'*.
- A socially validated consensus about the creative value of music arising from the elicited process.

In the current study, and in accordance with Amabile's (1982) assertion that evaluators must not be primed as to how they might define creativity, the experimental measure was simply stated as 'creativity.' This is important for Amabile's (1982) technique as the analysis of social psychology rests on the view that assessors can achieve consensus without having being trained what to think in relation to the experiment. Creative evaluation was measured on a scale of 1–10, again in line with the Amabile's (1982) method of measuring agreement on the extent to which a social group value the content created in the experiment.

The MIDI recordings made during the course of the study were presented in a randomised order to a panel of two music psychology students who were familiar with piano performance, and who were asked to score each piece according to their subjective view of how creative it was. Subsequently the level of agreement between the raters was analysed statistically, and is detailed in Section 5.2.5.1.

5.2.3.4 Cognitive performance

The WCST was administered by computer, with the stimuli being displayed onscreen and responses made using the computer keyboard.

Cognitive performance in relation to frontal brain function was measured with a computerised implementation of the Wisconsin card sort task WCST[1], which provided the 9 measures of performance:

1. Number of Trials
2. Categories Done/Seen
3. Correct Responses
4. Total Errors
5. Perseverative Responses
6. Perseverative Errors
7. Non-Perseverative Errors
8. Unique Errors
9. Trials to complete 1st category

5.2.4 Measurement Procedures

The experimental assessments detailed above were implemented according to procedures outlined here:

Rest The nap condition in this study was a 30-minute 'sleep opportunity' where participants rested in an easy chair with their eyes closed whilst EEG was recorded. In the wakeful-rest (control) condition, participants sat in an easy chair watching a 30-minute silent movie. Before the movie began, participants were told that they

[1]The WCST was performed with the PEBL software: `http://pebl.sourceforge.net/`

would be asked comprehension questions about the movie to ensure they followed to protocol.

All sleep and movie sessions were held at 3pm (±90 minutes), to coincide approximately with the timing of the afternoon 'dip' (Nishida and Walker, 2007). It is worthwhile mentioning that the current study does not study napping using standard polysomnographic methods. In standard sleep research, the use of EEG (C3/A2[2]) is combined with measures of ocular and muscular electrophysiology in the identification of sleep stages and electrical artefacts. Furthermore, the classifying sleep stages is performed according to visual waveform characteristics, as opposed to the spectral approach used here and informed by De Gennaro et al. (2001), who used standard sleep-study electrode placements, in difference from those used here.

Music Tasks In this study, evidence of a distinct neurophysiology associated with spontaneous processing of emotional content was explored for through a music improvisation paradigm. The creative aspects of improvisation, particularly in respect to the experimental observation of music creation is discussed in Section 1.5.3.

The EEG correlates of music creation were explored in this study by comparing three forms of improvisation to a control condition in which participants played a score.

This study maintains the exploration of improvisation from Chapters 3 and 4 as the operational means of realising spontaneous emotional neural activity and behaviour that might translate into socially defined creativity, but it also intensifies the focus on improvisation by further deconstructing it into subtypes that vary according to the degree of constraint that is placed on randomness.

As Simonton (2003) argued, creation originates at random - and improvisation does seem to provide opportunities for random variations, yet his notion of selective retention suggests a heuristic process at work too, and constraint is important in music improvisation as it is used to mediate selection criteria. Since a top-down selection process is limited by working memory capacity (Pinker, 1999), the need to make high-level choices in live improvisation is reduced by some of the heuristic techniques employed by improvisers.

[2]A2 is the right earlobe or mastoid; C3 (or C4) is the cortical lead recommended for standard sleep scoring (Rechtschaffen and Kales, 1968)

The first heuristic is the use of feed-back driven responses. Both Sawyer (2000) and Dietrich (2004b) observe that free-jazz improvisation is made up of a series of musical phrases or motor procedures that are represented sub-cortically and are have been previously acquired in the form of musical skill and practice. In improvisation, or in any complex process that feeds-back motor responses to changing sensory input, the execution of one motor sequence can trigger subsequent procedures reflexively, and with limited recourse to conscious intervention[3]. Dietrich (2004b) illustrates this point in reference to the lightning fast escape manoeuvres of a squirrel trying to get to safety:

> ***``Lacking an overall strategy or plan, the squirrel gets to safety entirely by relying on moment to moment adjustments. Such smooth feedback-driven sensory-motor integration can produce extremely complex movement patterns that can serve an overall and/or higher goal (safety), yet requires no more than the reaction to immediately preceding input.'' — (Dietrich, 2004b)***

In the music improvisation scenario, the limitation on the motor response is not driven by the same requirements. Rather than an escape manoeuvre, where the only limit on a response is how safe it is, most improvisation contains restrictions such as tempo, meter, timbre, tone and pitch — one notable exception to this rule is free 'non-idiomatic' improvisation, although even that is limited by the sonic capabilities of the instrument being played.

In any case, the initiation of musical responses is, by virtue of human consciousness, also available to a second heuristic for response selection: 'feed-forward' editing (Pressing, 1988). The counting of bars, the changing of mode and the conscious moderation of dynamics are examples of how explicit meta-representations enable forward planning in realtime during music improvisation. Despite this, it is not necessary to control all motor procedures via higher-order functions, and given that the reflexive induction of sub-cortical motor sequences provides faster responses in realtime (Dietrich, 2004b), it is plausible that improvisation also diminishes higher-order cognitive functions, and 'transient hypofrontality' occurs (Dietrich, 2003).

[3]The sensation of sequences of motor procedures forming chains with minimal conscious intervention is often referred to by musicians as 'muscle memory'

Considering that the role of randomness in the spontaneous processing of emotional content might be mediated by the scope for musical variation, the current study explores the role of constraint on on improvisation by introducing tasks that gradually reduce the potential for randomness. The final task is a control performance that nominally gives no scope for randomness. The reason the tasks were given in an increasing order of constraint was an attempt to design a study that avoided the potential 'melodic anchoring' effect (Bharucha, 1984). That is, that if the tasks had begun with highly limited scope for variation, participants may have found it harder to move beyond that initial reference point. Admittedly, performing a largely unconstrained task to begin could also influence subsequent activity by initiating a musical reference or anchor, but the design of this order (also shown in Section 5.2.5) was an attempt to set a standard in each task that excluded prior activity.

Task 1 — Scribble This task is taken from the first part of a task from the book Search & Reflect (Stevens, 1985). The exercise was originally envisaged as a form of practice in which musicians were encouraged to start by simply playing in a technically undemanding way referred to as 'scribbling,' without self-evaluation for a period, before gradually increasing concentration and enabling a phrase to be picked out and developed. In this study only the scribble part of the task was used, and lasted for 2 minutes.

The instruction given for scribble task is as follows:

> ***``Take your instrument and scribble on it – that is, let anything come out, don't think about the sound you are producing, just keep a rapid activity going. You should be detached from your activity in the sense that your playing is undirected – you are not trying to play a tune or anything specific, you are merely playing. You could be looking out of the window or at a picture whilst keeping the rapid activity going. Don't worry about being musical – there is nothing that you can do on a musical instrument, which does not in some way involve the rudiments of music.'' — Stevens (1985)***

After two minutes, the EEG recording automatically stopped, and the midi recording was stopped by the experimenter before preparing the next task.

Task 2 — Graphic score In this task, a short video with no sound was used as a graphic score for improvising to. The video animates Wehinger's (1970) graphic score for Ligeti's Artikulation with a moving line indicating the current point of the score. Figure 5.2 shows the first page of the score, and participants were asked to play for 2 minutes using the score as a guide, and with the following instructions:

> Above is the first page of a scrolling graphic score you are about to see on screen.
>
> - Pitch is mapped to vertical position on the score
> - Time follows the scrolling bar across the screen

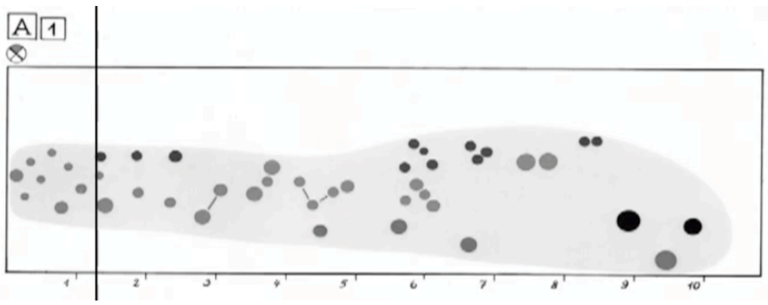


Figure 5.2: Wehinger's (1970) graphic score for Georgy Ligeti's Artikulation (1958) In the animated version the vertical line moves from left to right across the image indicating the current point of play

Task 3 — Melody In this task, a short 2-bar melodic-template written by Felicia Cheng was used as the basis for a melodic variation. The score is shown in Figure 5.3, and participants were asked to play the phrase through once, and then improvise on the theme until asked to stop (after 2 minutes).

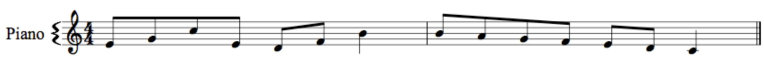



Figure 5.3: Melodic-template for a 2-minute improvisation.

Task 4 — Score This task was employed as a non-improvisation control condition for comparing performance from score to spontaneous improvisation. The score was also composed by Felicia Cheng, and participants were asked to repeat the same phrase for 2 minutes (approximately eight times), see Figure 5.4.

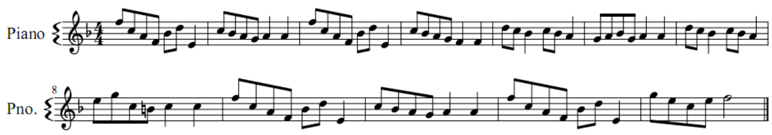



Figure 5.4: Score used as a non-improvisational control task which was repeated for two minutes.

Wisconsin Card Sort The Wisconsin card sort test of frontal lobe function was administered with the PEBL software (v0.11) (Mueller, 2010). In the task, the participant has the objective of responding to unannounced changes in the rules determining how their single card should be matched with one of four other cards on the basis of colour, shape, or quantity (see 5.5).

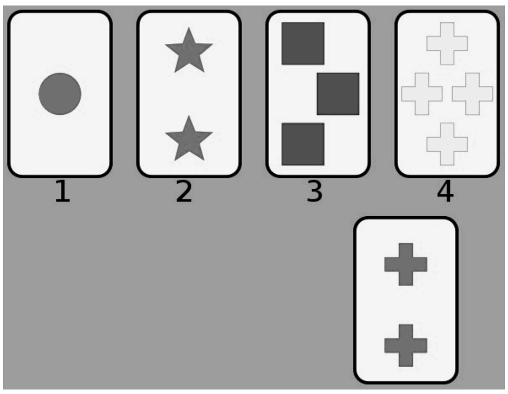


Figure 5.5: Computerised display of the Wisconsin card sort task.

5.2.5 Experimental Design

All participants attended twice as part of a crossover design in which two groups of n=6 completed sleep-then-movie or movie-then-sleep conditions in a counterbalanced order. The order in which they completed the experiment was assigned randomly as they were recruited. The flow of participants through the study is shown in Figure 5.6. In order to reduce the effect of learning and to avoid the effect of the first session on the second session, the two sessions were separated by a 7–8 day interval. In each session, participants performed the same music and cognitive performance tasks after the experimental condition.

Immediately following the nap/movie intervention, participants performed 4 midi piano recordings with the level of constraint on musical response gradually increased: first was a free improvisation ('scribble'); second a graphic score; third a melodic-template ('melody'); finally participants were asked to render a score. Subsequently they performed the Wisconsin card sort task.

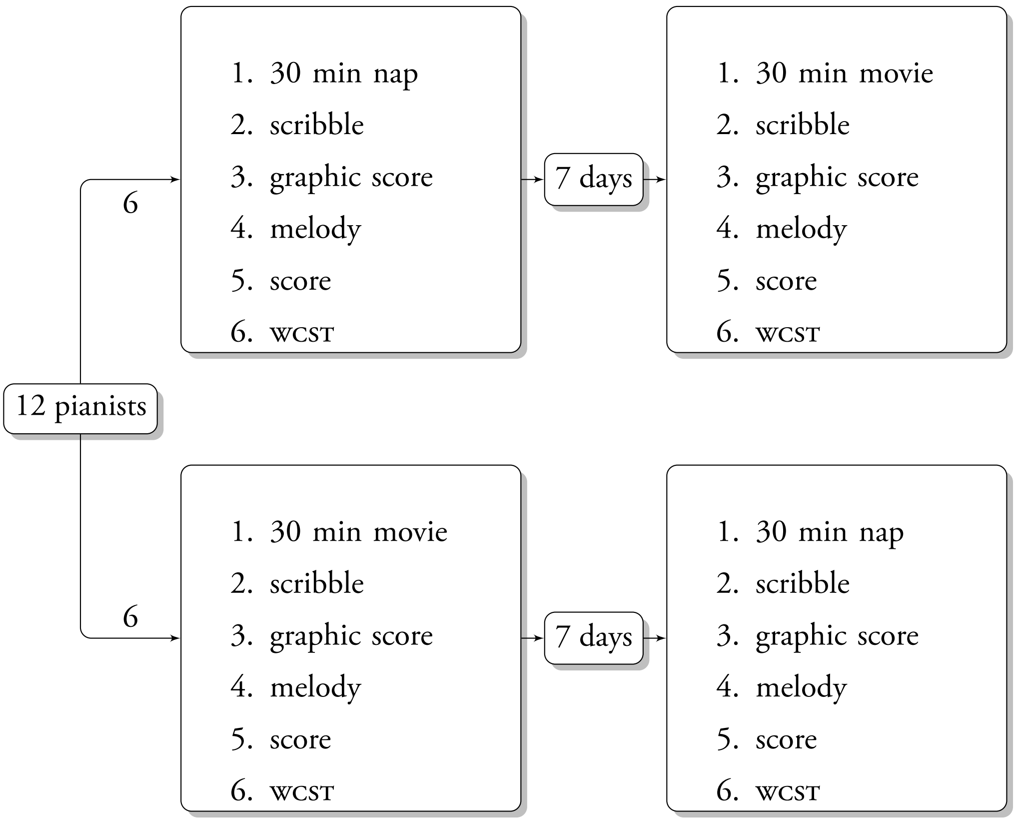


Figure 5.6: Flow of participants through the balanced-crossover design of the study

5.2.5.1 Data analysis

The EEG data were visually screened for recording accuracy, and sampled data were processed for removal of electrical interference (e.g. eye movement) using the Biotrace software. Data were then exported to MATLAB for further post-processing and the removal of datapoints >3STD than the recording mean.

Measures of the amount, velocity and duration of MIDI data were extracted with the MATLAB midi toolbox (Eerola and Toiviainen, 2004).

The WCST measures were extracted with the PEBL software.

The music ratings of the two judges were screened for ratings consistency with the Intraclass Correlation Coefficient (ICC) statistic ('C-1' type, (Wong, 1981)). If the ICC was higher than .5 ratings were considered suitable for further analysis as rater averaged values (Thompson and Williamon, 2003).

The between-tasks comparisons of alpha activity were performed repeated measures ANOVAS with four levels (musical tasks 1–4) with two-tailed paired samples t-tests, according to *a priori* predictions that alpha synchronisation in improvised performance would be different from that of score rendition. The data were compiled by collapsing EEG measures across the two sessions that each participant attended.

The between-conditions analyses of music ratings, EEG, and WCST were performed with 2 × 2 (rest-order × time) Linear Mixed Mode ANOVAS applicable for the crossover design, with session as a repeated measure; session, sequence and condition as fixed factors; and participant ID entered as both a random factor and a subject identification.

Comparisons of changes during a 30-minute period of nap/wakeful-rest were performed by separating each session into 10 × 3-minute blocks, and contrasting the mean alpha amplitude from each block between conditions.

5.3 Research questions

5.3.1 Between-tasks comparisons

EEG measures of improvisation will show greater inhibition compared to score rendition. This addresses RESEARCH QUESTION 6 (IMPROVISATION AS CREATIVITY) introduced in Section 2.2.1.1.

Frontal and parietal neural processes in music improvisation are different from those of musical score rendition: during improvisation, frontal/parietal inhibition is greater than in score rendition.

5.3.2 Between-condition comparisons

Alpha synchronisation and hypofrontality This addresses RESEARCH QUESTION 1 (CREATIVITY) as it explores sleep for evidence of hypofrontality in the form of alpha synchronisation.

It is explored whether a period of nap will contain more alpha synchronisation at Fz and Pz than in a comparative period of wakeful rest (watching a silent movie). It is additionally explored whether during a sleep-offset period after napping/resting, this difference will be reversed, with less inhibitory EEG activity after nap compared to wakeful rest.

According to Dietrich's (2003) hypofrontality hypothesis, the nap condition of this experiment would be characterised by greater alpha amplitude measures than the movie condition. Measures of parietal alpha were predicted to be in accordance with those of Fz, and furthermore reflect trajectories observed in Pz alpha-theta neurofeedback training.

Music performance will modulate as a function of prior rest

Response slowing This addresses RESEARCH QUESTION 1 (CREATIVITY) and considers the short-term after-effects of hypnagogia on the motor response in spontaneous performance and cognitive performance in tasks examining frontal function.

MIDI values (notes played, note velocity and note duration), would differ following different types of prior rest, with nap (in relation to wakeful rest) impacting negatively as a result of transient motor impairment following napping: reducing the number and velocity of notes played, and lengthening note durations.

Creativity Evidence of motor impairments would additionally be reflected in reduced creativity measures following nap compared to rest.

Cognitive performance will modulate as a function of prior rest In line with the question as to whether there will be less frontal inhibition following napping — Research question 1 (Creativity) — it is questioned whether measures of frontal lobe cognitive performance will be enhanced following nap compared to rest.

5.4 Results

5.4.1 Data screening

5.4.1.1 Inter Rater Consistency

The panel ratings were assessed for inter rater consistency, with a mean level of consistency (Intraclass Correlation Coefficient 'C-1' type (Wong, 1981)) of r(23)=0.74, p<0.01, and ratings were subsequently averaged for further analysis.

5.4.2 Between-tasks study

These comparisons were conducted to compare EEG differences between different forms of improvisation against a scored control condition in relation to Research question 5 (Hypnagogia and improvisation) that relatively more frontal/parietal alpha synchronisation would be in evidence during improvised performance; it was not predicted in advance which form of improvisation would contain the most alpha synchronisation. Task data were collapsed across 2 repeated measures to provide an n of 12 when averaged across sessions.

Table 5.1 documents the means and standard deviations of all the EEG measures in this analysis.

A repeated measures one-way ANOVA (with 4 levels, music tasks 1–4) revealed a near significant difference in Fz alpha measures between tasks (F(3, 33)=2.813, p=0.054), and subsequent planned contrasts (see Table 5.2) revealed that the melody task contained relatively more hypofrontality than performing a score, indicating that electrophysiological processes in these performances differed. Further comparisons between the different improvisation types revealed a difference in Fz alpha amplitudes between the melody and graphic score tasks, with melody being relatively greater,

Table 5.1: Descriptive statistics of EEG amplitudes in between-tasks comparisons

Measure	Task	n	Mean ± STD
Fz alpha	Scribble	12	10.03 ± 3.13
	Graphic	12	9.53 ± 2.09
	Melody	12	10.68 ± 1.88
	Score	12	9.21 ± 1.55
Pz alpha	Scribble	12	8.81 ± 1.94
	Graphic	12	9.27 ± 2.01
	Melody	12	8.89 ± 1.13
	Score	12	7.63 ± 1.34

possibly indicating that the graphic score was reliant on the activation of frontal functional anatomy due to online transformations of spatial stimuli to musical responses. Table 5.2 also includes effect size and corresponding statistical power calculations, demonstrating that Melody and Score performances exhibited a strong difference in frontal and parietal alpha synchronisation measures. This suggests that the sample size was adequate to detect these differences, and invites follow-on investigation of a hypothesis that neuroelectric measures of melodic improvisation are different from those of melody rendition.

A repeated measure ANOVA applied to Pz alpha measures showed a clearer distinction between tasks ($F(3, 33)=4.271$, $p=0.01$), and planned contrasts showed that both the melody and graphic score tasks disclosed relatively greater alpha amplitudes than score rendition, plus the scribble task disclosed higher alpha synchronisation that was marginally significant.

Table 5.2: EEG amplitude contrasts

Fz alpha	Mean	± STD	t	df	p	d†	Power‡
Scribble – Score	1.00	3.20	0.78	11	0.45	0.33	0.18
Graphic – Score	0.40	1.15	0.88	11	0.40	0.17	0.08
*Melody – Score**	1.28	1.39	4.07	11	<0.01	0.85	0.76
Melody – Scribble	1.14	1.06	0.94	11	0.12	0.25	0.12
*Melody – Graphic**	1.10	1.31	3.05	11	0.01	0.58	0.44
Scribble – Graphic	1.11	3.34	0.42	11	0.68	0.19	0.09
Pz alpha	Mean	± STD	t	df	p	d	Power
Scribble – Score	0.71	1.76	2.14	11	0.06	0.71	0.61
*Graphic – Score**	1.95	2.23	3.31	11	0.01	0.96	0.86
*Melody – Score**	1.12	1.70	3.29	11	0.01	1.02	0.89
Melody – Scribble	0.23	1.73	0.37	11	0.72	0.05	0.05
Melody – Graphic	0.48	1.26	-0.85	11	0.41	-0.23	0.11
Scribble – Graphic	1.13	2.50	0.72	11	0.49	-0.23	0.11

*Difference is significant at the 0.05 level
† Cohen's (1988) d measure of effect size
‡ Cohen's (1988) measure of statistical power

5.4.3 Between-conditions study

5.4.3.1 Rest EEG

The nap and movie conditions were compared both as a series of 3-minute blocks, and as single 30-minute blocks.

Fz alpha 2 × 2 (rest-order × time) Linear Mixed Mode ANOVAs revealed that the first, second and fifth blocks of time (1–3, 4–6 and 13–15 minutes) showed significant differences between rest conditions (block 1: $F(1, 10)=19.695$, $p=<0.01$; block 2: $F(1, 10)=7.899$, $p=0.02$; block 5: $F(1, 10)=5.241$, $p=0.045$). Figure 5.7 shows the differences with significantly different blocks highlighted.

ANOVA on mean alpha amplitudes of entire 30-minute rest periods disclosed a differential effect of rest-type ($F(1, 10)=6.795$, $p=0.03$), and these differences are detailed in Table 5.3.

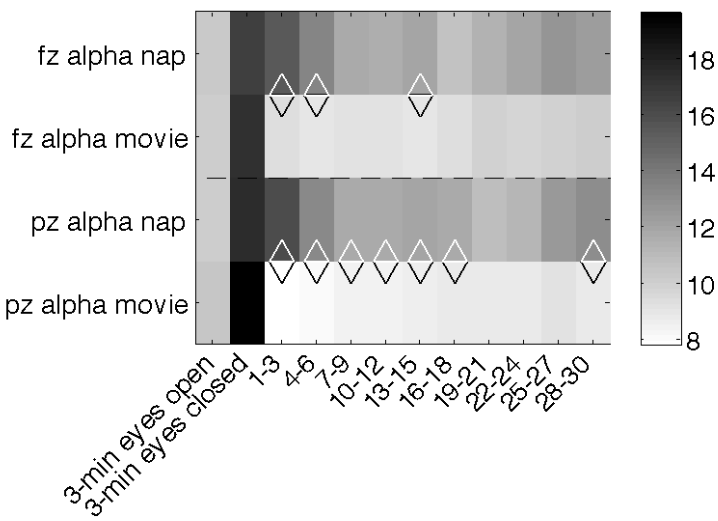


Figure 5.7: Comparison of Fz and Pz alpha EEG amplitude during nap and movie conditions
(Diamonds mark significant between-condition differences.)

Pz alpha 2 × 2 (rest-order × time) Linear Mixed Mode ANOVAs revealed that the first, second, third, fourth, fifth, sixth and tenth blocks of time showed significant differences between rest conditions (block 1: F(1, 10)=27.802, p<01; block 2: F(1, 10)=8.027, p=0.02; block 3: F(1, 10)=6.048, p=0.03; block 4: F(1, 10)=7.191, p=0.02; block 5: F(1, 10)=5.638, p=0.04; block 6: F(1, 10)=6.468, p=0.03; block 10: F(1, 10)=6.587, p=0.03).

ANOVA on mean alpha amplitudes of entire 30-minute rest periods disclosed a differential effect of rest-type (F(1, 10)=6.795, p=0.03), demonstrating an overall difference in parietal alpha EEG between conditions (see Table 5.3).

Table 5.3: Descriptive statistics for alpha amplitude during nap and movie conditions

Electrode	Nap	Movie
Fz	14.11 ± 4.74	10.19 ± 2.86
Pz	14.30 ± 4.96	9.26 ± 2.71

Overall, these results demonstrate that in the nap condition, alpha was initially significantly higher than in the movie condition. This possibly results from visuomotor suppression activity in earlier stages (Paskewitz and Orne, 1973), but also may arise from a later progression of SLEEP STAGE I to II when alpha EEG begins to increase (De Gennaro et al., 2001) — this is supportive of the view that hypnagogic EEG was observed.

5.4.3.2 Music performance

Response slowing Table 5.4 contains the descriptive statistics of the number of notes played in each task by each condition, plus the velocity of notes played, there were the first two indices of 'response-slowing' (Milner et al., 2006) measured in this study. In relation to RESEARCH QUESTION I (CREATIVITY) asking if these measures would be lower in the nap condition compared to movie, the predicted direction of difference was in evidence, however no significant differences were observed.

Further evidence of response slowing was investigated in the form of note durations (see Figure 5.8). According to RESEARCH QUESTION I (CREATIVITY), participants would play longer notes following the nap as opposed to movie condition, and as with the number of notes and note velocities, the differences observed were in line with predictions; a greater proportion of short notes was played in the movie condition, however the only reliable difference was in the scribble task, with significantly more

Table 5.4: Descriptive statistics for the response slowing measures extracted from MIDI data

			NAP	MOVIE
Measure	Task	n	Mean ± STD	Mean ± STD
Notes Played	Scribble	12	599.27 ± 212.16	783.09 ± 540.83
	Graphic	12	751.70 ± 268.93	846.50 ± 471.98
	Melody	12	472.00 ± 201.47	571.70 ± 257.01
Note Velocity	Scribble	12	51.03 ± 12.75	58.20 ± 12.95
	Graphic	12	64.56 ± 12.43	67.07 ± 16.81
	Melody	12	53.69 ± 6.30	54.63 ± 10.41

notes lasting approximately 0.7 of a beat played post-nap (F(1, 10)=5.04, p=0.05). In the melody task a trend towards a significant difference at the alpha=0.10 level was observed in notes lasting $^1/_4$ of a beat (F(1,10)=3.91, p=0.078), with post-movie performances containing a greater proportion of short notes.

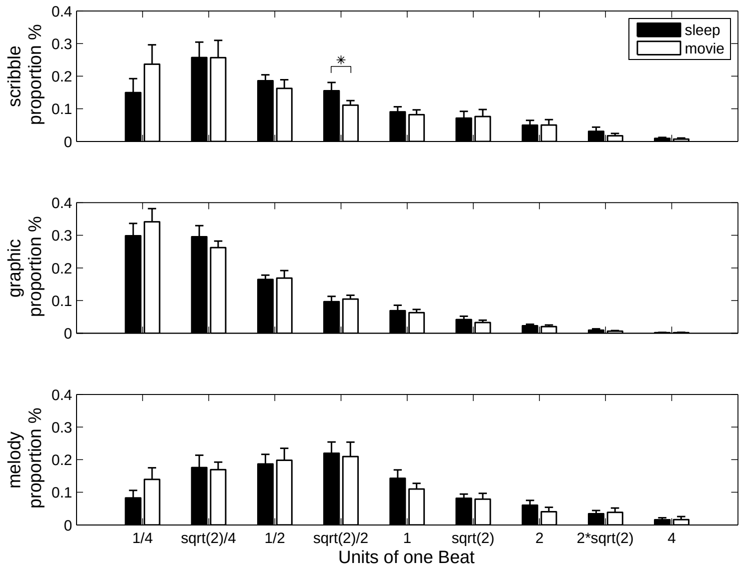


Figure 5.8: Note duration distributions in different tasks
(*. Significant between-condition difference)

Overall, the MIDI data provide very limited support for the response-slowing research question — RESEARCH QUESTION 1 (CREATIVITY) — with group differences being negligible and the sole significant result possibly arising by chance.

Creativity evaluations Table 5.5 contains the means and standard deviations for the musical creativity evaluations in the three improvisational tasks. It is noteworthy that the mean scores are rather low in relation to the 1–10 scale used, possibly indicating a floor effect was present in evaluations.

Table 5.5: Descriptive statistics of the creativity evaluation assessments (points out of 10).

		NAP	MOVIE
Task	n	Mean ± STD	Mean ± STD
Scribble	12	2.58 ± 1.08	2.66 ± 1.23
Graphic	12	2.36 ± 1.00	2.77 ± 1.66
Melody	12	3.08 ± 1.55	3.18 ± 1.76

In relation to RESEARCH QUESTION 1 (CREATIVITY) — whether ratings of music performance would modulate as a function of rest-type — Linear Mixed Mode ANOVAS revealed that there was no between-condition difference in measures of creativity in any of the tasks. As with the response slowing question, the difference was in the predicted direction, with all mean creativity scores being lower post-nap than post-rest, however the differences were not significant.

Alpha synchronisation Table 5.6 contains the descriptive statistics for alpha EEG measurements at the Fz/Pz electrodes. The research question — RESEARCH QUESTION 2 (EEG TRAINING) — was that alpha EEG would be significantly lower during motor task related recordings following nap compared to wakeful rest in line with Hayashi et al. (1999a,b) who have provided suggestive evidence that afternoon napping maintains daytime arousal levels.

Linear mixed mode ANOVAS on task related alpha synchronisation disclosed no significant differences between conditions on the frontal or parietal measures. These data do not support RESEARCH QUESTION 2 (EEG) as to whether post-nap alpha would be significantly reduced relative to post-wakeful-rest, although it is noted that the differences in means are in line with the idea that frontal activation would increase following a short daytime sleep.

Table 5.6: Descriptive statistics of the Fz/Pz alpha amplitudes in between-condition comparisons.

		NAP	MOVIE
Task	n	Mean ± STD	Mean ± STD
Fz Scribble	12	8.97 ± 2.71	11.68 ± 3.24
Pz	12	8.44 ± 3.34	8.68 ± 2.07
Fz Graphic	12	10.00 ± 2.66	10.05 ± 2.61
Pz	12	8.85 ± 2.30	9.06 ± 2.43
Fz Melody	12	10.11 ± 2.72	10.96 ± 2.24
Pz	12	8.50 ± 2.49	8.70 ± 1.36
Fz Score	12	9.15 ± 1.81	10.55 ± 2.01
Pz	12	7.36 ± 2.11	7.78 ± 1.70

5.4.3.3 Cognitive performance

Table 5.7 contains the descriptive statistics for this task in the experiment. The differences between the two conditions are in line with RESEARCH QUESTION 1 (CREATIVITY) as to whether frontal function would be changed following nap as opposed to wakeful-rest, however linear mixed mode ANOVAS revealed no significant differences in task performance between the two conditions. Only measures of Non-perseverative errors approached confirmation of the approach, with a trend towards significance at alpha=0.10 ($F(1,10)=3.75$, $p=0.08$). Perseverative responses are those that would have been correct under the previous rule, so non-perseverative errors are those in which the change in sorting response was unsuccessful and may reflect fluctuations in frontal function (Barceló and Knight, 2002).

Overall the current data do not support the research question as whether napping would improve subsequent measures of frontal function.

The secondary question was that frontal alpha amplitudes measured during the WCST would modulate as a function of prior rest-condition — RESEARCH QUESTION 2 (EEG). Following nap and during WCST, Fz alpha was lower than following movie-watching, (nap: mean=7.96 ± 3.81; movie: mean=9.82 ± 6.88), however the predicted difference in means was not reflected in a significant F statistic.

A single (positive) Pearson correlation between Fz alpha and perseverative re-

Table 5.7: Wisconsin Card Sort Descriptive Statistics

(Percentages)

		NAP	MOVIE
Measure	n	Mean ± STD	Mean ± STD
Categories done/seen	12	86.30 ± 6.18	88.07 ± 8.30
Number of trials	12	99.54 ± 1.58	98.05 ± 4.22
Correct Responses	12	77.66 ± 4.76	74.49 ± 13.13
Total errors	12	22.33 ± 4.76	25.50 ± 13.13
Perseverative responses	12	33.08 ± 5.82	35.26 ± 8.75
Perseverative errors	12	14.36 ± 4.02	15.68 ± 9.39
Non perseverative errors	12	7.96 ± 3.81	9.82 ± 6.88
Unique errors	12	2.48 ± 3.78	1.69 ± 3.52
Trials to complete 1st category	12	16.50 ± 6.40	13.67 ± 6.23

sponses was found in the nap condition (r=0.68, p=0.03), which indicates that post-nap alpha reductions co-varied with improvements in frontal function, although this relationship was not also observed in further measures of perseverative errors, which would have added validity, and may be a chance finding.

5.4.4 Results summary

Between-tasks comparisons indicated that the 'Melodic template' approach was most appropriate for eliciting spontaneous processing of emotional content as evidence of frontal alpha (expressed as hypofrontality) and parietal alpha were highest.

Between conditions comparisons showed that sleep EEG showed the hallmarks of Fz alpha synchronisation (hypofrontality) in relation to wakeful control at 13-15 minutes. Pz measures showed higher alpha up to 18 minutes, and then from 28–30 minutes.

Post-sleep response-slowing evidence was very limited to some longer note durations in scribble following sleep and melody cued improvisation containing more short notes following wakefulness.

Creativity differences in post-sleep/rest were not seen at all, and scores indicated a floor effect. Melodic template improvisation received the highest mean scores of 3.08 after sleep and 3.18 after rest.

Evidence for post-sleep frontal-cognitive improvements and alpha reduction were limited to a single correlation positively linking alpha to perseverative responses.

This study failed to support the first aim of the research: to link evidence of spontaneous processing of emotional content — expressed as hypofrontality in this study – to social perception of creative worth. Frustratingly, differences across all measures, including the brain/social measures of creativity, were in the direction anticipated by the research questions, but only a very small amount were distinctively so.

5.5 Discussion

Demographic considerations In their discussion of the difference in neural mechanisms observed in a study of improvisation in musicians from a non-improvising European classical tradition (Bengtsson et al., 2007) and their own study of jazz improvisers, Limb and Braun (2008) attributed these differences in part to demographics. It was pointed out that the jazz musicians had finely developed improvisational skills, whereas Creech et al. (2008) observed that musicians in the European tradition regarded the ability to improvise as the least important musical skill.

In relation to this, the novelty of the music tasks in this study was likely to have been greater for the classical musician participants in the current study, and that sense of novelty may have undermined the attempt of this study to elicit spontaneous processing of emotional content.

Whilst Limb and Braun (2008) attributed observed deactivation in the Dorsolateral prefrontal cortex (DLPFC) in jazz musicians to transient hypofrontality (Dietrich, 2003) – and this can also be interpreted as spontaneous reflexiveness arising from improvisational skill (Dietrich, 2004b) – the processing of novel information activates process in the DLPFC (Kishiyama et al., 2009).

A comment made by one of the participants has some relevance to the discussion of task novelty and creative performance. During the post-experiment debrief, where it was explained that spontaneous processing of emotional content was being explored, the participant who has been a church organist commented that the 'melodic template' task (see Section 5.2.4) was the one in which he'd " … felt most able to play creatively." This observation is interesting in the light of Dietrich's (2004b) and Limb and Braun's (2008) that prior improvisation skill is a precondition for a kind of spontaneous processing being explored, furthermore the data bore this out too, with this task receiving the highest creativity scores in the audience response.

Between tasks comparisons The between-tasks comparisons revealed some supporting evidence for the transient hypofrontality hypothesis (Dietrich, 2003). It was found that alpha synchronisation at Fz was higher during the melody task than during rendition of both a standard score and a graphic score.

Alpha synchronisation during the 'scribble' task was not significantly different from any of the above. The reasons for these differences and similarities might be attributable to the design of the experiment: the melody task possibly provided the most scope for the pianists to use top-down inhibition of prefrontal cortex and associated executive functions; it began with the playing of a 2-bar musical phrase, in which the tonal constraints imposed on the rest of the task were set, however beyond this point the pianists could activate internalised pitch sequences stored at a lower level of processing (Dietrich, 2004a). The graphic score and score tasks on the other hand required the pianists to monitor their performance and to map sensory information into motor responses, requiring attentional control and top-down activation and monitoring of motor responses during the task. The scribble task ostensibly provided scope for hypofrontality by freeing the pianists of all idiomatic constraints (Stevens, 1985), however eight of the twelve participants performed tonal music, which suggests they combined some selective behaviour in deciding how to interpret the task and establishing a template, with some reflexive playing as in the template task.

Taken together the performance task results reply to Research question 6 (Improvisation as creativity) suggesting that in a largely classically trained population, the melodic template means of disclosing spontaneous processing of emotional content is most appropriate and most closely uses their reflexive skills.

The measures of Fz alpha amplitude suggest that the melodically cued improvisation contains more hypofrontality, and that this is a neural characteristic of music creation behaviour. This finding complements the fMRI results of Limb and Braun (2008), which reported deactivation of the DLPFC during jazz-blues free accompaniment in comparison to rendition of a pre-learned piano solo.

Although Research question 1 (Creativity) is mainly examined in relation to hypofrontality, parietal (Pz) alpha synchronisation — recorded in line with the alpha-theta NFT method — was also explored in relation to two recent studies documenting parietal inhibitory activity in creative behaviour amongst performance artists (Fink et al., 2009; Berkowitz and Ansari, 2010).

As with Fz measures, Pz results showed that the melody task featured greater alpha synchronisation in relation to the score task, providing a preliminary answer to RESEARCH QUESTION 5 HYPNAGOGIA AND IMPROVISATION which considers the similarity between the two states.

The improvisation/score Pz difference was additionally observed during rendition of the graphic score. Considering that the melody task featured increased alpha at both electrodes, this invites the question "where is inhibition originating?" In the introduction to the study two candidate sources of cortical alpha were considered: (a) an idling process in some cortical areas to optimise energy demands when underlying neuronal populations are more active (Pfurtscheller and Lopes da Silva, 1999); (b) intracortical inhibition in which irrelevant or potentially interfering parts of neural networks are closed off (Klimesch, 1996). In the case of the melody task, the cortical idling explanation may apply, whereby motor sequences stored at a lower level of processing are respondent, for example in the so-called 'muscle memory' phenomenon. Again however, this is where the limitations of the current study begin to show, as the lack of spatial coverage precludes the investigation of cortical and sub-cortical activity beyond the two sites showing inhibition.

The fact that the graphic score task included significantly more parietal but not frontal alpha might be interpreted as a form of parietal inhibition when stimulus driven attention is suppressed in order to retain feed-forward motor sequences in working memory Pressing (1988). Despite this, the graphic score task would be expected to activate visual processing pathways in parietal areas as the score was presented as a computer screen animation. This in turn suggests that parietal inhibition of the type implicated in Fink et al. (2009); Berkowitz and Ansari (2010) would not be present in the current study. A possible resolution to this discrepancy may lie in the finding of Gevins et al. (1997) who reported practice dependent increases of posterior alpha power during working memory tasks; in this case habituation to the graphic score may underlie alpha amplitude increases relative to those in the score task. A limitation of the current study here is that whilst the graphic score task featured evidence of parietal inhibition, this preliminary analysis did not include a measure of communication between neurons at Fz and Pz, which could have tested for evidence that frontal neurons regulate posterior ones as part of a network. Sauseng et al. (2005a,b) has demonstrated that frontal neurons modulate the excitability of the parietal cortex via alpha phase coupling during both working memory and attention tasks, and Berkowitz and Ansari (2010) suggested that the ACC may down-regulate the primary visual areas during music improvisation, so further investigation is required if the source of inhibition is to be identified.

Overall the Pz results provided some support for the question that parietal brain areas are inhibited during creative behaviour, although the two improvisation studies compared here both implicated right-hemisphere inhibition to a greater extent, and the current study lacked analysis of lateralised activity.

Turning now to the creativity evaluations, the analysis did not reveal any significant differences between the perceived creativity of improvisations, and the mean scores were found to be close to the floor level, (the maximum creativity rating was 6). Amabile (1982) stresses that evaluations should be given relative to the sample, in which case the most creative piece(s) in the experiment should be awarded scores approaching the ceiling level, however in practice this would require the judgement of music performances to be conducted according to a ranking exercise. Despite this, reliable differences would have emerged if they existed, and so whilst Research question 6 (Improvisation as creativity) was addressed in terms of physiology, it was not validated against social perception and this undermines the aim of mapping personal processes to social ones.

Between conditions comparisons The second element of this study was to explore sleep-offset effects on music performance, in part to ascertain whether post-nap response-slowing might impair impact subsequent behavioural and perceived measures of music performance.

This addressed Research question 1 (Creativity) in terms of the immediate after-effects of hypnagogia, and was conducted in relation to the findings of Chapter 4, in which transient effects of alpha-theta physiology were interpreted as being detrimental of performance. The current study was then conducted specifically to determine whether post-nap physiology may affect performance substantively.

The comparison between nap and wakeful rest did confirm that EEG measures of frontal alpha were significantly different, both at specific points in the recording (1–3 and 22–24 minutes) and in whole recording contrasts. Whilst the early difference may have been attributable to visuomotor factors which enhance alpha-theta as a function of the eye lenses adjusting to darkness (Paskewitz and Orne, 1973), the difference at 22–24 minutes is possibly reflective of a progression beyond SLEEP STAGE I (De Gennaro et al., 2001), and furthermore provides some evidence of non-visuomotor hypofrontality during a 30-minute period of sleep opportunity, which is also consistent with Muzur et al.'s (2002) contention that hypofrontality is a feature of NREM sleep.

Despite the generalised indications of sleep related hypofrontality in the sample, post-napping measures did not confirm the response-slowing hypothesis in the vast majority of motor measures drawn. The number and velocity of notes played following napping were, on average, lower than after wakeful rest, whilst the distributions of note durations included less shorter notes, and in the scribble task significantly more notes lasting approximately 70% of a beat. Overall however no clear difference emerged, and the same was true of the creativity comparisons: lower means following nap, but not substantively so. The lack of clear separation between conditions may possibly be due to one of two factors: the amount of sleep, and the effect of movie-watching. As stated previously, the current study utilised non-standard analysis of napping, and did not measure the amount or staging of sleep for participants, the correlational analysis went some way towards addressing individual differences in napping, and the negative relationship between nap Fz alpha and note velocities in the scribble and melodic-template tasks indicates that an analysis based more closely on sleep parameters might come closer to disclosing post-nap response slowing. The effect of movie watching on the participants could also be considered as a possible factor confounding hypofrontality between conditions, since deactivation of the prefrontal cortex has been associated with reduced self-awareness during movie watching in an fMRI study (Hasson et al., 2004), although in this study participants were made aware they would be given a comprehension test after the movie, and so it is likely they would have maintained some degree of self-monitoring, and thus prefrontal activation, in order to monitor the storage of the plotline.

The subsequent analysis of frontal alpha between-conditions showed no significant differences, possibly for the reasons outlined above, although it is notable that alpha was higher following sleep in the graphic score whilst all other comparisons were in line with predictions. Similarly, the comparisons of post-nap performance on the WCST showed non-significant differences that were in line with predictions, and a single (positive) correlation was found between perseverative behaviour and alpha, which provides very limited, and possibly chance support for the association between post-nap alpha and cognitive performance. Due to the focus of the current study on cognition associated with frontal brain areas, cognitive tests of creativity were not included in this study, however some recent sleep research has indicated that sleep may additionally enhance performance on creative problem solving tasks seen prior to and solved following a period of REM sleep (Cai et al., 2009), as well as evidence of correlations between components of NREM sleep and subsequent divergent thinking performance.

Conclusion In conclusion, and with respect to future studies designed to modulate music creation behaviours, or to explore their neural correlates, the use of melodic-templates for improvisation offers the experimenter both the opportunity to observe hypofrontality in relation to RESEARCH QUESTION 6 (IMPROVISATION AS CREATIVITY) as well as exploring parietal inhibition in RESEARCH QUESTION 5 HYPNAGOGIA AND IMPROVISATION and finding parietal inhibition in improvisation as with hypnagogia.

Music created during hypofrontality was not reliably connected to the social perception of creativity however — and the assessment technique did not distinguish any performances as being distinctively creative.

The comparison between nap and movie conditions was very limited in the scope of its conclusions: there was however some very tentative evidence suggesting that there might be dissociated post-nap reductions in motor performance and improvements in cognitive performance, relating to RESEARCH QUESTION 1 (CREATIVITY) by suggesting that transiently, hypnagogia aids cognitive performance but hinders the motor response.

6
Conclusions

6.1 Research aims

6.1.1 Primary aims

Exploring creativity by attempting to quantify and modulate it The overall aim of the research was to gain a greater understanding of creativity by defining it in a way that could be realised in neuroscientific studies.

Furthermore, and using an applied neuroscience approach, the research aimed to modulate the working definition of creativity.

Realising these two broad aims in practice gave three smaller aims:

1. Define creativity in an experimentally tractable way Define creativity in a way that addresses the tensions in psychology and cognitive neuroscience about how to make it experimentally tractable.

2. Regulate creativity via hypnagogia To use applied neuroscience to modulate hypnagogia — and in so doing reinforce physiologies underlying spontaneous creative insight.

3. Disclose creativity through improvisation To explore the application and cognitive neuroscience of music improvisation as a candidate scenario for measuring creativity.

6.1.2 Secondary aims

Optimise novice performance The possibility of optimising sensory-motor skill regulation in novice musicians was explored.

Replicate and re-focus Egner and Gruzelier (2003) Replication of the first study associating NFT with creativity was a starting point from which to advance the current methodology.

6.2 Research questions

The aims translated as the following questions for use in practice

6.2.1 List of research questions

6.2.1.1 1. Creativity

Can measures of creativity be modulated by hypnagogia and alpha-theta NFT?

6.2.1.2 2. EEG training

Can alpha-theta NFT be shown to regulate hypnagogic electrophysiology? Additionally, and in relation to Research question 3, can SMR training be shown to regulate sensorimotor activity?

6.2.1.3 3. Novice performance

Can measures relating to sensory-motor control in novice performance be elevated by reinforcement of sensory-motor inhibitory control via SMR NFT?

6.2.1.4 4. Effect relation

Can changes in NFT be associated with changes in performance?

6.2.1.5 5. Hypnagogia and improvisation EEG

As candidate neurophysiologies thought to disclose the spontaneous processing of emotional content, can these states be shown to address the transient hypofrontality hypothesis (Dietrich, 2003) using applied neuroscience methods?

6.2.1.6 6. Improvisation as creativity

Does the operational definition of improvisation as spontaneous processing of emotional content work in distinction from other types of performance — as a candidate for disclosing creativity in the brain and eliciting a social response that validates creative judgement, which forms of improvisation are most useful to the experimenter.

6.2.1.7 7. Is Egner and Gruzelier (2003) replicable

Are relevant earlier reports replicable?

6.3 Review of aims and questions

6.3.0.8 Aim 1. Define creativity in an experimentally tractable way

The tensions in the psychology and neuroscience literature were considered in the light of ongoing difficulties in finding creativity in the brain. Psychometric tests of creative thinking were thought to pose a 'Criterion problem' in that they encompass some behaviours that contribute to some creativity, but not creativity itself. Extensive cognitive neuroscience studies profiled tests of 'Divergent thinking', but taken together were not able to show underlying patterns of activity leading to calls for the tests to be replaced with more basic measures of creativity (Dietrich, 2004a). One of the proposed basic types, 'Spontaneous processing of emotional content' has been reported historically in the form of hypnagogic insight and discussed in research concerning music creation.

Prior to current neuroscientific interest in the creative process, commentators had addressed the criterion problem by emphasising the importance of social and cultural selection in defining creativity according to subjective and implicitly held values.

This dissertation attempts to resolve these two areas of investigation by using neuroscience to profile spontaneous processing of emotional content, and social psychology to explore whether the outcome in society has any definable relationship with the personal process from which it originated.

6.3.0.9 Aim 2. Regulate creativity via hypnagogia

Hypnagogia is classically thought to give rise to spontaneous creative insight. Alpha-theta NFT is designed to regulate hypnagogia, and so as well as profiling neural activity underlying improvisation, NFT is used to try and modulate that self-same activity with the aim of reinforcing creative neurophysiology.

6.3.0.10 Aim 3. Disclose creativity through improvisation

In realising the implications of the literature review leading to in Aim 1, music improvisation was selected as a plausible candidate for disclosing the process of spontaneous music creation, which in turn is characterised as being formed of emotional content (Dietrich, 2004a).

Furthermore, improvisation can also disclose a socially subjective and implicitly held view of creativity in audiences (Amabile, 1982).

This combination of tractable personal and social features appears to make improvisation ideal as a means of reveal creativity in the brain and society in parallel, and in so doing address Aim 1.

6.3.1 Answers to research questions

6.3.1.1 1. Creativity

Can measures of creativity be modulated by hypnagogia and alpha-theta NFT?

The underlying assumption of the whole dissertation is that hypnagogic neurophysiology is a correlate of creative neurophysiology, and so by attempting to regulate and condition the former with applied neuroscience, the latter might be brought under experimental control.

Experiment 1 provided the first controlled evidence of post-NFT differences in spontaneous performance. The Stripsody task disclosed a difference in perceived measures of 'Confidence' rather than a measure more closely identified with creativity such as 'Interpretative imagination' in (Egner and Gruzelier, 2003). The results appeared to advantage those receiving alpha-theta NFT in comparison to SMR or no training controls, but were not distinguished in post-hoc analysis.

The difference in variance suggests that alpha-theta interacted with a task eliciting spontaneous creative behaviour: Stripsody. The benefit was seen in a category not closely identified with creativity: Communication. Despite this, Confidence, plus two further communication measures that showed a trend for difference — 'Emotional commitment' and 'Deportment' — might facilitate spontaneous processing of emotional content, as confidence instils increased options for performing. Examples of this include Kurtzberg and Amabile's (2001) association of self-confidence and risk-taking as antecedents to creative behaviour, and Tierney and Farmer (2002) who note that confidence gives rise to the adoption of non-conforming perspectives.

Confidence is also an interesting variable in the context of stage fright, which is known to manifest in reduced confidence (Brotons, 1994), and so given the threat of evaluation in Experiments 1 & 2 (in which cameras were training on participants, and cameras have been found to impair performance on tests of divergent thinking (Chamorro-Premuzic and Reichenbacher, 2008)), it is of interest that confidence may have been optimised following alpha-theta NFT. Raymond et al. (2005b) too associated alpha-theta NFT with increases in self-reported confidence, and so this outcome can be interpreted in the light of confidence impairments in other experimental groups that did not manifest in alpha-theta participants. Nonetheless, the absence of effect mediation data — confidence changes did not co-vary with alpha-theta EEG changes however, and so it is not possible to attribute the change to neurophysiology based change.

The role of Stripsody, as a graphic score, is also interesting in the light of outcomes seen in Chapter 5 in examining task-related EEG measures of a different graphic score. Unlike its predecessors, Experiment 3 measured EEG during graphic score response, and showed that parietal alpha activity was different to that recorded during musical score performance. This finding shows that in the absence of relations between alpha-theta dynamics and Stripsody, a graphic score in piano performance nonetheless distinguished parietal alpha from a standard performance. In summary, the interaction between EEG, graphic score and the social perception of performer confidence suggests that the use of graphic scores may continue to have a role in eliciting distinct neurophysiology as part of the search for creativity in the brain. Other studies of music (Berkowitz and Ansari, 2010) and imagined dance (Fink et al., 2009) improvisation have found lateralised deactivation in parietal areas, and so the inclusion of graphic score tasks does appear to constitute a means of exploring parietal activity underlying spontaneous performance.

Experiment 2 introduced the possibility that in the short-term, alpha-theta can impair spontaneous processing of emotional content. Post alpha-theta changes were almost all negative, and significantly different from those in the first cohort on measures of Stripsody and Instrumental solo performance. SMR and control group performance appeared undiminished in the second round, and 'Clarity of diction' in folk singing suggested SMR trainees were distinguished by their improvement. Literature on motor performance, cognitive performance and sleep indicated that whilst daytime sleep benefited cognitive performance including attention (Lovato et al., 2009; Lovato and Lack, 2010), it impaired motor function in non-habitual daytime sleepers (Milner et al., 2006). This indicates that whilst alpha-theta might reinforce neurophysiology underlying spontaneous processing more generally, it may not be appropriate as a means of priming motor function for spontaneous emotional processing.

Experiment 3 further examined the short term effects of hypnagogia on motor and cognitive function implicated in spontaneous creativity. Limited evidence was found to sustain the view developed in Experiment 2, that daytime sleep may benefit cognition, yet impair motor function. A response slowing measure found that after sleep, the scribble task contained more long notes, and the melodic template task contained less short notes than wakeful rest. Evidence of frontal cognitive reinforcement was limited to a single, and potentially chance correlation between alpha and perserverative responses in a cognitive flexibility task. Perceived creativity scores showed no effects, and appeared to suffer from floor effects.

If post-hypnagogia did transiently impair spontaneous processing of emotional content, this would invite the question as to how the long-term reinforcement of neurophysiology for spontaneous processing is achieved via alpha-theta NFT. This question remains unanswered, although having conducted an experiment in which task related EEG has been recorded in a way that is comparable with NFT EEG — the stage as been set for combined alpha-theta and music improvisation data to be compared.

6.3.1.2 2. EEG TRAINING

Can alpha-theta NFT be shown to regulate hypnagogic electrophysiology? Additionally, and in relation to RESEARCH QUESTION 3, can SMR training be shown to regulate sensorimotor activity?

Alpha theta training Experiment 1 provided marginal evidence of within-session differences in the ratio of theta to alpha EEG at Pz — this served as the experimental measure of crossover, that is the degree to which theta raised over and above alpha in training.

Experiment 2 provided strong evidence of within- and across-session effects on the training ratio. Furthermore these measures interacted, and the within-session ratio increased with each session.

Overall, the alpha-theta protocol provided the best evidence that a spectral (as opposed to sleep scoring) representation of hypnagogia can be reinforced in practice.

The question remains however whether the changes resulted from volitional controls acquired as a result of training, or another phenomenon such as progressive relaxation. The alpha-theta literature from the turn of the 21^{st} century is relevant in this respect: Lowe (1999), Moore et al. (2000) and Boynton (2001) all reported that alpha-theta NFT did not elevate the t/a ratio any more than other forms of relaxation. Nonetheless, hypnagogia, expressed as SLEEP STAGE 1 (Tanaka et al., 1996), falls away when the t/a ratio stops increasing in SLEEP STAGE 2 (De Gennaro et al., 2001). It was observed in Experiment 2 that the t/a ratio began to fall during the final 3 minutes of a typical 15 minute session, and so whilst the evidence is supportive of the view that hypnagogia occurred, SLEEP STAGE 2 may have also occurred — and the extent to which the protocol sustained the borderline state in comparison with an alternative relaxation intervention is unknown.

Sterman (1996) argued that the alpha-theta protocol sustained hypnagogia because the audio feedback cues hypnagogia simply by preventing a subject from going to sleep, rather than by reinforcing a distinct state. Despite this strong criticism, Egner et al.'s (2002) found that the final 6 of 15 minutes of alpha-theta NFT compared to pre-recorded playback of an alpha-theta session disclosed higher t/a ratios, challenging Sterman's (1996) proposal, which suggests that mock feedback would elicit the same t/a ratio as contingent feedback.

The other interesting thing about alpha-theta training in the current review is the difference in training outcomes between Experiments 1 & 2. The first cohort of trainees produced t/a ratios roughly equivalent to those in Egner and Gruzelier (2003), differentiating ratios on within-session measures of period. The second experiment showed reliable changes in the t/a ratio in each of the three indices of training. Speculatively, this is perhaps attributable to the fact that a slightly more private training location was used, less experimenters were present, and the feedback was delivered through headphones rather than computer speakers, shielding the participant from the sounds of the experimenter making adjustments to the feedback thresholds using a computer keyboard.

In the absence of EEG controls — recorded from a relaxation alternative sham alternative condition for example — it is not clear that hypnagogia was reinforced by NFT. By extension, the analysis of covariance between EEG and music changes could have made a stronger case for NFT mediated performance changes.

SMR training In SMR training, only Experiment 2 was shown to raise the training ratio of SMR in relation to theta and beta EEG at Cz, but only in the within-session measure.

The SMR training data showed a far less reliable pattern of change than alpha-theta. Only Experiment 2 disclosed a reliable difference between periods within-session. Interestingly, the actual gains in amplitude were very small, suggesting that in healthy subjects, the scope for moderating SMR in relation to both theta and beta frequencies was limited using the protocol applied.

Other studies demonstrating SMR training in healthy subjects do not generally report the training ratio in this way: most similarly, Vernon et al. (2003) compared individual blocks of Cz SMR to theta and beta separately — and was able to demonstrate changes between certain epochs; Ros et al. (2009) used a median split to contrast those able to significantly raise SMR/theta ratios to those unable to do so; Hoedlmoser et al. (2008) compared C3 SMR amplitudes between sessions 2-4 and 8-10.

Given the variety of ways that related studies which reported SMR data have analysed this type of training, it is difficult to contrast the training data with other labs' findings. Despite this, it is clear that in relation to the available data, other studies have clearly shown that SMR can be progressively raised in healthy participants, whilst the current approach showed this only to a limited extent in Experiment 2. It is not known why the protocol appeared to be sub-optimal at moderating the targeted relationship, but it appears that participants found it difficult to map the feedback to self-regulated EEG parameters in a way they could control.

6.3.1.3 3. Novice performance

Can measures relating to sensory-motor control in novice performance be elevated by reinforcement of sensory-motor inhibitory control via SMR NFT?

A secondary question explored in Experiments 1 & 2 was that SMR NFT might modulate novice performance. The rationale for this was that sensory-motor integration might be optimised following a series of studies demonstrating protocol related gains for healthy subjects in attention (Egner and Gruzelier, 2004b), memory (Vernon et al., 2003), perceptuo-motor skill acquisition (Ros et al., 2009) and sleep/learning (Hoedlmoser et al., 2008).

Furthermore, and in relation to optimal performance (Loomis et al., 1938) and clinical SMR (Sterman and Friar, 1972) literature, the context for understanding previously described performance gains stemmed from the idea that in optimisation for healthy subjects, performance impairments under conditions of load might be mitigated.

In the context of performing arts, stage fright and the threat of evaluation, symptomised by over-arousal in fine motor control for example (Brotons, 1994), is an appropriate candidate for exploring the idea of NFT optimised motor neurophysiology. The early work of Sterman and Friar (1972) in conditioning the inhibitory response in sensory motor cortex and mitigating the symptoms of epilepsy was considered as a candidate mechanism by which over-arousal during stage fright might be managed.

Highly experienced performers are considered able to turn stage fright to their advantage (Kokotsaki and Davidson, 2003; Vuust et al., 2010), possibly through conditioning their performance skills to states of high arousal, and so novice performers may be more susceptible to stage fright under the threat of evaluation.

Experiments 1 & 2 contained a Folk song task selected specifically in an attempt to disclose any protocol effects in novice singing, with a particular emphasis on reinforcing inhibitory control

Stage fright induced over arousal is also known to effect emotions in performance, such as the loss of confidence (Brotons, 1994), and it was additionally considered whether the proposed parallel between hypnagogia and spontaneous processing of emotional content might be interact with alpha-theta NFT via reinforcement of spontaneous emotional processing against stage fright. Again, and since all participants in Experiments 1 & 2 were non-singers, the task is performed at the novice level, and allowed the novice performance question to be asked of alpha-theta NFT too.

In Experiment 1's post-intervention performances of the Stripsody task, Confidence disclosed significant group differences, without post-hoc distinction between groups however. Additionally, 'Overall vocal competence' and Pitch scores co-varied with within-session SMR training ratio changes.

The parallel between Brotons's (1994) description of lost confidence in stage fright, and Experiment 1's suggestion that confidence varied between group means invites the the possibility that emotional processing may have been interacted with hypnagogia reinforcement. Confidence did not however co-vary with t/a changes, so the mediation of this finding is not known, and the likelihood that it occurred by chance is considerable due to its being one of many variables measured. In Experiment 2, Stripsody did not reveal any group differences, and this was attributed to the significant drop in performance outcomes in Experiments 2 compared to its predecessor — these score reductions particularly affected the Stripsody performance measures of commitment and confidence indicating that the threat of evaluation was not mitigated in Experiment 2.

Within-session t/a ratio changes predicted the slight falls in the 'At one with voice' measure and 'Overall Musicality' co-varied with across-session SMR training measures. Neither of these relations are explicitly identifiable with the symptoms stage fright, precluding a clear argument for optimisation.

Turning now to the 'Folk song' task, Experiment 1 revealed group differences in evaluations of Pitch, although without supporting post-hoc disclosure. Pitch changes co-varied with longitudinal changes in alpha-theta training EEG. The ability to pitch a vocal performance during stage fright is considered a potential area in which SMR might plausibly moderate the motor response, so the fact that changes in this measure co-varied with alpha-theta training precludes relating to the novice framework in use.

The same task in Experiment 2 revealed that the change in 'Expressive range' was significant between groups, although without post-hoc confirmation. Again, an artistic interpretative as opposed to technical variable shows a possible optimisation effect, but an isolated one that does not relate to the stage fright symptoms being considered.

6.3.1.4 4. Effect relation

Can changes in NFT be associated with changes in performance?

As stated previously, measuring EEG in the control group would have enabled stronger claims to be made regarding the electrophysiological mediation of outcomes. As it was Experiments 1 & 2 used within-subject relations only to analyse the covariance of EEG and music performance.

In summary:

Experiment 1 found that in Folk singing, 'Overall Musical Understanding,' 'Interpretative imagination' and 'Stylistic accuracy' all co-varied with the within-session SMR training ratio. No other relations were observed.

Experiment 2 found no relations between Instrumental solo and Folk singing and NFT training ratios. In Stripsody, within-session SMR changes predicted pre-training 'Overall musicality' and 'Confidence' measures, plus post-training 'Overall communication,' and a marginal extent, post-training 'Breathing' and 'Emotional commitment.' Improvisation results showed within-session t/a ratio changes predicted declining performance scores in 'Overall Improvisational Competence,' 'Fluency' and 'Overall Communicative Ability.'

As with music and training measures, the covariance analyses differed considerably between Experiments 1 & 2. This too may be attributable to the differences of experimental design that saw post-NFT performances taking place immediately following the final NFT session, introducing transient effects of training into the study. It may also be the case that the relations observed in Experiment 1 were not reliable enough to be replicable.

Some of the observed relations did address the overriding questions about the relationship between SMR and performance optimisation in Experiment 1, relating training to Musicality measures only however. This may fit the idea that SMR moderates arousal in novice performance and mitigates stage fright, but this was not replicated in Experiment 2 however, undermining this interpretation. Furthermore, within-session SMR NFT did not change the training ratio decisively in Experiment 1, which it did in Experiment 2, and given that Experiment 2 SMR participants did not appear to suffer post-training performance impairments, it might plausibly be expected that the SMR relation with novice performance would replicate in Experiment 2, which it didn't. This indicates that observed changes might not be reliable.

It's interesting that although training changes to EEG were more clearly demonstrated in Experiment 2, fewer musical changes co-varied with NFT, which again seems counter to the view that NFT mediates music performance, transient effects notwithstanding.

In the replication of Egner and Gruzelier (2003), the alpha-theta training correlations with music changes observed in their first experiment were not found to be replicable in their second, and neither were they replicable in the current analysis.

Taken together, the case for effect mediation is weak — unlike Sterman and Friar's (1972) finding that training SMR EEG mitigated symptoms of epilepsy, the idea that regulating EEG dynamics in NFT might for example condition that same dynamic in music performance has not been reliably observed.

6.3.1.5 5. Hypnagogia and improvisation EEG

As candidate neurophysiologies thought to disclose the spontaneous processing of emotional content, can these states be shown to address the transient hypofrontality hypothesis (Dietrich, 2003) using applied neuroscience methods?

Having run into severe doubts over the relation between hypnagogic EEG and music performance, the next step was to collect music performance EEG and examine it for commonalities with sleep-onset. This was approached from the theoretical angle of the 'Transient hypofrontality hypothesis' (Dietrich, 2003) which predicts that all altered states share frontal hypofunction in common. These states include sleep and music improvisation, and given that Limb and Braun (2008) discovered supporting evidence in jazz-blues 12-bar improvisation, and Muzur et al. (2002) described executive deficiencies brought on in sleep onset, an EEG study examining both states together was conceived.

The same experiment additionally adopted an empirical approach, and explored parietal EEG in keeping with the alpha-theta NFT protocol, which records at the location where alpha in eyes closed wakefulness is most distinct (Niedermeyer, 2005). Interestingly recent studies of spontaneity in performance art have found alpha (Fink et al., 2009) and BOLD deactivation (Berkowitz and Ansari, 2010) in parietal lateral areas by differentiating expert performers. This invites the possibility that parietal alpha-theta training may regulate parietal alpha in a way that contributes to spontaneity in creative behaviour. The current study sought to explore this possibility, although did not differentiate analysis based on musical expertise.

Experiment 3 compared 30-minutes of eyes-closed daytime rest/sleep to eyes-open rest (watching a Charlie Chaplin film). It also compared improvisation to rendition.

Between conditions comparisons showed that sleep-onset EEG had more hypofrontality (Fz alpha) in relation to wakefulness at 13-15 minutes. Pz measures showed higher alpha from 0–18 minutes, and then from 28–30 minutes.

Muzur et al.'s (2002) analyses of sleep-onset suggest that hypnagogia (SLEEP STAGE I) occurred alongside hypofrontality at 13–15 minutes, and this is in agreement with the t/a ratio data in Experiments 1 & 2 that indicated (using different measures) SLEEP STAGE I occurring at this point in time.

In parallel, improvisation, particularly the 'Melodic template' approach, also demonstrated both hypofrontality and parietal alpha relative to score rendition.

These were among the more promising results of the dissertation, supporting the 'Transient hypofrontality hypothesis' and the recent empirical data indicating the role of parietal deactivation in both sleep-onset and improvisation. This approach has lent some support to the idea that alpha-theta NFT, in attempts to reinforce sleep-onset physiology, might simultaneously be conditioning cortical processes underlying improvisation. Whether the application works as effectively as in Sterman and Friar's (1972) management of epilepsy symptoms remains to be seen however.

6.3.1.6 6. Improvisation as creativity

Does improvisation — the spontaneous processing of emotional content — work in distinction from non-improvised performance? As a candidate for disclosing creativity in the brain and eliciting a social response that validates creative judgement, which forms of improvisation are most useful to the experimenter?

Experiment 1 introduced the role of improvisation into the methodology for testing the historical association between alpha-theta and creativity (Green et al., 1972). It also provided suggestive evidence of a link between NFT and improvements in the audience perception of 'Confidence' in alpha-theta trainees, which was interpreted as an emotional optimisation against stage fright.

If the alpha-theta/Stripsody interaction can be shown to hold in replication, then the idea that Stripsody *is* creativity — the audience perception of creativity in spontaneous emotional processing — can be sustained.

Experiments 1 & 2 also considered another type of improvisation, descriptive cues, e.g. 'A walk in the woods.' This tasks tended provided no evidence that improvisation is creativity, and provoked such a variety of responses from the varied choice of cues that the audience may not have been able to readily compare performances.

Being able to compare is of course important for experimentation, and the Stripsody task, with its combination of stimuli that remain comparable over time, but which also provide room for difference in interpretation, does afford spontaneity over and above that which might be done in a rendition of a normal musical score, where interpretational differences are limited within the confines of music theory.

The methodological implications of using different improvisation methods to make creativity tractable were further explored in Experiment 3, which looked at 3 types of improvisation, each with a different way of limiting the musical bounds of variation. The outcome was what the most familiar task, that of 'Melodic variation' on a short score, provided the highest scores of perceived creativity, although not distinctively so. This task also most clearly elicited the neural patterns identified with creativity, hypofrontality and parietal deactivation.

The role of melodic cues for improvisation were interpreted in the light of (Dietrich, 2004b), who conceptualised jazz-improvisation as a sequence of pre-existing phrases that reflexively trigger each other with minimal interference from meta-cognition — which might only be needed to count bars or intervene to stop playing. The use of a melodic template in this context can then be seen as as task that triggers musicians' pre-existing musical patterns, whereas the other tasks recruited high-level interpretations on an ongoing basis to monitor the task in relation to the brief. This is not to say that non-melodic improvisation cannot invoke spontaneity in musicians, but in the non-improvising European tradition from which all but one participant came, melody provides the most direct route to reflexive play.

The question of music tradition was also discussed by Limb and Braun (2008), who thus far has provided the best case for transient hypofrontality — attributing this in part to the fact that the Jazz-blues musicians in that study had finely developed improvisational skills which could extemporise quite naturally from a 12-bar blues motif, and in so doing down-regulate higher order cognition.

Overall, the introduction of improvisation into the NFT methodology appears to have been fruitful, and as such is worthy of further exploration, particularly given that the same EEG measures used in alpha-theta NFT can demonstrate neural differences between improvisation and other forms of music performance.

6.3.1.7 7. Is Egner and Gruzelier (2003) replicable

Are relevant earlier reports replicable?

Egner and Gruzelier (2003) was comprised of two studies, and Experiment 1 replicated the latter of the two. Experiment 1 replicated the within-subjects improvements in alpha-theta participants in 'Overall quality,' 'Stylistic accuracy,' 'Musicality' and marginally 'Interpretative imagination.' Experiment 2 found that all Instrumental solo scores went down after alpha-theta NFT.

Although Experiment 1 replicated prior alpha-theta outcomes, it is noteworthy that it did so having seen alpha-theta participants start at a distinctly lower baseline evaluation than counterparts in SMR and control protocols. This was not the case in Egner and Gruzelier (2003), in which baseline audience ratings showed equivalence.

There is no EEG data in (Egner and Gruzelier, 2003), although based on an associated report (Egner and Gruzelier, 2004a) in which alpha-theta NFT was found to elicit significant within-session t/a ratio changes, the current study showed marginally significant agreement.

Intriguingly Keizer et al. (2010a) claimed to have unsuccessfully attempted to replicate Egner and Gruzelier (2003), although they did not report the findings, and confirmed via correspondence that they had only tested theta NFT (finding no effects) without measuring music performance outcomes.

Taken together then, none of the above studies conclusively replicated the first NFT and music study.

6.4 Limitations and Future Directions

6.4.1 Strengths

The main strengths of the dissertation are in its addressing of Research questions 2, 5 & 6. The most important, Research question 1. Does NFT modulate creativity? was not addressed closely enough.

The design of Experiment 1 might have been able to answer Research question 1 if the apparent benefits of alpha-theta NFT in Stripsody performance were controlled in an active way, such as in the use of alternative relaxation therapies (Lowe, 1999; Moore et al., 2000; Boynton, 2001). Experiment 2 introduced the consideration that transient alpha-theta NFT effects on creativity might be negative, forcing the question to be re-conceptualised in the light of conflicting cognitive and motor processing.

Research question 2 was addressed with some strength. The data was able to demonstrate targeted t/a changes in NFT data, particularly in Experiment 2, which showed consistent changes across all measures. The lack of control data holds back the claim that this change emanates from NFT however. Alpha-theta and SMR data in Experiments 1 & 2 respectively showed within-session changes.

Research question 5 saw Experiment 3 providing evidence of relative frontal alpha synchronisation in both daytime napping and melodically cued improvisation. This added evidence to the claim that transient hypofrontality underlies many altered states of consciousness by effectively limiting the policing role of conscious awareness in managing attention and working memory (Dietrich, 2003).

Research question 6 saw Experiments 1 & 3 both being able to address the question about whether improvisation constitutes creativity in a lab setting. The role of Stripsody in disclosing group differences was interpreted as a differentiation that rested on the role of confidence in spontaneous performance, reinforced against stage fright by alpha-theta training. Experiment 3 provided suggestive evidence that melodically cued improvisation was perceived by an audience as more creative than other types which were less closely associated with reflexive spontaneous processing. This difference was not reliable however, although alongside evidence of hypofrontality in melodically cued improvisation, it does appear that improvisation has a methodological role that deserves further consideration in the field of creativity.

6.4.2 Weaknesses

6.4.2.1 Defining creativity

It has been said that: "To most neuroscientists, the prospect of looking for creativity in the brain must seem like trying to nail jelly to the wall. — Dietrich and Kanso (2010)" The evasiveness of creativity, the lack of advance awareness of spontaneous insight, and the conceptual difficulties in trying to explore it from a reductionist standpoint has resulted in a collection of neuroscientific data that "precludes interpretation — Arden et al. (2010)."

Prior to the current wave of creativity neuroscience, the problem of measurement was approached from a relatively holistic perspective that inferred creativity in retrospect, that is, once something has implicitly held to be creative in relation to its environment. This selection proceeds without ever explicitly saying how creativity is defined other than it is selected from a randomly assembled choice of offerings (Simonton, 2003) or that it is selected according values that aren't guided by aesthetic and technical considerations (Amabile, 1982).

In an attempt to resolve the previous approaches, this dissertation proposed that by examining a basic type of creativity: 'Spontaneous processing of emotional content' (Dietrich, 2004a) using cognitive and applied neuroscience methods, and then by examining outcomes in the retrospective way detailed by (Amabile, 1982), it could then determine whether a common ground might be established. This was approached by using improvisation as the method of observation, rather than tests of 'Divergent thinking' which had resulted in the mess of data discussed previously.

In some ways this worked, Experiment 3 found some parallel between improvisational EEG and audience response, but not in a reliable sense. In other ways, the idea that creativity is tractable as spontaneous processing of emotional content was shown to be a concept that might be yet further distinguished into motor and non-motor responses. Experiment 2 introduced the possibility that motor processes involved in creativity may have different requirements than cognitive ones — especially in the context of sleep, which by down-regulating higher-order cognition can provide more scope for spontaneous combinations to be represented, but can also down-regulate motor function and as a result reflexive interplay ('muscle memory') in sensory-motor integration.

This definitional approach then invites questions about spontaneous processing, and whether this might further be isolated to motor specific production (Brennan, 1982) in future work.

Despite misgivings over the extent of concept reduction, improvisation does appear to be fit for purpose as a means of eliciting spontaneous processing of emotional content. The application of Amabile's (1982) consensual assessment technique in gaining retrospective accounts of creativity was sub-optimal in the present studies though. Factor distinction between creative, aesthetic and technical measures was precluded by the amount of data.

In order to fully test this combined definition that encompasses neural and social indices of creativity, a large study capable of factor analysis should be attempted (n=100 (MacCallum et al., 1999)). Considering that NFT participants typically attend 10-12 appointments, this constitutes a large-scale undertaking, although single session studies (e.g. Ros et al. (2010)) may provide a way around this — not that single-session alpha-theta training is advised for optimising motor performance given the results of Experiment 2. The best way forward from here then is to mount a study like Experiment 3, on a larger scale.

Another important issue when thinking about further investigation of improvisation creativity is this advice. Use expertise, either in the sense of profiling musicians with finely honed sensory-motor integration (Haueisen and Knösche, 2001), so that the musical response is reflexive, or perhaps better still, do not profile musicians from the European classical tradition who tend to shun improvisation. Instead, Jazz musicians for example, have already developed their improvisational skills (Creech et al., 2008) and may be better able to exhibit reflexiveness in an experimental setting (Limb and Braun, 2008).

6.4.2.2 Guidance for experimenters

Control for musical biography Although the profiling of Jazz musicians is one possible way of advancing the methodology, variations exist within all musical traditions, so controlling for the amount of improvisational expertise, skill acquired, music theory limitations applied and of course for instrument may help to isolate the role of improvisation in disclosing spontaneous processing of emotional content.

Statistical power A limitation of the first two studies is the small number of participants, which when considered alongside the small estimated effect size of previous significant reports (.02 - .25 in Egner and Gruzelier (2003)), resulted in underpowered studies. The research questions were largely rejected, and the possibility exists that these may have been false negatives.

Other experimenters are recommended to raise statistical power to a level of 0.8 by increasing the sample size to a minimum of 14 per group in a three-group study.

The third study showed differences in ANOVA comparisons of all the music task alpha EEG measures, plus paired comparisons. Large effect sizes were observed in both frontal and parietal electrode sites when focussing on the $melody - score$ difference, and other experimenters are recommended to follow this line of investigation using a group size of 12 or more.

Variability of training timetable As is a common problem in neurofeedback studies, the first and second studies were both characterised by variation in NFT attendance patterns that did not control for time of day or inter-session delay for example. Despite using relative EEG measures to adjust for spectra-wide power changes, it was found that measures of within-session EEG (collapsed across sessions) provided more robust estimates of 'learning' than did across sessions comparisons. The latter index was also possibly compromised by the amount of training sessions held, and only led to marginally significant changes in EEG training parameters. This is also a feature of other studies conducting 10 training sessions, and according to linear predictions, just one additional training session may have been able to consolidate learning differences.

Controlling for naturally occurring EEG changes The design of experiments one and two did not include EEG measurements of controls. This means it's not possible to determine whether the changes described in the active groups may have occurred any-way. Had the non-active controls had their EEG measurements taken during the course of the studies, changes in the active groups could have been compared against these to partial out non training related changes. Similarly, had participants received an active control such as cognitive sleep onset regulation (Haimov and Shatil, 2013) against alpha-theta, or attention training games (Gevensleben et al., 2009b) against SMR - the EEG of this control could have been compared against that of NFT to determine the efficacy of the intervention against alternatives. Another control for NFT might have been a placebo in which non-contingent feedback is administered to replicate the participation scenario without physiological cues. Equipped with such EEG controls, the interpretation of NFT effects in the first two studies could have been conducted against alternative EEG measures rather than within-subjects training/performance covariance.

Controlling for sleep habits The third study did not document the napping habits of participants, and given that one of its hypotheses was based on evidence suggesting that non-habitual daytime sleepers maintain alertness less effectively after daytime sleep, this information could have been used as a covariate in analysis, possibly helping to distinguish the effects of sleep-offset with more precision. This study also did not take account of individual differences in sleep stages experienced, which also may have been able to differentiate the post-nap performances to a greater extent.

Overall, the recommendations for future research as are follows:

- Further attempts to isolate the interaction between alpha-theta NFT and creativity should continue to use improvisation as the first experiment suggested that improvised performance may interact with neurofeedback.
- Further attempts to identify the mediator(s) of alpha-theta effects on creativity should employ task-related EEG measures, either at the electrode site(s) used in NFT, or at sites hypothesised to interact with training neurons, or, if equipment allows: whole scalp EEG. Additionally, parallels may be sought between task and NFT EEG by capturing whole scalp EEG of training. Furthermore, additional EEG measures such as phase coherence could be used if evidence of network activity is being investigated.
- The surprise findings concerning transient effects of NFT protocols suggests that short-term effects are worthy of further investigation in their own right, due to

their apparent distinction from longitudinal applications.

- To control for EEG changes during NFT, by measuring the EEG of control participants during the intervention stage of NFT trials. An alternative or placebo intervention could be administered to controls - enabling measurement of the comparative efficacy of NFT in regulating EEG.
- The use of piano improvisation specifically has some merits that deserve consideration. Firstly, this constraint imposes experimental control on instrumental variation (the first two studies incorporated instruments of several types: percussion, piano, wind and string; and this may have affected comparability). Secondly, piano affords the additional capture of MIDI data that can be used to analyse the musical properties of performance using quantitative methods. It is worth pointing out that many of the musicological techniques for analysing performance are based on monophonic music, and so it is worthwhile incorporating monophonic tasks depending on the experimental hypotheses.

6.5 Final Conclusions

This thesis incorporates a series of studies which further distinguished the interplay between hypnagogia, EEG and creativity through increasing protocol specificity of effects on spontaneously created music, differentiating between short- and long-term effects of alpha-theta NFT, and demonstrating the applicability of electrophysiological measures of improvisation into the NFT research methodology.

A
Clinical applications of the Alpha-Theta protocol

During the same period that Kamiya (1962) began to investigate alpha discrimination and training, high amplitude measurements of alpha were being found in studies examining altered states of consciousness in meditating yogis (Anand et al., 1961; Wenger and Bagchi, 1961), and Zen masters (Kasamatsu and Hirai, 1966). In addition to alpha, theta activity (4–8Hz) was observed during meditation by Green et al. (1970), who noted that following an initial rise and fall of alpha amplitude, theta activity increased to the point of 'crossover,' where it became more powerful. The transition between alpha and theta signal dominance is one of a set of phenomena that occur during the wake-sleep transition, collectively referred to as the hypnagogic state (Schacter, 1976) or SLEEP STAGE 1. This transient period is also characterised by qualitative changes in mental content (Tanaka et al., 1996) and reductions in muscle tone (leading to the sensation of falling that causes the hypnagogic jerk), and Green sought to use neurofeedback to increase volitional control of this state. An alpha-theta protocol was developed (Green et al., 1974), whereby both oscillations were monitored, and Green reported that the point of crossover was aligned to subjective reports of profound relaxation and reverie. Green stressed that whereas the EEG changes produced are similar to SLEEP STAGE 1, the subjects were maintained in a relaxed yet focused condition, subjectively similar to a hypnotic trance with reverie.

Goslinga (1975) was first to test alpha-theta feedback as part of a larger SUD course of treatment for alcoholics at the Topeka Veterans Affairs Medical Center, a clinic for recovering armed forces personnel. The clinic specialises in biofeedback treatments, and in this study alpha-theta neurofeedback was provided along with electromyogram (EMG) and temperature control biofeedback, and the 12-step alcohol recovery program used by Alcoholics Anonymous. The neurofeedback treatment consisted of daily 20-minute sessions over a period of 6 weeks. Patients were brought together in groups to discuss their insights and experiences associated with biofeedback several times a week. The outcome from group discussions was that participants reported being more able to create free, loose associations, and experienced heightened sensitivity and increased suggestibility. This study was not controlled, and by combining neurofeedback with other treatments, it was not therefore possible to isolate any protocol specific effects. However, as an anecdotal report, it did provide scope for further exploration.

The next study of alpha-theta training took place at the same veterans medical centre. Twemlow and Bowen (1976) explored the impact of alpha-theta training in 67 chronic male alcoholic inpatients. In this non-controlled study, the examination of psychodynamic factors that 'religiousness' as a predictor of 'self-actualization' may have increased as a result of imagery experienced during periods of dominant theta synchronisation. In line with the emphasis on faith within the 12-step program, the authors concluded that alpha-theta biofeedback served to augment the motivational goals of the recovery program. Shortly afterwards the same first author published a paper in which he indicated that NFT appealed to the high suggestibility of his more religious patients; "treatments such as brainwave training, which utilize abstract, ill understood techniques are potential repositories of magical projection and fantasy and would logically be more acceptable to alcoholics who are able to have 'faith' (devoutly or moderately religious)" (Twemlow and Bowen, 1977). In a further uncontrolled study by the same author, it was reported that 21 alcoholics exhibited within and across session increases in the amplitude of occipital theta oscillations. This was interpreted as an EEG manifestation of the ability to achieve an increasingly deeper state of relaxation (Twemlow et al., 1977). Taken together, these four initial studies advanced the possibility that neurofeedback might have an application in promoting insight and attitude change that could enhance a period of recovery from alcohol addiction. Their anecdotal nature and the lack of experimental control in these studies preclude their ability to attribute the reported psychodynamic or EEG changes to alpha-theta NFT exclusively, and their publication occurred at a time when the active research of neurofeedback in general was going into decline. However, these early studies did establish a possible new application of neurofeedback, and preceded the first randomised controlled trials of alpha-theta NFT by over 10 years.

Alongside the relatively new alpha-theta protocol, the more established alpha training procedure was also being examined as a possible form of treatment for alcoholism (Passini et al., 1977; Watson et al., 1978). In line with the arousal model of alpha synchronisation, the authors hypothesised that the high anxiety accompanying alcohol withdrawal might be offset by down-regulating arousal with alpha NFT as a replacement for the anxiety relieving effects of ethanol. 50 male alcoholics who had been hospitalised for their condition and were without any other psychiatric or neurological conditions were assigned to age-matched groups of alpha NFT (n = 25) or a no- training control group (n = 25). Each group was tested before and after the intervention on subjective measures of anxiety (the State/Trait Anxiety Inventory (STAI), (Spielberger et al., 1983)), the Multiple Affect Adjectives Check List (MAACL) (Zuckerman et al., 1965), the Brief Psychiatric Rating Scale (BPRS) (Overall et al., 1962), the Minnesota Multiphasic Personality Inventory (MMPI) (Hathaway and McKinley, 1940), the Anhedonia Scale (Watson, 1972), and the Sensation Seeking Scales (SSS) (Zuckerman, 1971). The authors set out to establish whether the changes in self-report data might correlate with changes in resting alpha measured before and after the experiment, with resting eyes-closed/open measures of alpha synchronisation across scalp locations. Alpha change was analysed in terms of the percentage of time alpha amplitude was higher than a baseline level. The training group received NFT during 10 hour-long sessions, over the course of 12 days. During training, participants relaxed with their eyes closed whilst alpha measurements were recorded from occipital sites dependent on handedness (O1 in right-handers, O2 in left-handers[1]). EEG feedback was auditory, and was presented when alpha amplitude was raised above baseline measures from the start of the session.

The authors reported a significant between groups difference in percentage of time post intervention alpha exceeded baseline thresholds. In the eyes-closed condition, training subjects increased time above baseline alpha from 38–55%, and from 20–32% in the eyes-open condition. The control group did not exhibit significant

[1]The international 10–20 scalp location sites are listed in Appendix G

changes. Effects on the self-ratings were seen on anxiety only (Spielberger's STAI); the experimental group significantly reduced their subjective scores of both state and trait anxiety, with no reported changes amongst controls. However, the authors drew attention to the lack of correlation between the changes in resting alpha and state/trait anxiety, concluding that a placebo effect on reported anxiety change could not be discounted. A further concern relating to the placebo effect in particular was that experimental participants had a far greater amount of experimenter contact than did the controls, whose inclusion was mainly to correct for test-retest and time dependent changes in the population. The higher level of contact time between experimenters and participants may then have raised the expectation of a treatment effect in the patients, leading to the reported reduction in anxiety. This concern is however partially offset however, as expectation effects might have also led to improved scores on the other self-report measures used in the trial, which was not the case. The effect of placebo is thought to attenuate over time, with the actual duration ranging from 8 weeks (Coryell and Noyes, 1988) to 2.5 years (Traut and Passarelli, 1957), and so the authors carried out a follow up study 18 months later in order to determine the persistency of anxiety reductions (Watson et al., 1978). They interviewed 46 of the original 50 participants, and collected further self-report assessments on the dependent measures used in the initial study. The Alcohol Rehabilitation Follow-up Questionnaire (ARFQ (Pucel, 1972). The authors found that differences between the alpha training and control groups in reported state and trait anxiety were "essentially identical" to those immediately following the initial study. This result was significant for two reasons, firstly it suggested that the placebo effect was not responsible for the initial anxiety reductions as its power would be expected to have dwindled in the intervening 18 months, and that being the case it was reasonable to assume that the long-term anxiety reductions were attributable to alpha training. The results of the newly included follow-up questionnaire did not show a significant between groups difference on 12 of 13 comparisons; the exception being that the alpha training group had longer abstinence periods (248 days in comparison to 142 amongst controls). The authors interpreted this result with caution since 1 change in 13 might arise by chance. Nonetheless, the suggestion that abstinence might be greater following NFT, coupled with the durable reductions in anxiety indicated that further investigation was warranted, which eventually happened, eleven years later!

The case for the therapeutic benefits of alpha training on anxiety received further support from Hardt and Kamiya (1978). The design of this study was formulated in response to Orne and Paskewitz (1974), which challenged the prevailing view that alpha accompanied pleasant calm. In Orne's study, high alpha density in the EEG was found to occur simultaneously with state anxiety (being in jeopardy of receiving electric shock) alongside other autonomic indicators of anxiety (increased heart rate and galvanic skin response). Hardt and Kamiya sought to redress what they proposed to be an imbalance in Orne's study, from which 12 cases had dropped out due to fear of electrocution. Although Orne had stated that the drop-outs exhibited similar patterns of resting alpha activity to those that continued with the painful part of the experiment, the criticism of his experiment was that it effectively excluded those of a more anxious disposition, and was thereby not a representative population sample. The response by Hardt and Kamiya was to compare both high (n = 8) and low (n = 8) anxiety cases, as measured by the MMPI anxiety scale. This sample was drawn from a larger one of 100 male volunteers. The study assessed participants' responsiveness to alpha NFT. Over 7 days, a daily alpha training session consisted of 8 minutes of resting EEG baseline recording, 32-minutes of alpha-enhancement NFT, a further 8 minutes of resting EEG measures, ending with a period of 16 minutes of alpha-suppression NFT. The authors collected self-report anxiety data before and after each session, and assessed MAACL affect scales prior to each session's baseline EEG, and after both alpha-enhancement and suppression NFT periods. EEG was recorded from OZ, O1, and C3, with null voltage reference electrodes attached to earlobes. EEG from location OZ was used for NFT, and alpha (8 – 13 Hz) amplitude changes were mapped to changes in the volume of the feedback tone. The EEG recordings showed that in the high-anxiety group alpha measures changed at all sites (OZ, O1, C3), in both amplitude and percentage of time above baseline levels. The increase in alpha was inversely related to state anxiety, either when alpha was being trained up *or* down. The authors also examined the sum of alpha increases across all 10 NFT sessions, and it emerged that the resulting figure was inversely related to trait-anxiety reductions amongst high-anxiety participants, who were shown to have produced large within-session alpha increases.

Whilst the findings of Orne and Paskewitz (1974) ran contrary to the prevailing hypothesis that there was an inverted-U shaped relationship between alpha and arousal

(Lindsley, 1952; Stennett, 1957), Hardt and Kamiya raised the possibility that Orne's participants possibly came from a low-anxiety population, and thereby would have to increase arousal to increase alpha, which is what Hardt then observed in low-anxiety participants. Hardt's high-anxiety group on the other hand arguably lowered anxiety to increase alpha, and taken together these findings support the inverse-U shaped alpha-arousal relationship. The contradictions between these studies may nonetheless arise from methodological problems in both experiments. Whilst it might be true that Orne's use of electrocution excluded high-anxiety participants, the group selection process used by Hardt may equally be flawed as it was based on solely subjective reports of state and trait anxiety, which are prone to 'hindsight perspective' effects where the participant has expectations of the outcome of an experiment (Ross et al., 1977). On balance, the outcome of the 1970's investigations into the therapeutic applications of slow-wave NFT for anxiety was equivocal, and over the course of the next ten years there were no attempts to bring robust experimental control to bear on this question.

In the first reported randomised controlled trial of alpha-theta NFT, Peniston and Kulkosky (1989) strengthened the case for the clinical validity of this protocol by demonstrating positive long-term outcomes amongst a sample of recovering alcoholics. The subjects were 30 inpatients in an armed forces veterans administration medical centre treatment program (Fort Lyon, Colorado). All participants were male, 20 of which had chronic alcoholism that had proved resistant to more than 4 previous hospital treatments. The 10 remaining participants were non-alcoholics who were included in the study for comparison with alcoholics in terms of alpha activity. At the outset the rationale of the study was informed by the fact that those with a predisposition to alcohol addiction (alcoholics and their descendants) are characterised by a deficiency of alpha activity compared to controls (Funderburk, 1949; Funkhouser et al., 1953), and that this deficiency is redressed by ethanol use (Pollock et al., 1983). It was also known that alcohol withdrawal is accompanied by symptoms of anxiety (Roelofs, 1985), so it was hypothesised that the combined alpha deficiency and anxiety in alcoholics might be treatable with alpha training. As well as rationalising the use of alpha training, Peniston's experimental protocol also included theta training, although the justification for doing this was not as well established. The author drew parallels between the observation of theta in meditation (Anand et al., 1961;

Green et al., 1970) and the use of learning to meditate and long-term abstention from chemical use (Wong, 1981). Surprisingly, the author appeared to be unaware of the alpha-theta studies of the 1970's (Goslinga, 1975; Twemlow and Bowen, 1976, 1977), although the similarities between the methods used are striking.

Experimental participants were divided into three groups: an alpha-theta NFT alcoholic group (n=10), a talk therapy alcoholic group (n=10) and a non-alcoholic control group (n=10). The NFT subjects completed 15 30-minute sessions of eyes closed occipital (O1) alpha-theta NFT. In addition to NFT, the first 8 sessions of alpha-theta training were preceded by a hand temperature biofeedback exercise in self-warming that was speculated to stimulate the transition towards a 'theta state' (Hall, 1977). As an additional further step prior to NFT, participants received specific guidance as to what they should do. They were instructed to close their eyes and "construct visualized abstinence/alcohol rejection scenes, and imageries of increased alpha rhythm amplitude and scenes of the normalization of their personalities," and then to "sink-down" towards a "theta (reverie) state keeping the mind quiet and alert (but not active), and the body calm." After having given the instructions, the experimenter would leave the participant alone resting in a comfortable chair for the remainder of the session. The subject would hear feedback tones when alpha amplitude exceeded a pre-training base-rate, and a different tone when theta amplitude was no less than basal alpha−10 microvolts.

The talk therapy alcoholic control group attended daily talk sessions normally offered at the medical centre, whilst the non-alcoholic controls were measured on dependent variables during the pre/post intervention assessments.

Both prior to and following the intervention all participants were assessed on three types of measure: resting EEG, Beck's Depression Inventory (BDI) (Beck and Steer, 1984), and vascular beta-endorphin. The EEG recordings were made over 60 minutes at 6 scalp locations (C3, C4, P3, P4, O1, O2). The alpha and theta production was measured by visual EEG inspections carried out by two raters who were blind to the experimental condition that each EEG was recorded in. The BDI is a self-report scale, and beta-endorphin, an endogenous opioid that increases in blood at times of stress (Naber et al., 1981; Watabe et al., 1987; Kalin and Loevinger, 1983) was measured in blood samples.

In comparison to the other participants, alcoholics receiving NFT showed significant overall increases in percentages of EEG recorded in both the alpha and theta rhythms across the scalp, and increased alpha rhythm amplitudes at occipital site pairs P3-O1 and P4-O2. The NFT group exhibited significant reductions in the BDI scores compared to both other groups, and their depression fell from high initial levels seen in both alcoholic groups to equality with the non-alcoholic group, which had remained normally low throughout. Control subjects who received standard treatment alone showed increased levels of vascular beta-endorphin, which was speculated to stem from stress caused by alcohol withdrawal. The NFT and non-alcoholic group did not change in levels of blood beta-endorphin.

As in the 1970's studies testing alpha NFT for recovering alcoholics (Passini et al., 1977; Watson et al., 1978), Peniston also measured the long-term outcomes for participants in the study in order to determine whether NFT acted as a cure for alcoholism, whilst also probing for the erosion of post-treatment differences that might be expected if they were only governed by placebo effects. Monthly telephone interviews were conducted over 13 months, and at the end of this period 2 out of 10 NFT participants had relapsed (drank constantly for a week or more) compared to 8 out of 10 alcoholic controls.

Whilst the results of Peniston's study provide a strong indication that his approach offers clinical benefits, there are a number of critical issues with the way his research was designed and reported that make it hard to say with confidence how the outcomes were mediated. The design of the experiment was such that the experimental treatment, which later became known as the Peniston protocol, was comprised of three different interventions (1) temperature biofeedback training (2) guided alcohol avoidance imagery, and (3) NFT. Whilst this combined method may be effective in itself, it is difficult to measure the extent to which patients derived clinical benefits from any one aspect of the treatment. The authors could have attempted to isolate the clinical effects of alpha-theta training by correlating shifts in alpha and theta activity across 15 NFT sessions with changes in resting EEG, as they did measure activity at the same scalp location in training and pre/post assessments. This was not done however, and no association between the dependent and independent EEG measures were reported. The report did not disclose its random selection criteria or describe the control treatment used, which hinder abilities to replicate these results independently. The anticipated lower alpha amplitudes in alcoholics compared to non-alcoholics were not observed in this study, and the alcoholic groups both exhibited marginally higher alpha amplitudes at baseline. The extremely large increases in the visually detected dominance of alpha (12-fold) and theta (7-fold) oscillations, plus the doubling of alpha amplitude at selected electrode pairings were suggested by Graap and Freides (1998) to possibly arise from habituation towards the EEG recording process amongst subjects receiving NFT. Alpha naturally occurs on eye closure, but may not occur in unfamiliar surroundings because of an orienting or blocking response, related to cognitive vigilance. Graap found that amongst participants providing EEG readings their initial apprehension would attenuate alpha activity, yet as participants became more familiar with the experiment, alpha blocking would reduce, and this was proposed to be a possible cause of Peniston's reportedly large increases in alpha. The same might be said for theta, as again, greater familiarity with the process of EEG recording might make it easier for subjects to relax sufficiently to enter sleep onset and thus produce more theta activity. Peniston's measure of relapse into alcohol use is also potentially misleading as it does not take into the amount of alcohol consumed, only whether subjects had maintained abstinence for more than 7 days per month, and therefore lacks sensitivity to binge drinking.

Following their first NFT report, (Peniston and Kulkosky, 1990) went on to demonstrate that the experimental participants in their first study also underwent changes in measures of personality compared to controls that were still apparent at a 4 year follow up. Prior to and following the first experiment, the authors administered the Millon Clinical Multiaxial Inventory (MCMI) (Millon, 1983), which is used in screening for personality disorders/pathologies as well as clinical syndromes, including substance dependency. Amongst the experimental treatment group, improvements were seen in 13 measures: schizoid, avoidant, passive aggression, schitzotypal, borderline, paranoid, anxiety, somatoform, dysthymia, alcohol abuse, psychotic thinking, psychotic depression, and psychotic delusion. In comparison, the alcoholics who received standard (undisclosed) therapy showed significant decreases only in two MCMI scales, avoidant and psychotic thinking and an increase in one scale — compulsive. The authors argued that this indicated greater improvements amongst the group receiving the Peniston protocol in both clinical and personality measures. However, it is interesting to note that, at post-test, the alcoholic controls were only significantly different from the experimental participants in two MCMI scales, schizoid and avoidant personality. This indicates that the experimental group scored more highly at baseline on a number of measures. This raises some concern since the authors omitted to mention the difference between the alcoholic groups at baseline, only stating that that 8 alcoholic control and 12 experimental group MCMI scales were significantly different from the non-alcoholic group at baseline. Visual inspection of plotted scores indicates that all 16 of the 20 scales are higher for the experimental group compared to alcoholic controls. This indicates that the (undisclosed) random selection of subjects may not have resulted in homogeneous alcoholic groups being selected in the study, and undermines the assumption of homogeneity of variance integral to parametric statistics. The authors speculated that the personality changes seen in the experimental group might be implicated in the long-term abstention from alcohol and normal levels of vascular beta-endorphins, although this is not supported with evidence of correlation between changes in any of the purportedly covarying measures and it remains unclear how personality changes might be causally related to training. A further criticism of this study is that it contrasts the reported clinical benefits in the experimental group with the apparently ineffectual standard therapy. Without knowing what the standard therapy consisted of, it is not really possible to say whether strategic comparisons such as these are valid, however in a separate study of MCMI outcome measures in a group of alcoholics, conventional 6 week community therapy treatment resulted in improvements in 14 of 20 scales (McMahon et al., 1985). So had the control treatment been more effective, and the control participants equally positioned on clinical scales at the beginning of the study, the outcome of this study might have been quite different.

Following their reported successes in managing alcohol withdrawal with biofeedback, Peniston and Kulkosky moved on to test the application of NFT in the treatment of combat related Post Traumatic Stress Disorder (PTSD) (Peniston and Kulkosky, 1991). Experimental participants were recruited from a population of Vietnam War veterans, and were divided into two groups, an experimental group receiving the same Peniston protocol as in the previous study (n=15), and a control group receiving antidepressant, antipsychotic and anxiolytic medication plus psychotherapy (n=14). The training group were also receiving medication at the start of the study, however during the course of the intervention all but one in each group voluntarily began to reduce their dosage. Although the training protocol was mostly reused from the previous experiment, the course of treatment was extended from 15 to 30 sessions, and the guidance given prior to NFT was modified, with alcohol withdrawal scenarios being replaced with combat related traumatic memories. The protocol for guiding the content of hypnagogic imagery was given to patients by the medical psychotherapist MP as follows:

> "Now, go back to Vietnam where these traumatic combat events occurred." Then, they were instructed to visualize imageries of increased alpha rhythm amplitude and scenes of the normalization of their personalities. Then the MP instructed the subjects to "sink-down" into a theta state keeping the mind quiet and alert (but not active), and the body calm. Finally, subjects were instructed by the MP to initialize the session with a quiet command: "Do it."

Prior to and following the experimental stage, all participants completed an MMPI questionnaire, and subsequently remained in monthly telephone contact with the experimenters for 30 months, in order to screen for symptoms of PTSD including flashbacks, panic attacks and nightmares.

In comparing the experimental and control groups' scores on the MMPI the authors found a group time interaction effect arising from significant decreases in clinical scales amongst the experimental participants. Robust interaction effects coupled with significant post-hoc analyses of scale reductions and a lower score in the post-test were seen in the experimental group on the following scales: "hypochondriasis" "depression," "hysteria," "psychopathic deviate" (Conflict, struggle, anger, respect for society's rules), "masculinity-femininity" (Stereotypical masculine or feminine interests/behaviours), "paranoia," "psychesthenia" (Worry, Anxiety, tension, doubts, obsessiveness). Both groups significantly reduced in reported symptoms of "schizophrenia," with the experimental group were significantly lower following the intervention. Less robust group differences were seen in measures of "hypomania" and "social introversion-extroversion," although a similar trend was in evidence.

Analysis of the MMPI PTSD scale demonstrated that whilst both groups were equal at the beginning of the experiment, the group receiving the Peniston protocol treatment significantly reduced on this scale, and were significantly lower than the control group post-intervention. The control group marginally reduced in this scale.

The MMPI also includes validity measures designed to detect exaggeration or down-playing of psychological symptoms. On the Frequency (exaggeration) scale, the experimental group reduced significantly and were significantly lower post-intervention, and on the Lie scale (down-playing), a group x time interaction was disclosed and stemmed from a slight increase in the experimental group.

The reduction in psychotropic medication that had been started during the experiment was reported to have been maintained over the 28-day course of the study in the experimental group only. 14 of 15 participants in that group had reduced their dose, whilst 1 of the control group had.

The final measure, follow up telephone interviews carried out over 30 months, disclosed that 3 of 15 experimental participants reported a relapse of PTSD symptoms, whilst all 14 controls did.

The clinical outcomes for the patients involved in this study indicate that talk therapy and medication appears to have little benefit for sufferers of PTSD. The group receiving the Peniston protocol on the other hand reported dramatic improvements in their condition. The authors observed that during training, some patients experienced a so-called "abreaction," the re-experience of traumatic memories that had been repressed by guilt and were the underlying cause of their nightmares, flashbacks and anxiety. The authors suggested that these traumatic memories were accessed consciously through hypnagogic imagery experienced during EEG theta dominance. Having identified the key events that underlay their symptoms, patients were then able to discuss them in a way they previously had not.

As with the application of the Peniston protocol in treating alcohol withdrawal (Peniston and Kulkosky, 1989), the PTSD study suffers has some methodological weaknesses that partly undermine the ability to draw clear conclusions as to whether the reported effects are related. For example, whilst MMPI scales are measured prior to and following training, they are not reported as part of the follow up measures. This means that it is not possible to clearly identify the long-term reductions in PTSD symptoms with the post-intervention reductions in clinical symptoms amongst the experimental participants. Similarly, the results section does not include any EEG data from the 30 training sessions, any changes in which could have been compared with clinical changes, and could have been used to deflect the assertion that the MMPI changes in the experimental group were mediated by training and not placebo effects that might be expected in a study that involved a high degree of patient-experimenter contact. Again in relation to the previous study, whilst the authors suggest that the alpha-theta training component of their protocol is instrumental in inducing hypnagogic imageries, and provide anecdotal evidence to support this (presumably gained from post training session reports), there is no empirical evidence to indicate that abreactions occurred during dominant theta oscillations.

Peniston et al. (1993) followed their preceding studies of alcohol recovery and combat related PTSD with a similar NFT study that compared synchrony between electrode pairs and EEG component amplitudes in a pre-training measurement and a final NFT session during which abreactive hypnagogic imageries were observed.

There were 20 participants in this study, all of whom were given the same Peniston protocol treatment as reported in the previous two studies. The subjects were drawn from the population of patients at a veterans clinic, and had both diagnoses of alcoholism and combat related PTSD.

The EEG measures used in this experiment were informed by a previous study by Banquet (1973) which analysed the EEG characteristics of Transcendental Meditation. The meditation study reported increased synchronous EEG activity between anterior and posterior channels as well as a gradual movement of non-sleep frontal theta into posterior channels.[2] In keeping with the proposal that the neuroscientific basis for the therapeutic effects of alpha-theta NFT, the authors sought to examine training data for evidence of changes in neural activity that might underpin the changes in alcohol use and PTSD symptoms. To this end the study was conducted as a within subjects analysis.

In order to explore synchrony, the authors derived their own measure, which appeared to be largely determined by the equipment they were using (a four channel CapScan Prism Five). The authors measured EEG from 4 locations (F7, F8, O1, and O2), and adjacent signals were considered synchronous in a given 1-second interval when the largest amplitude component in the spectrum of the first signal occurs at the same frequency as its counterpart for the second signal, and secondly the FFT-derived phase angles of the two dominant amplitude components lay in the same vector quadrant (i.e., 0–90, 180–270, 270–360). The authors used these measures as

[2]Frontal theta EEG is the most commonly observed manifestation of this rhythm outside sleep onset, and is correlated with encoding new information in working memory (Klimesch, 1999).

evidence of synchrony defined as the predominance of a single brainwave frequency (from alpha: 9–13Hz, theta: 4–8Hz, or beta: 14–29Hz) throughout several lobes, both hemispheres, or the entire cortex. Additionally the authors compared the average amplitudes of alpha, theta and beta band activity between baseline and final training sessions.

By comparing the 4 possible electrode pairings arising from their method, the authors reported that observation of synchrony between sites was close to 0% of the time during a 30-minute baseline measurement. The final training session on the other hand saw all site pairings exhibiting synchrony around 70% of the time, with the neighbouring occipital channels showing a marginally smaller amount. The repeated measures ANOVAs analysis showed a significant main effect of time, however the reported within-groups degrees of freedom reported with the F statistic was 3040, which is incorrect considering that the number of participants was 20, the number of measures was 2 and the number of electrodes was 4. The data appears to have been analysed incorrectly, which means that despite the apparently dramatic change in synchrony, the reported statistic should be interpreted with severe caution. The authors concluded that this finding indicated a whole-cortex distribution of synchronous activity.

The authors additionally reported significant increases of theta and beta band EEG amplitudes when comparing final training session data to that of the baseline measures, whilst alpha amplitude remained relatively consistent, dropping below that of theta during the latter observation. It is not clear which electrode(s) the reported data are from.

The final reported outcome of the study was that of the 26 month follow up, which showed that during the period following treatment PTSD relapse occurred in 4 of the 20 participants, although alcohol use is not reported here.

The methodological flaws in this study do not add credibility to the previous works of Peniston and Kulkosky. A major criticism of this uncontrolled study is that it bases it's conclusions regarding EEG synchrony and amplitude changes on the comparison of two completely different test situations; the first being a measure of resting EEG, and the second being an NFT session, during which subjects are visualising traumatic memories through hypnagogic imagery. The reported long-term benefits in terms of reducing symptoms of PTSD are not however linked by way of correlation analysis with the EEG changes. Although the results are so unclear as to be unusable, this study did begin to generate testable neuroscientific hypotheses for examining the therapeutic effects of alpha-theta NFT in ways the preceding reports did not. The report provided suggestive evidence in support of the association between alpha-theta NFT and meditative states by disclosing higher than resting EEG amounts of theta frequency amplitudes, and the authors also suggested that increased synchrony between brain areas might be instrumental in enabling repressed long-term memories to be represented in working memory.

Prior to withdrawing from active research, Peniston was involved with one further alpha-theta study, (Saxby and Peniston, 1995). This study was designed as an uncontrolled replication of the prior uses of the Peniston protocol in treating alcoholism (Peniston and Kulkosky, 1989, 1990). This study selected 14 participants randomly from a mixed gender population of outpatients at a biofeedback centre in California, none of whom had any psychotic symptoms or other known dysfunction. The outcomes measured by the study were personality (BDI and MCMI) and alcohol use (21 month follow ups).

The training procedure differed slightly from previous attempts insofar as the temperature biofeedback training was conducted in isolation over four sessions, with a further session being devoted to the construction of imagery associated with alcohol abstinence in situations relevant to previous alcohol use, and with the increasing of brainwave amplitudes. Subsequently patients had 20 40-minute alpha-theta NFT sessions, each of which was followed by a short interview to review any hypnagogic imageries perceived.

After treatment, the participants reported significantly reduced scores on the BDI depression inventory, and 14 of the 20 MCMI scales. Alcohol relapse was only reported in one case. Whilst this report indicates that Peniston's successes in using alpha-theta NFT to manage alcohol withdrawal are replicable, it does not otherwise improve the validity of the Peniston protocol. The study contained no control group, so whilst the report has the benefit of reporting similar results in a slightly different population, the lack of experimental control limits the claims to efficacy that can be made by this study. In common with previous reports, the link between intervention and outcome measures is not even explored, and the continued problem of the mixed treatment program means that it's not possible to tell which part of that program is effecting the outcome measures.

Peniston and Kulkosky's active contribution to the investigation of the alpha-theta protocol ceased at this point, and whilst they were instrumental in reviving interest in the therapeutic application of NFT to anxiety and SUD, their particular elaboration of it was criticised by a number of commentators (including its originators) for confounding three treatment variables (Taub and Rosenfeld, 1994; Peniston, 1998; Moore and Trudeau, 1998; Lowe, 1999). The main barrier to further evaluation of the protocol is that it is not possible to determine whether alpha-theta biofeedback is instrumental or even able to facilitate apparently clinically beneficial hypnagogic states. By the authors' own admission, temperature biofeedback for hand warming was included into the protocol to facilitate hypnagogia, yet the outcome effects are always discussed in terms of the NFT element of the protocol. Without a study that adequately controls for temperature, guided imagery, NFT, placebo, Hawthorne effects, or relaxation, it was argued that the validity of the Peniston's early findings remain questionable.

Further criticism of Peniston's work with alpha-theta NFT was that it was not made clear in the original reports whether alcoholism and PTSD were treated in isolation from each other, and that it was therefore impossible to disentangle whether the positive outcomes were attributable to treating one or the other condition, or both (Graap and Freides, 1998). The commentator also indicated that Peniston's reports lacked sufficient detail of experimental method to be able to provide for independent replication. Graap added that the increases of alpha and theta EEG activity observed in the treatment group might have been simply arisen out of the familiarity that these participants had developed towards eyes closed relaxation in NFT training sessions, indeed convincing evidence that the NFT induced theta state is distinct from normal sleep onset has not yet been demonstrated (Sterman, 1996).

Because of these problems, the combined Peniston protocol has largely fallen into disuse, with subsequent investigations modifying the methodology and revising the treatment to include only the alpha-theta training component. All the published independent studies that followed in the wake of Peniston's reports were uncontrolled observational studies treating mixed SUD (Fahrion et al., 1992; Finkelberg et al., 1996; Skok et al., 1997; Kelley, 1997; Fahrion, 1999; Burkett et al., 2003; Bodenhamer-Davis et al., 2004; Callaway and Bodenhamer-Davis, 2008). Unfortunately as with the Saxby and Peniston (1995) study, whilst these studies tended to approve the use of alpha-theta training, at least in non-stimulant substance use, they do not add to the case made by Peniston as they exert even less experimental control over the treatment.

In addition to the aforementioned uncontrolled studies, two studies attempted to identify whether the alpha-theta NFT alone was instrumental in conditioning the hypnagogic response, or whether it might arise in sham feedback (Lowe, 1999) or alternative biofeedback conditions (Moore and Trudeau, 1998; Moore et al., 2000).

The study by Lowe (1999) was a closely observed replication of the original Peniston and Kulkosky (1989) study, with a key elaboration: the inclusion of a sham feedback group who were added to control for placebo and Hawthorne effects. Another key difference was that the study's 45 participants was not sampled from a similar type of population. Subjects were recruited from a clinic for patients with mixed SUD diagnoses; and 68% of the sample used alcohol and cannabis, whereas Peniston's participants were only referred to as alcoholics. 28% of the sample were female, and the mean age of the sample was 27, whereas Peniston's participants had a mean age of 49 and were men. All participants received the standard therapy offered at the clinic, noting here that Peniston's NFT participants had not received group therapy.

The training procedure was also different from Peniston's alpha-theta audio tone feedback that was set according to baseline readings of alpha amplitude only. Participants in the NFT group received both alpha and theta feedback consisting of natural sounds.[3] The sham NFT group simply listened to the same natural sounds continuously whilst EEG recordings were made. All real/sham NFT sessions were preceded by the guided imagery of alcohol avoidance and EEG modulation, and followed by a short discussion of the recorded EEG in order to ensure subjects remained blind to the differences between treatment groups. Both groups received 6 sessions of temperature biofeedback prior to 24 sessions of real or sham feedback, plus continued receiving community therapy. A third control group received community treatment only.

The outcomes measured by this study that replicated those used by Peniston were resting EEG, MCMI, and substance use. EEG measures taken prior to and following the intervention were broadly the same as those carried out by Peniston, however the author did not report the scalp locations used. Whilst Peniston observed large post

[3]Subjects could choose between audio tapes of stream sounds, bird sounds, sea sounds, and sounds of a heart beat, and in NFT the experimenter manually adjusted thresholds so that alpha and theta feedback were heard 50–60% and 20–30% of the time respectively.

treatment increases in alpha and theta in his treatment group, Lowe found large reductions in alpha and theta in the control group that were not echoed after either treatment, and these contributed to a significant group control-treatment group differences at the end of the study.

The MCMI profiles were quite different at pre-test between studies. However, the pattern of change was the same. Eleven of the 13 MCMI personality scales that significantly improved amongst NFT participants (Peniston and Kulkosky, 1990), also improved significantly for both experimental groups in Lowe's study, with paranoid personality and delusional no significantly changing. Dependent personality did significantly improve in the replication alone. Lowe's control group improved in the same scales as the experimental groups, although not as reliably (some scales only approached significance), whereas Peniston's control group did not improve.

More sensitive measures of substance use during a 17 month year post-treatment delay were also used, and participants reported abstinence periods and quantities and frequency of use. Whilst Peniston's control group had reported 80%/20% relapse amongst control/treatment cases respectively,[4] Lowe found that only 8%/20%/14% relapsed in the NFT/sham/control groups, and these figures were not significantly different from each other. By additionally measuring the mean amount of days using substances, significant differences did emerge with 14%/11%/30% of days in follow-up where substances were used in the NFT/sham/control groups respectively.

Although Lowe established that the experimental groups exhibited desirable post experiment results in EEG, MCMI and relapse measures compared to controls, the treatment groups did not differ from each other. This led the author to conclude that the although the Peniston protocol does have clinical utility in aiding substance withdrawal, possibly by normalising physiology and personality, the benefits disclosed are not reliant on its EEG biofeedback component. It seems only reasonable then to assume that either temperature biofeedback, guided imagery, deep relaxation or a combination thereof is responsible for the changes observed. This finding contradicts Peniston's intimation that alpha-theta training promotes assistive hypnagogic imagery more than sleep onset. By contrast Lowe found that the sham group reported more instances of sessions in which imagery occurred, although within the NFT group alone

[4]Peniston defined relapse as having spent seven continuous days drinking during the 13 month follow up period.

it was observed that participants experiencing more sessions with imagery were more abstinent in the long-term.

The author used correlation analysis to demonstrate parallels between positive changes in measures of slow wave EEG, abstinence and personality in all three groups, confirming the rationale for raising alpha and theta EEG as part of a substance withdrawal treatment.

The Lowe study is quite important in the alpha-theta literature as it constitutes the closest attempt to an independent replication of the experiments by (Peniston and Kulkosky, 1989, 1990). A number of possibly confounding differences do exist however; the population, the fact that the treatment groups also received the same community therapy, the substances used, and the EEG equipment used that limit the scope of these findings to completely negate previous findings, in particular the evaluation of the Peniston protocol in isolation from standard group therapy.

The possibility that alpha-theta feedback might not be necessary for promoting the hypnagogic state was also addressed in a study by Moore et al. (2000). In this experiment, 35 male volunteers were recruited from a population of residential and outpatient substance abuse patients at the Minneapolis Veterans Home or the Minneapolis. Initially the authors had intended to compare the alpha-theta and EMG training as part of a repeated measures design, however due to a problem with the data collection part of the study, alpha training was given in some sessions as well, and so the resulting analysis compared EEG and imagery characteristics of 106, 43 and 45 alpha-theta, alpha and EMG sessions respectively.

The study had two hypotheses:

> (a) crossover states and elevated theta amplitude states occur more commonly in alpha-theta feedback than in another relaxing feedback condition, and (b) theta crossover and elevated theta/alpha (t/a) amplitude states are associated with self reported visual reverie.

In 40 minute-long alpha-theta biofeedback sessions, EEG was recorded from the O2 10–20 site, alpha (8–12 Hz) and theta (4–8 Hz) were both signalled by tones, with thresholds for producing sounds adjusted so that alpha feedback occurred 50–70% of the time and theta 20–40%. The previously unused O2 site for EEG recording was justified as the authors proposed that the right hemisphere may be more involved in visual processing. In EMG training participants attempted to reduce amplitudes below the threshold set, with higher and lower levels being represented with the same tones as for alpha and theta in the alpha-theta protocol. The report does not make it entirely clear where EMG electrodes were placed, although the authors indicated that the protocol was designed to be indistinguishable in experience to alpha-theta training. The alpha protocol differed in the sounds that were used and was comprised of three tones and was designed to promote progressive relaxation.

Training was carried out in groups of 2 to 6, and following each session participants were asked to complete forms and talk about their experiences; a treatment blind rater counted instances of hypnagogic imagery per session from this data, and the ensuing figure served as the first outcome measure. The second dependent measure was that of t/a 'crossover', Peniston's proposed indicator of the neural correlate of hypnagogic imagery. The authors measured crossover as the mean session ratio of theta to alpha and the mean percentage of time spent in crossover.

Due to the previously stated problems with experimental design leading to participants effectively being members of more than one experimental group, the authors analysed each session as a data point that was independent of the subject. In the use of ANOVA this entailed that the within subjects degrees of freedom was around 190, which artificially raises the statistical power of the test, leading to increased likelihood of a false positive. Indeed the authors did report a significant difference between the groups, with post-hoc analysis indicating that EMG cases exhibited greater mean t/a ratios than the alpha participants. This result however is not necessarily valid. No group differences were reported concerning percentage of time spent in theta alpha crossover. Considering the incidence of reported imagery, it was found that no group differences existed, but in analysing all sessions together the authors found an unexpected inverse relation between the mean theta>alpha measure and the presence of imagery in a session.

Since the study data was analysed incorrectly, coupled with the report that many participants dropped out of the study, the findings of this experiment are suggestive at best. Nonetheless, the comparison of alpha-theta training with an EMG control is a valid approach in attempting to isolate any protocol specific effects of alpha-theta training. EMG relaxation has been used in other alcohol withdrawal studies (e.g. Denney and Baugh (1992)) that reported its ability to promote self regulation of anxiety during alcohol withdrawal. This study suggests that EMG relaxation leads to t/a crossover just as effectively as alpha-theta training, and this would support the assertion by Sterman (1996) that alpha-theta feedback might not train a distinct theta state as suggested by Green and Green (1977); Peniston and Kulkosky (1989) but simply facilitates a "functional transition towards sleep." If this were the case, one might expect any other form of relaxation to have a similar effect in promoting sleep physiology; and this appears to have been observed by Moore. Sterman proposes that the efficacy of alpha-theta NFT in sustaining hypnagogic EEG lies not in training volitional control of sleep onset, which is naturally accompanied by a loss of self-regulation, but rather that the subject is prevented from progressing beyond SLEEP STAGE 1 due to the continued reinforcement of alpha or by experimenter intervention[5]. Sterman concludes that whilst alpha-theta feedback may promote hypnagogia, it does not bring it under operant control. In the light of this remark Moore's finding that theta>alpha measures are inversely related to occurrences of imagery would possibly indicate that above an undefined level, the t/a ratio expresses not only the transient crossover period, but also further stages of sleep onset too. It follows then that neither form of training prevented progression beyond the hypnagogic EEG indicative of SLEEP STAGE 1. Although Moore's study does not constitute an empirically valid challenge to the efficacy of the alpha-theta protocol, it does nevertheless raise questions about the proposal by Green et al. (1974); Peniston and Kulkosky (1989), that theta dominance occurs in a state distinct from normal sleep onset. In the light of the comments by Sterman (1996) a further question is raised regarding the ability of alpha-theta NFT to bring the hypnagogic state under operant control. This question could be addressed by comparing measurements of hypnagogia EEG prior to and following alpha-theta NFT.

[5]There is some evidence that auditory awareness attenuates during theta cycles accompanying drowsiness (Makeig and Jung, 1996; Makeig et al., 2000) which would indicate that experimenter intervention would be more important in preventing a deepening of sleep

B

Clinical applications of the SMR protocol

Although NFT procedures designed to train attentional networks include both SMR/beta and SCP methods, this review will focus on SMR/beta applications. There are two reasons for doing this. Firstly, the historical development of SMR/beta protocols parallel that of the slow wave methods seen in the previous section and reviewing them here provides an overall illustration of the development of the field. Secondly, EEG frequency band conditioning as opposed to excitability or imaging measures are currently the most widely used in clinical and research practice, and this thesis reflects the dominance of these methods.

Neurofeedback training for attention processes began with the 1976 publication of an ADHD case study (Lubar and Shouse, 1976). The previous work demonstrating a relationship between SMR and motor inhibition in epilepsy (Sterman and Friar, 1972) provided the rationale for examining whether this relationship might be observed, and treated in another condition characterised by 'overactivity,' ADHD.

The data for Lubar and Shouse (1976) came from a single case study drawn from a group of 4 who had participated in the first study of SMR training for ADHD. Dependent measures consisted of treatment-stage blind classroom observations of hyperactivity and inattention (Wahler et al., 1975), and 40 minute EEG recordings which provided counts of events where SMR exceeded 5 microvolts whilst theta (4–7 Hz) remained below 12.5 microvolts. The experimental design was made up of five stages which were as follows: Stages 1 and 2- baseline measures of EEG and behaviour without then with Ritalin medication respectively; Stage 3- SMR training with Ritalin (75 sessions); Stage 4- reversed SMR training with Ritalin (40 sessions); Stage 5- SMR training with Ritalin (30 sessions). The final three stages consisted of an ABA design in which initial training goals were reversed and then reinstated to control for extraneous variables influences such as maturation.

The NFT protocol itself comprised divergent regulation of SMR and theta frequencies, EEG was recorded from C3 and C4 as in a previous epilepsy study by Sterman and Friar (1972). Feedback consisted of the presentation of lights, tones, and money during targeted EEG responses and a different light during un-targeted EEG signatures. Sessions lasted 40 minutes, with a five minute baseline and 15 minute training period being repeated. EMG was recorded from the chin in order to probe for evidence of motor inhibition.

Being a study of a single case, descriptive data only was provided. Targeted values of SMR and theta are shown to have progressively increased during stages 3 and 5, and decreased in stage 4.

These trends were inverted in EMG measures, suggesting that motor inhibition did occur in training. Session baseline measures of SMR activity also changed in line with the amount of training, suggesting that training effects carried-over beyond training. Classroom measures of hyperactivity and inattention further attest to the persistence of training effects, and the study indicated that 8 of 13 measures changed in line with the training and reverse-training conditions. EEG and behavioural improvements happened to a greater extent than under medication alone.

Whilst the preliminary nature of the results in a single subject are stressed, the authors nonetheless felt that this line of inquiry warranted further investigation in a greater population sample. The fact that their study illustrated bi-directional effects on both EEG training parameters and behavioural measures provided encouragement that these measures might be linearly related. The addition of reversal training did clearly demonstrate effects of SMR/theta NFT in contrast to its inversion rather than against controls, although using a treatment to worsen clinical symptoms is ethically questionable, and a suitable control is preferable. The use of the ABA design does nonetheless demonstrate relationship between SMR/theta parameters and ADHD measures, which, for what was a brand new protocol adds some credence to the inclusion of theta training into the protocol. The mixing of SMR and theta NFT does however make it impossible to calculate their individual input to the results of the study.

Lubar and Shouse's (1976) preliminary report was later expanded into a full report detailing measures taken in all four cases that were originally studied (Shouse and Lubar, 1979). The sample consisted of four boys who were being successfully treated with Ritalin medication, and presented no other symptoms that might confound the results of a study (8 cases were rejected on these grounds). The design of the study was mostly identical to that of the previous Lubar and Shouse (1976) report, with a further off-medication SMR training phase at the end.

Lubar's data analyses were seemingly based on visual inspection of plotted data, and did not report statistical inferences. Three cases were described as exhibiting SMR learning, i.e. SMR increases during medication, medication+NFT, and NFT alone, and decreases during reversal NFT. Following the withdrawal of medication SMR measures continued to increase. In terms of behaviour analysis, Ritalin improved 6/13 scales, and combined treatment 8/13; in association with SMR measures, behavioural improvements were reversed during reversal training, and were not adversely affected when NFT alone was conducted.

Although these extended results further support claims made in the preliminary Lubar and Shouse (1976) report, the analytical approach used remains descriptive in a study that could have used inferential methods to disclose whether significant quantitative changes occurred. The author also made an unsupported claim that measures of hyperactivity were inversely related to SMR production — this argument appears to be further borne out by the indication that the 'non-learner' case, who did not regulate EEG in line with training objectives presented mainly ADD symptoms.

As this report is based on the same experiment as the preceding one, it has the same methodological flaws, the lack of a control group, the small size of the sample, the omission of inferential statistical analysis, and the non-random selection of the population sample, which may have inadvertently introduced uncontrolled biases into the study. The use of two electrodes for training is also open to criticism as a bipolar montage such as the C3-C4 combination used bases measures on the differences between two electrodes — apparently without reference to a proximate non-EEG benchmark such as an earlobe or mastoid; this means that the measured value could be affected by differences in oscillatory phase which modulates inter-electrode amplitude differences, relative amplitude differences between the two electrodes, and external electromagnetic interference.

In summary, the first reports of SMR based NFT for ADHD (Lubar and Shouse, 1976; Shouse and Lubar, 1979) do not represent conclusive evidence of clinical efficacy. They did however initiate what has developed into *the* dominant strand in NFT research, and so are included for completeness.

The same laboratory that produced the previous two reports continued to investigate SMR for diagnosing and treating ADHD. In Lubar and Lubar (1984) documented data from 6 adolescent males exhibiting variable levels of ADD/ADHD/Learning Disability (LD). In the period between Shouse and Lubar (1979) and Lubar and Lubar (1984) being published, the laboratory introduced several modifications to their protocol: the expansion of the SMR band from 12–14Hz to 12–15Hz, and the inclusion of an additional 16–20Hz band hypothesised to positively relate to focused attention and arousal. The experimental design was also expanded to include pre/post intervention QEEG measurements. As in previous work, pre/post measures of behaviour were included, this time on measures of educational achievement. During the intervention, EEG recordings over scalp loci F7-T5 and F8-T6 during rest, reading and drawing.[1] The justification for recording EEG at these locations is not made clear. The electrode location(s) of training measures are not stated. As in previous work, the study did not include a control group.

The procedure for NFT training was similar to that of the lab's previous studies, although it was separated into distinct periods spent elevating either SMR or beta, in both cases theta activity was inhibited, as was facial EMG. Targeted thresholds for elevation/suppression were set during pre-training baseline measures. Positive feedback was signalled by a light. Participants received 40 × 40-minute training sessions, which included periods spent on the aforementioned educational tasks. Time spent in NFT/task performance varied between participants.

As in previous reports, the documented results include descriptive statistics only. Improved scholarly performance, elevated SMR/beta amplitudes and decreased theta/facial EMG was shown in all subjects. Evidence of NFT 'learning' is reported in all subjects, but measures of learning are not described, and the provided plots do not visually confirm the existence of a learning trend.

[1] The 10–20 EEG electrode placement has been changed: T5 is now P7, and T6 is P8 (Klem et al., 1999).

The scant description of experimental design and procedure means that this study could not be independently replicated on the strength of the available information. Whilst the bi-polar montage may have been referenced to an EEG free proximal site this is unclear, as are the positioning of training electrodes, the length of training/task performance periods. The introduction of a further training frequency further confounds the ability to explain the contributions of SMR and theta training seen in previous studies, coupled with the lack of analysis that would enable strategic predictions to be formed. In the absence of a control group, evidence of covariation between dependent and independent variables, such as shown in the ABA design used previously would have strengthened the authors' case, however, their refusal to employ inferential statistics on the grounds that training times varied amongst participants precludes the generalisation of these results to a wider population. Overall, this study, despite attempts to increase the efficacy of the protocol, further increased its complexity and resistance to explication, and the study did not improve on previous experimental designs or analytical methods, and actually reduced the scope of the designing without addressing the lack of experimental control.

Despite this apparent reduction in the quality of SMR NFT experimentation in Lubar's laboratory, the same year saw the publication of an independent SMR study by Tansey (1985). The experimental sample was 6 young boys with learning disabilities. Prior to and following NFT, participants were measured on an undisclosed period of resting SMR production, the Revised Wechsler Intelligence Scale for Children (WISC-R) test (Wechsler, 1974) and an unspecified measure of Learning Disability.

Between these dependent measures, a weekly regimen of SMR training was administered, although the number of training sessions varied. On the strength of this and other contemporary reports (Tansey and Bruner, 1983; Tansey, 1985), it seems that participants stopped NFT at their own request, as patients at a private practice. The mean number of appointments was 27. Training lasted 30 minutes, with SMR (14 ± 0.5 Hz) being recorded from a position around 2.6 cm behind Cz. Reference and ground electrodes were attached to earlobes. The feedback representation was a continuous audio tone, which modulated in volume in line with changes in SMR amplitude.

The results section of the report states that as a group the six boys raised the mean resting amplitude of SMR by 137.6%, although this increase is inflated by one case who saw an increase from 6 to 24 microvolts (%300). The post-training measures of intelligence (WISC-R) disclosed some improvements, with the author stressing that cases with an initial discrepancy between verbal and performance measures equalising on these measures following training.

In evaluating Tansey's (1984) report, many of the methodological and analytical issues present in (Lubar and Shouse, 1976; Shouse and Lubar, 1979) are repeated here, the lack of a control condition, the emphasis on individual cases and the inability to generalise from these results. The author does however, despite applying SMR NFT in a completely different way to Lubar, declare the decisions informing his experimental design to a greater extent. Whilst Lubar's laboratory employed different bipolar electrode placements without justification, Tansey bases his monopolar montage on the assertion that training at the junction of brain hemispheres will increase their interaction, which he proposes is deficit in a state of Learning Disability. Tansey uses his evidence of equalisation in scores on verbal/performance measures to suggest that SMR NFT promotes efficacy in bilateral networks. Whilst these results and their associated implications do not generalise beyond the cases documented, the introduction of a single EEG electrode NFT procedure did nonetheless introduce an arguably more reliable measure of EEG into the practice of NFT, thus paving the way for more controlled examination of training parameters in relation to outcome measures in subsequent studies.

Tansey (1985) reports the findings of a further SMR study in learning disabled boys who, following NFT had their diagnoses removed. In common with the previous study, the main dependent measures was the WISC-R employing IQ as an index of learning ability. In what appears to be a further collection of case studies from data collected in his private practice, the author does not clarify the amount of NFT given to each subject. In departure from the previous study, the author expanded the dependent measures made prior to and following NFT by measuring resting EEG at in small 1Hz bands with median frequencies at 4, 7, 10 and 12Hz, in addition to the previously employed 14Hz (±0.5) band. These measures were introduced for exploratory purposes without prior predictions as to how they might change following NFT.

In his results Tansey reports that SMR activity increased by a mean of 76% after treatment, which contrasts with 137% in his previous study. The other EEG measurements described in the methods are not documented. As in Tansey (1984), WISC-R performance are described as equalising in cases who previously had disparity between verbal and performance measures, and once again the author speculated that learning improvements were mediated by increased inter-hemispheric interaction promoted by SMR NFT.

Tansey's (1984) contribution to SMR research at this point did not substantially develop upon prior claims as to the efficacy of this form of NFT. As with Lubar and Shouse (1976); Shouse and Lubar (1979); Lubar and Lubar (1984), the use of solely descriptive results precludes generalisation, and the experimental designs continued to be uncontrolled. Support for Tansey's hypothetical linear association between inter-hemispheric interaction and learning ability is limited, and his evidence in support of this hypothesis is based on speculative interpretation of data based on single electrode data that does not provide strong evidence of distributed functional connectivity.

With the exception of a review attempting to gather the findings of the previously evaluated 5 papers into a cohesive argument for the efficacy of NFT (Lubar, 1991), investigation of NFT applications in relation to attention disorders or their superset of learning disabilities was largely abandoned between 1985 and 1995. In the latter year however, Lubar et al. (1995) reported on a study that represented a attempt to improve on previous experimental designs. A sample of 23 8–19 year olds from a population presenting behavioural symptoms indicative of disordered attention, no confounding illness, and QEEG based diagnosis of ADHD.[2]

The dependent measures of the study incorporated the WISC-R, presumably in an attempt to replicate Tansey; Tansey's (1984; 1985) findings in a specifically ADHD sample. Parents completed the ADD Evaluation Scale (ADDES) (McCarney and Services, 1989) at the start and end of the study. The Test of Variables of Attention (TOVA) (Greenberg, 1987) was also introduced to the study, and has since gone on to become a widely used diagnostic tool in attention disorder NFT applications in clinics and research. The TOVA assesses several measures, principally impulsivity and inattention, and the resulting test scores indicate ability to sustain attention over an extended period in comparison to a normal performance for the age and sex of the participant. The authors also examined EEG changes by comparing levels of theta to the amount

[2]Lubar used QEEG diagnosis of ADHD based on deficient beta and excessive theta compared to a characteristically normal QEEG (Mann et al., 1992).

of training sessions held.

All participants received the same protocol in 40 training sessions over the course of approximately 10 weeks, with each session lasting 50 minutes. As in Lubar's previous work, EEG was measured as the difference between bipolar electrodes, although recording locations were at CPz and FCz. During training positive feedback was provided on the basis that beta (16–20Hz) exceeded pre-training baseline values whilst theta (4–8Hz) and EMG values were below those established at the session start.

As in previous studies the authors looked for evidence that subjects learned to reduce theta in line with training contingencies, and compared subjects whose theta amplitudes correlated negatively with the amount of sessions held (n=12) to those that didn't (n=6). This measure is presumably based on absolute measures of theta, which might be contaminated by uncontrolled factors such as baseline theta — Lubar and colleagues had previously analysed the SMR/theta ratio: a more reliable of inter-session dynamics. Whilst beta frequencies were trained in this study, they are conspicuously absent from the NFT analysis.

Having divided the sample into 'learners' and 'non-learners,' NFT efficacy was assessed based on the number of TOVA measures in which improvements had been made, with learners improving on an average of 3 and non-learners on 1.5. This assumes that improving on one measure, say impulsivity, is equal to improving on another, say inattention, when these are mutually exclusive in some cases. There appeared to be little prior justification for taking this analytical approach apart from that it does provide a more general measure of learning disability. Despite having disclosed a between-group difference, within-group changes were not assessed.

A subset of the sample was analysed for changes in the ADDES (n=13) and WISC-R (n=10) scales, although it is not clear which of the total of 18 cases are documented here, although the WISC-R data is reported as coming from learners. ADDES measures disclosed improvements in ratings of inattention, impulsivity and hyperactivity although improvements are uncorrelated with NFT learning. WISC-R measures showed improvements in verbal and overall IQ measures.

In evaluating the contribution of Lubar et al. (1995) to the NFT literature, the most striking gain is the increase in the sample size extending the scope of attention research beyond the level of case studies. The derivation of a formal measure of NFT learning and its inter-relation with changes in dependent measures is also an important step in controlling for extraneous influences and represents good design. However, the omission of beta training measures from the learning index undermines their use in the protocol, plus the use of absolute EEG measures makes the learning data sensitive to differences between session baseline values. Finally, whilst some inferential statistics are used, representing an improvement on previous reports, their inclusion is sporadic, making it difficult to draw general inferences from this paper.

Despite the shortcomings of (Lubar et al., 1995), the year of its publication marks something of a turning point in the literature concerning NFT for ADHD. From this point on, controlled trials became increasingly used, and this process of refining experimental designs culminated in several randomised controlled trials. In Arns et al. (2009) the NFT ADHD literature to-date was subjected to a meta-analysis, which will be evaluated here. Some studies were not included in this meta-analysis, either because the mean and standard deviation of pre and post treatment measures of ADHD were not available for further analysis (Lubar et al., 1995; Linden et al., 1996) or in the case of two double-blind placebo controlled trials, were disseminated in the form of unpublished conference presentations (Picard, 2006; DeBeus, 2006).[3] The omitted study by Lubar et al. (1995) has been reviewed, and prior to examining the Arns et al. (2009) meta-analysis, the other omitted paper will be evaluated.

Linden et al. (1996) reported on a controlled trial of a beta (16–20 Hz)/theta(4–8 Hz) protocol in comparison with a passive (waitlist) control group. 18 children with ADHD including some with LD between the ages of 5 and 15 took part in the first randomised controlled trial of NFT for attention disorders. Treatment consisted of 40 × 45-minute sessions of training in elevating beta activity whilst inhibiting theta. The trial took place over a 6 month period, with a concurrent control group participating in prior and subsequent measures with the Kaufman-Brief Intelligence Test (K-BIT) (Kaufman, 1990) and parent rating scales for inattention, hyperactivity, and oppositional behaviours with the IOWA-Conners Behaviour Rating Scale (Conners, 1969) and the SNAP Rating scale for diagnosing ADD (Swanson et al., 1981).

The NFT procedure was composed of 10 minute periods spent either attending to feedback, reading + feedback, or listening to a story + feedback. EEG was recorded as

[3]One of the criticisms of the meta-analysis method is that inflates overall effect-size by omitting unpublished data, which is more likely to contain null results. The Arns et al. (2009) paper addresses this issue by discarding data violating assumed heterogeneity of effect-size, and by calculating the number of null results required to negate a significant effect-size.

the difference between Cz and Pz, and feedback was contingent on the presence/absence of beta/theta in respect to baseline levels.

Following intervention the training group demonstrated improvements in K-BIT and inattention measures although there were no between group differences. The authors speculated that IQ improvements were mediated by attentional performance, although they were unable to confirm this assertion as they did not explicitly measure attention. EEG training data was not analysed because two different types of equipment had been used during the trial, and these had calculated training thresholds differently, making it impossible to provide a consistent analysis of EEG activity across the study.

Linden et al. (1996) constitutes an important turning point in the NFT ADHD literature as it marks the beginning of an era of controlled study. It is the first to be conducted in the style of a clinical trial, and to include a control group. It does however have several shortcomings. Firstly, the control condition was inactive, and so only controlled for environmental effects without adjusting for the possible benefits of participation. Secondly the EEG data was not analysed, and as such the authors were unable to demonstrate evidence of a link between training and outcome measures. Finally, the assertion that improvements in IQ were mediated by reductions in measures of inattention was not supported through correlation.

Although Linden et al. (1996) might be criticised for failing to disclose the terms of the relationship between EEG and clinical measures, this discrepancy is also true of the field as a whole. Evidence in support of the clinical efficacy of NFT in treating ADHD has grown rapidly in recent years, but this rate of progress has not been accompanied by similar gains in the understanding of how neurofeedback works. In a recent meta-analysis of NFT trials in ADHD treatment, Arns et al. (2009) argued that in clinical terms at least, the question "Does NFT work?" can be addressed without recourse to understanding "How NFT works." For this reason the meta-analysis does not discriminate between different NFT protocols and includes both spectral EEG and SCP trials.

The rationale for conducting a meta-analysis appears to have been performed in order to re-consider the previous classification[4] of NFT as a "probably efficacious" form

[4]The Association for Applied Psychophysiology and Biofeedback (AAPB) and the Society for Neuronal Regulation (SNR) jointly agreed a template for assessing the clinical efficacy of a biofeedback

of treatment for ADHD (Monastra et al., 2005) in the light of the studies that had subsequently taken place, particularly those employing a randomised controlled trial RCT design.

Studies included in the analysis were either collected from a neurofeedback bibliography (Hammond, 2008), a keyword search of the PubMed bibliographic database, or by approaching presenters at meetings of the Society of Applied Neuroscience (SAN) or the International Society for Neurofeedback and Research (ISNR). The studies evaluated in the meta-analysis studies met specific inclusion criteria: participants had a prior diagnosis of ADHD; between-groups designs had either passive or comparable active control groups; within-group designs were also included, as was a retrospective within-group study that had a large (n>500) population sample (Kaiser and Othmer, 2000). In addition to design requirements, all included studies were published in peer-reviewed journals, with one exception, RCT documented in a PhD

---

intervention under scientific review (La Vaque et al., 2002). The levels of evidence of efficacy are as follows:

1. Supported only by anecdotal reports and/or case studies in nonpeer reviewed venues. Not empirically supported.
2. Possibly Efficacious. At least one study of sufficient statistical power with well identified outcome measures, but lacking randomized assignment to a control condition internal to the study.
3. Probably Efficacious. Multiple observational studies, clinical studies, wait list controlled studies, and within-subject and intrasubject replication studies that demonstrate efficacy.
4. Efficacious In a comparison with a no-treatment control group, alternative treatment group, or sham (placebo) control utilizing randomized assignment, the investigational treatment is shown to be statistically significantly superior to the control condition or the investigational treatment is equivalent to a treatment of established efficacy in a study with sufficient power to detect moderate differences,
   (a) The studies have been conducted with a population treated for a specific problem, for whom inclusion criteria are delineated in a reliable, operationally defined manner,
   (b) The study used valid and clearly specified outcome measures related to the problem being treated,
   (c) The data are subjected to appropriate data analysis,
   (d) The diagnostic and treatment variables and procedures are clearly defined in a manner that permits replication of the study by independent researchers, and
   (e) The superiority or equivalence of the investigational treatment have been shown in at least two independent research settings.
5. Efficacious and Specific. The investigational treatment has been shown to be statistically superior to credible sham therapy, pill, or alternative bona fide treatment in at least two independent research settings.

thesis (Bakhshayesh, 2010). Studies were only included if NFT was conducted in a "standardized manner," although in practice this is a fairly loose criterion as there are no established international standards for NFT other than a tendency to use protocols based on previous studies. Included studies had to contain at least one ADHD measure from Impulsivity, Hyperactivity, or Inattention at pre and post intervention stages, and these measures had to be available as mean and standard deviation (SD) statistics, either in the original report or by personal communication.

Considering the above criteria, several reports were deemed unsuitable. Two studies were excluded as the SDs were not obtainable (Lubar et al., 1995; Linden et al., 1996); the only double-blind placebo controlled trials of NFT (Picard, 2006; DeBeus, 2006) and a controlled study (Fine et al., 1994) were excluded as they had been disseminated at conferences only.

The authors simplified the dataset before proceeding with analysis, categorising all spectral EEG training as one form, whether it was based on SMR enhancement/theta suppression, SMR enhancement/beta-2 suppression, or beta-1 enhancement/theta suppression. Furthermore SCP studies are also included under the NFT category as it is has been found that this type of NFT helps to regulate cortical excitability via the same mechanism as SMR based protocols: the striatum of the basal ganglia nuclear complex (Birbaumer, 2006).

The results of the analysis were principally based on two effect-size calculations, in controlled studies the between-subjects post-pre differences in each group were compared to pooled pre-test SDs to calculate the size of between-group effects. in between and within-subjects studies pre and post NFT means and SDs were used to calculate effect-size. The extent of effect-sizes were adjusted to express their 95% confidence intervals, and grand means of all studies were computed to give an overall indication of clinical relevance in measures of Inattention, Hyperactivity and Impulsivity. The meta-analysis included two safeguarding measures designed to improve the validity of the exercise, firstly the heterogeneity of effect-size (the Qt statistic) was used to filter out studies with especially diverse results, and secondly the fail-safe number calculated the amount of unpublished null results that would be required to reject a significant grand-average effect-size.

In inattention and impulsivity NFT vs. control effect-size was described as large (Cohen, 1992). The fail-safe figure established that more than 52 unpublished null results would be required to revoke the effect on inattention, and 37 on impulsivity. In hyperactivity the contrast disclosed a medium effect-size, with a fail-safe figure of 15.4. NFT vs. methylphenidate comparisons were only possible in impulsivity measures, and showed no difference in effect-size. In pre-post comparisons all contrasts revealed large effect-sizes and fail-safe figures of more than 320 — effect-sizes were larger in within- than between-subject studies, which the authors attributed to the effectiveness of active controls such as computerised attention training (Gevensleben et al., 2009b; Holtmann et al., 2009) or EMG biofeedback training (Bakhshayesh, 2010).

Having pooled studies that were different in potentially significant ways, post-hoc checks were performed to probe for difference in effect-size by protocol (smr/theta, beta/theta, smr/high-beta, and SCP), studies conducted before and after 2006, studies employing RCT or not, and studies in which no participants were on medication against those with some. Of the above comparisons, only randomisation proved significant, with RCTs producing studies with a significantly lower effect-size in hyperactivity only, which indicates the importance of randomisation. The final post-hoc check was a correlation between effect and outcome measures, and it was found that that studies with more training produced a greater reduction in inattention measures.

In summing up, the authors take the addition of 3 RCTs (Gevensleben et al., 2009b; Holtmann et al., 2009; Bakhshayesh, 2010) into the literature as evidence enough that NFT for ADHD is suitable for classification as 'efficacious and specific,' the highest rating of clinical efficacy according to the AAPB/SNR template (La Vaque et al., 2002). This assertion is largely based on the grounds that the RCTs mentioned used 'semi-active' controls that also had some efficacy in reducing ADHD symptoms, and controlled for the 'cognitive training' criticism levelled at NFTs use of attention demanding exercises (Loo and Barkley, 2005).

In evaluating this analysis, the first critical issue is its scope. The authors explicitly forego any examination of 'how' NFT works, preferring instead to concentrate on the principal issue of 'if' NFT works. Whilst this allows a straightforward analysis of a mixed NFT dataset with many protocol differences, it is also unable to show how they differ, leading the authors to speculate that the same mechanism underlies all the SMR variant and SCP protocols. The problem then is that this method, whilst demonstrating the efficacy of NFT in treating symptoms of inattention and impulsivity is not able to address the question of why NFT doesn't effectively modulate hyperactivity. Despite this concern, it should be noted that that hyperactivity is measured by parent and teacher questionnaires, whilst inattention and impulsivity are often measured by Go-NoGo tasks such as the TOVA, which may be more sensitive to small changes in behaviour. Another criticism of the analysis is that although the fail-safe statistics appear to offer a reasonable margin of error: 52 for inattention, 37 for impulsivity and 15 for hyperactivity, there have been approximately 60 papers published on NFT and ADHD since 1995 (Hammond, 2008), so the problem of bias can not be completely ruled out. The authors attempt to deflect this issue by indicating that they included additional unpublished data, obtained by personal communication with the writers of the original studies, so to an extent it does appear that unpublished data are at least partly represented here, although the actual amount is unclear. Inspection of the forest plots of effect-size do indicate a positive bias, and although this may be a product of NFT effects, the inherent issue of exclusivity in meta-analysis may explain why, in their closing statement, the authors emphasise the results of the RCTs on inattention and impulsivity over and above those of the meta-analysis.

Of the three recent RCTs analysed by Arns et al. (2009), there is strong contrast in the reach of the trials. Holtmann et al. (2009) is a pilot study published in a German journal, and Bakhshayesh (2010) is a PhD thesis, in German. On the other hand (Gevensleben et al., 2009b,a, 2010) are published in international journals written in English, but more significantly, this trial contains the best experimental design seen in an NFT study to date, including a large sample (n=94) recruited at three research centres across Germany, a suitable alternative control treatment, both clinical and EEG based outcome measures, a comparison of spectral and DC potential based protocols, *and* a long-term clinical follow-up study. As such, this study in particular is worth singling out for further examination.

Besides having the best experimental design of any NFT study, the Gevensleben et al. (2009b) study also marks a turning point in the use of randomisation. In the mid-2000's several researchers who, bearing in mind that NFT is considered an alternative to pharmacological intervention in ADHD, attempted to subject NFT to the same kind of comparisons used in medical trials, namely the double blind placebo controlled trial (Picard, 2006; DeBeus, 2006; Orlandi and Greco, 2005). Yet all attempts to do so have remained unpublished. In Orlandi and Greco (2005) the author described the problem of high-drop out rates in a control group as these subjects complained of the ineffectiveness of placebo feedback. In addressing this issue Gevensleben et al. (2009b) highlight the need for participants to exert effort whilst in training, and express concern that the possibility of being in a placebo group may reduce motivation, and thus learning in some subjects. The alternative strategy employed in their trial was to use a semi-active control condition; an attention skills training computer game (AST). During the game, players are required to maintain perceptual vigilance and attentional reactivity to click on the correct onscreen items at any given time. This use of alternative as opposed to placebo controls has produced a methodologically robust approach that has led a number of strong findings, and has in terms of method, established a high standard for future investigation into NFT for ADHD.

The researchers recruited enough unmedicated participants (n=94) to be able to reach sufficient statistical power to reveal at least moderate effect sizes, and the sample was subdivided into two groups receiving (NFT: n=59; AST n=35). Around a week following initial dependent measures, the intervention consisted of two 3–4 week blocks, during which participants received 18 sessions of NFT or AST. In a balanced design, the NFT training blocks consisted of alternate theta/beta or SCP protocols. Dependent measures were also carried out between blocks, and around a week following the end of training, with a 6-month follow up. Principally the study reported clinical outcomes, but also those in resting EEG and event related brain potentials.

Gevensleben et al. (2009b) compared clinical measures following NFT and AST; NFT treatment conferred significantly higher benefits in parent/teacher scores on the German ADHD rating scale (FBB-HKS) (Doepfner and Lehmkuhl, 2000), and a six-month follow-up found the earlier post-training effects persisted (Gevensleben et al., 2010); In the absence of placebo control, this step goes some way to deflect the possibly of a placebo being responsible for post-training differences, as it could be expected to have started diminishing from 2 months (Coryell and Noyes, 1988). Gevensleben et al. (2009a) disclosed that NFT produced reductions of central and parietal midline theta in 2-minute periods of rest. Theta/beta NFT specifically accounted for reductions in parietal-midline theta, and SCP saw an increase in central-midline alpha activity — both of these changes were predictive of improvements in FBB-HKS total scores suggesting that training distinct neuronal networks produce similar changes in behaviour. Wangler et al. (2010) investigated protocol specific effects on event related brain potentials recorded during an attention task (Fan et al., 2002), and found that SCP training produced an enhancement of 'cognitive preparation' expressed as the contingent negative variation brain potential (CNV). Baseline measures of CNV were associated with clinical improvements, with larger initial scores leading to better improvements, although there were no group differences, and AST cases also improved.

In summary, the reports emanating from the Gevensleben et al. (2009b) study represent the strongest evidence yet as to the clinical effectiveness of NFT for ADHD. By combining a suitable control, a large enough sample to reveal effects statistically, randomisation and follow-up, they have addressed many of the issues raised by Loo and Barkley (2005) such as the ambiguity of previous trials, and their limited generalisability. The authors also go further and attempt to isolate effect mediators, such as evidence of increases in the allocation of attentional resources. Whilst this additional step might be considered of secondary importance to the "Does NFT work?" question (Arns et al., 2009), it does also indicate that the literature is now in a position where having arguably proved Lubar's initial hypothesis that NFT could normalise cortical activity in ADHD, the neuroelectric mechanism by which this operates should be isolated as part of attempts to maximise possible benefits. The finding that theta/beta and SCP protocols effected different neuronal changes whilst producing similar effects on ratings of behaviour indicate that clinical measures are not capable of disclosing the differences between protocols, and so to understand which are most suitable in different patients further measures, including those previously eschewed in favour of clinical ones should now play a greater part in NFT for ADHD research.

To summarise the NFT in ADHD literature, the early work of Lubar and Shouse (1976) established a rationale for SMR training in ADHD by drawing parallels between overactivity in epilepsy and ADHD indicating that the neural correlates of hyperactivity might be regulated by SMR inhibition strategies. Lubar also introduced a theta inhibition element to treat inattention, which furthermore provided a relative EEG measure, the SMR/theta ratio, which was less sensitive to situational and individual differences than absolute EEG measures, facilitating comparison between sessions and people. Despite the empirical shortcomings of his pioneering studies, Lubar's protocol has survived to become the most carefully tested and widely used NFT approach of all, with the recent addition of RCTs into the literature providing the strongest support yet for the clinical relevance of NFT. The mechanisms by which NFT protocols confer clinical benefits in ADHD have not been isolated, although protocol specificity is being addressed in recent literature.

Study	Country	Conditions	Groups	n	Age	Measure	Instrument	NF Site	Treatment	Mean No. Sessions
Controlled Trials										
(Rossiter and La Vaque, 1995)	USA	Stimulant control group	ADHD: Control:	23 23	12,9 12,9	Hyperactivity Impulsivity Inattention	BASC TOVA	Cz, FCz,CPz	Beta/Theta	20
Monastra et al. (2005)	USA	Control group	ADHD: Control:	51 49	10 10	Hyperactivity Impulsivity Inattention	ADDES TOVA ADDES	CPz and Cz	Beta/Theta	43
Fuchs et al. (2003)	USA	Control group	ADHD: Control	22 11	9,8 9,6	Impulsivity	TOVA	C3 or C4	Beta/Theta	36
(Heinrich et al., 2004)	DE	Waiting List Control group	ADHD: Control:	13 9	11,1 10,5	Hyperactivity Impulsivity Inattention	FBB-HKS TOVA	Cz	SCP	25
(Rossiter, 2004)	USA	Stimulant control group	ADHD: Control:	31 31	16,6 16,7	Hyperactivity Impulsivity Inattention	BASC TOVA BASC	C3 or C8	Beta/Theta	50
(Lévesque et al., 2006)	CA	RCT control group	ADHD: Control:	15 5	10,2	Hyperactivity	CPRS-R	Cz	Beta/Theta	40
Bakhshayesh (2010)	DE	RCT control group EMG Biofeedback	ADHD: Control:	18 17	9,61 9,06	Hyperactivity Impusivity Inattention	FBB-HKS CPT FBB-HKS	FCz-CPz	Beta/Theta	30
(Drechsler et al., 2007)	CH	Group Therapy Control group	ADHD: Control:	17 13	10,5 10,2	Hyperactivity Impulsivity Inattention	FBB-HKS Tap No-Go FBB-HKS	Cz	SCP	30
Gevensleben et al. (2009b)	CH	Group therapy Control Group	ADHD: Control:	59 35	9,1 9,4	Hyperactivity Impulsivity Inattention	FBB-HKS FBB-HKS	Cz	SCP and Beta/Theta	36
Holtmann et al. (2009)	DE	RCT Captain's Log Control Group	ADHD: Control	20 14	10,3 10,2	Hyperactivity Impulsivity Inattention	FBB-HKS FBB-HKS	Cz	Beta/Theta	20
Within-Subjects Trials										
6) Kropotov et al. 2005	Russia	Pre/post-design	ADHD	18	11,4	Hyperactivity Impulsivity Inattention	SNAP-4 Go-No-Go SNAP-4	C3-Fz or C4-Pz	Beta (C3) SMR C4	17
7) Xiong et al. 2005	China	Pre/post-design	ADHD	60	>6	Omissions	IVA	?	Beta/Theta	40
12) Leins et al. 2007	DE	Pre/post-design Randomised to SCP or Beta/Theta	ADHD	19	9,2	Hyperactivity Impulsivity Inattention	DSM-IV RS	C3 and C4	Beta/Theta	30
Retrospective Within-Subjects Trial										
15) Kaiser & Othmer 2000	USA	Multisite naturalistic pre/post-design	ADHD	530	17,3	Impulsivity	TOVA	C3, C4	Beta/Theta	30

Table B.1: Overview of studies used in Arns et al. (2009)

C

Folk Assessment

Directions – Circle Appropriate Score by Each Statement

	1	2	3	4	5	6	7	8	9	10
Overall Quality										
Overall rating of Performance Quality	1	2	3	4	5	6	7	8	9	10
Vocal Competence										
Overall rating of Vocal Competence	1	2	3	4	5	6	7	8	9	10
Breathing with Music in Mind	1	2	3	4	5	6	7	8	9	10
Clarity of Diction	1	2	3	4	5	6	7	8	9	10
Pitch	1	2	3	4	5	6	7	8	9	10
Musicality										
Overall rating of Musical Understanding	1	2	3	4	5	6	7	8	9	10
Interpretative Imagination	1	2	3	4	5	6	7	8	9	10
Expressive Range	1	2	3	4	5	6	7	8	9	10
Being at one with Voice	1	2	3	4	5	6	7	8	9	10
Stylistic Accuracy	1	2	3	4	5	6	7	8	9	10
Rhythmic Accuracy	1	2	3	4	5	6	7	8	9	10
Degree of Engagement	1	2	3	4	5	6	7	8	9	10
Communication										
Overall rating of Communicative Ability	1	2	3	4	5	6	7	8	9	10
Deportment on stage	1	2	3	4	5	6	7	8	9	10
Emotional commitment and conviction	1	2	3	4	5	6	7	8	9	10
Confidence in the situation	1	2	3	4	5	6	7	8	9	10
Sense of Performance	1	2	3	4	5	6	7	8	9	10

D

Stripsody Assessment

Directions – Circle Appropriate Score by Each Statement with reference to your copy of the Score

	1	2	3	4	5	6	7	8	9	10
Overall Quality										
Overall rating of Performance Quality	1	2	3	4	5	6	7	8	9	10
Vocal Competence										
Overall rating of Vocal Competence	1	2	3	4	5	6	7	8	9	10
Diction	1	2	3	4	5	6	7	8	9	10
Pitch	1	2	3	4	5	6	7	8	9	10
Breathing with the Music	1	2	3	4	5	6	7	8	9	10
Tonal Spectrum	1	2	3	4	5	6	7	8	9	10
Musicality										
Overall rating of Musical Understanding	1	2	3	4	5	6	7	8	9	10
Interpretative Imagination	1	2	3	4	5	6	7	8	9	10
Being at one with Voice	1	2	3	4	5	6	7	8	9	10
Communication										
Overall rating of Communicative Ability	1	2	3	4	5	6	7	8	9	10
Deportment on stage	1	2	3	4	5	6	7	8	9	10
Emotional commitment and conviction	1	2	3	4	5	6	7	8	9	10
Confidence in the situation	1	2	3	4	5	6	7	8	9	10
Enjoyment in Performing	1	2	3	4	5	6	7	8	9	10
Holding of Attention	1	2	3	4	5	6	7	8	9	10

E

Instrumental Solo Assessment

Directions – Circle Appropriate Score by Each Statement

	Fail	Pass	III		II:2		II:1		I	
	1	2	3	4	5	6	7	8	9	10
Overall Quality										
Overall rating of Performance Quality	1	2	3	4	5	6	7	8	9	10
Instrumental Competence										
Overall rating of Instrumental Competence	1	2	3	4	5	6	7	8	9	10
Rhythmic Accuracy	1	2	3	4	5	6	7	8	9	10
Level of Technical Security (including state of preparation)	1	2	3	4	5	6	7	8	9	10
Tonal Quality and Spectrum	1	2	3	4	5	6	7	8	9	10
Musicality										
Overall rating of Musical Understanding	1	2	3	4	5	6	7	8	9	10
Stylistic Accuracy	1	2	3	4	5	6	7	8	9	10
Interpretative Imagination	1	2	3	4	5	6	7	8	9	10
Expressive Range	1	2	3	4	5	6	7	8	9	10
Communication										
Overall rating of Communicative Ability	1	2	3	4	5	6	7	8	9	10
Deportment on stage	1	2	3	4	5	6	7	8	9	10
Emotional commitment and conviction	1	2	3	4	5	6	7	8	9	10
Confidence in the situation	1	2	3	4	5	6	7	8	9	10
Sense of Performance	1	2	3	4	5	6	7	8	9	10

F

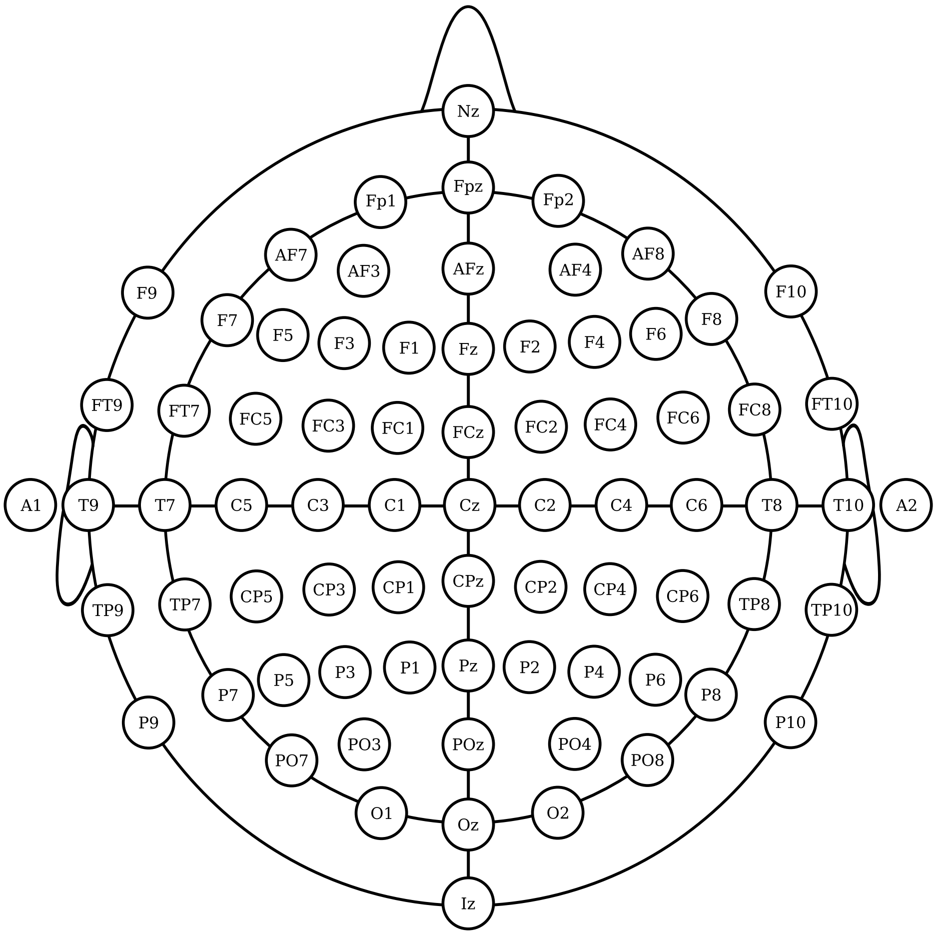
Instrumental Improvisation Assessment

Directions – Circle Appropriate Score by Each Statement with reference to the Theme of the Improvisation

	Fail	Pass	III		II:2		II:1		I	
	1	2	3	4	5	6	7	8	9	10
Overall Quality										
Overall rating of Performance Quality	1	2	3	4	5	6	7	8	9	10
Improvisational Competence										
Overall rating of Improvisational Competence	1	2	3	4	5	6	7	8	9	10
Musicality										
Overall rating of Musical Understanding	1	2	3	4	5	6	7	8	9	10
Appropriateness to Theme	1	2	3	4	5	6	7	8	9	10
Fluency	1	2	3	4	5	6	7	8	9	10
Temporal Sense	1	2	3	4	5	6	7	8	9	10
Communication										
Overall rating of Communicative Ability	1	2	3	4	5	6	7	8	9	10
Deportment on stage	1	2	3	4	5	6	7	8	9	10
Emotional commitment and conviction	1	2	3	4	5	6	7	8	9	10
Confidence in the situation	1	2	3	4	5	6	7	8	9	10
Sense of Performance	1	2	3	4	5	6	7	8	9	10

G

10–20 system of EEG electrode locations



Bibliography

Aeschbach, D., Postolache, T. T., Sher, L., Matthews, J. R., Jackson, M. A., and Wehr, T. A. (2001). Evidence from the waking electroencephalogram that short sleepers live under higher homeostatic sleep pressure than long sleepers. *Neuroscience*, 102(3):493–502.

Amabile, T. (1982). Social psychology of creativity: A consensual assessment technique. *J. Pers. Soc. Psychol.*, 43(5):997–1013.

Amabile, T. (1996). *Creativity in Context: Update to the Social Psychology of Creativity*. Westview Press, Cumnor Hill, Oxford.

Amthauer, R. (1970). Intelligenz struktur test (ist 70, 4. aufl.).[test of the structure of intelligence]. *Gottingen, Stuttgart: Hogrefe*.

Amzica, F. and Steriade, M. (2002). The functional significance of K-complexes. *Sleep Medicine Reviews*, 6(2):139–149.

Anand, B., Chhina, G., and Singh, B. (1961). Some aspects of electroencephalographic studies in yogis. *Electroencephalogr. Clin. Neurophysiol.*, 13(3):452–456.

Andersen, P. and Andersson, S. (1968). *Physiological basis of the alpha rhythm*. Plenum Pub Corp, New York.

Arden, R., Chavez, R. S., Grazioplene, R., and Jung, R. E. (2010). Neuroimaging creativity: A psychometric view. *Behav. Brain Res.*, 214(2):143–156.

Arns, M., de Ridder, S., Strehl, U., Breteler, M., and Coenen, A. (2009). Efficacy of neurofeedback treatment in adhd: the effects on inattention, impulsivity and hyperactivity: a meta-analysis. *Clin. EEG Neurosci.*, 40(3):180–9.

Backhaus, J. and Junghanns, K. (2006). Daytime naps improve procedural motor memory. *Sleep Medicine*, 7(6):508.

Bakhshayesh, A. (2010). *Die Wirksamkeit von Neurofeedback im Vergleich zum EMG-Biofeedback bei der Behandlung von ADHS-Kindern*. GRIN Verlag.

Bangert, M. and Altenmüller, E. O. (2003). Mapping perception to action in piano practice: a longitudinal DC-EEG study. *BMC Neurosci*, 4:26.

Banquet, J. (1973). Spectral analysis of the EEG in meditation. *Electroencephalogr. Clin. Neurophysiol.*, 35(2):143–151.

Barceló, F. and Knight, R. T. (2002). Both random and perseverative errors underlie wcst deficits in prefrontal patients. *Neuropsychologia*, 40(3):349–56.

Barnea, A., Rassis, A., and Zaidel, E. (2005). Effect of neurofeedback on hemispheric word recognition. *Brain Cogn.*, 59(3):314–21.

Beck, A. T. and Steer, R. A. (1984). Internal consistencies of the original and revised beck depression inventory. *J. Clin. Psychol.*, 40(6):1365–7.

Begic, D., Hotujac, L., and Jokic-Begic, N. (2001). Electroencephalographic comparison of veterans with combat-related post-traumatic stress disorder and healthy subjects. *Int. J. Psychophysiol.*, 40(2):167–72.

Bengtsson, S., Csikszentmihalyi, M., and Ullen, F. (2007). Cortical Regions Involved in the Generation of Musical Structures during Improvisation in Pianists. *J. Cogn. Neurosci.*, 19(5):830–842.

Berberian, C. (1966). Stripsody. C.F. Peters.

Berg, E. A. (1948). A simple objective technique for measuring flexibility in thinking. *J. Gen. Psychol.*, 39:15–22.

Berger, H. (1929). Uber das elektrenkephalogramm des menschen. *Arch. Psychiatr. Nervenkr.*, 87:527–570.

Berkowitz, A. and Ansari, D. (2008). Generation of novel motor sequences: The neural correlates of musical improvisation. *Neuroimage*.

Berkowitz, A. and Ansari, D. (2010). Expertise-related deactivation of the right temporoparietal junction during musical improvisation. *Neuroimage*, 49(1):712–719.

Bessel, J. and Gevirtz, R. (1998). Effects of breathing retraining versus cognitive techniques on cognitive and somatic components of state anxiety and on performance of female gymnasts. *Biological Psychology*, 48(1):18.

Bharucha, J. J. (1984). Anchoring effects in music: The resolution of dissonance. *Cognit. Psychol.*, 16(4):485–518.

Birbaumer, N. (1999). Slow cortical potentials: Plasticity, operant control, and behavioral effects. *The Neuroscientist*, 5(2):74.

Birbaumer, N. (2006). Breaking the silence: brain-computer interfaces (bci) for communication and motor control. *Psychophysiology*, 43(6):517–32.

Birbaumer, N., Elbert, T., Rockstroh, B., Daum, I., Wolf, P., and Canavan, A. (1991). Clinical-psychological treatment of epileptic seizures: A controlled study. *Perspectives and promises in clinical psychology*, pages 81–96.

Bland, B. H. and Oddie, S. D. (2001). Theta band oscillation and synchrony in the hippocampal formation and associated structures: the case for its role in sensorimotor integration. *Behav. Brain Res.*, 127(1-2):119–36.

Bland, J. M. and Altman, D. G. (1994). Regression towards the mean. *BMJ*, 308(6942):1499.

Bodenhamer-Davis, E., Callaway, T., and DeBeus, M. (2004). Extended follow-up of peniston protocol results with chemical dependency. *Journal of Neurotherapy*, 8:135–135.

Boynton, T. (2001). Applied research using alpha/theta training for enhancing creativity and well-being. *Journal of Neurotherapy*, 5(1/2):5–18.

Brennan, M. (1982). Relationship Between Creative Ability in Dance and Selected Creative Attributes. *Percept. Mot. Skills*, 55(1):p47–56.

Breton, A. (1924). Le manifeste du surréalisme. Manifesto.

Britten, B. (1948). Folksong arrangements volume 1 british isles : Medium voice. Boosey and Hawkes pp22.

Brooks, A. and Lack, L. (2006). A brief afternoon nap following nocturnal sleep restriction: which nap duration is most recuperative? *Sleep*, 29(6):831–40.

Brotons, M. (1994). Effects of performing conditions on music performance anxiety and performance quality. *J. Music Ther.*, 31:63–63.

Brown, B. (1974). *New mind, new body: bio-feedback: new directions for the mind*. Harper & Row, New York.

Brown, B. (1975a). Biofeedback: An exercise in self control. *Saturday Rev.*

Brown, B. (1975b). *The biofeedback syllabus: A handbook for the psychophysiologic study of biofeedback*. Charles C. Thomas Publisher, Springfield, Ill.

Brown, B. B. (1970a). Awareness of EEG-subjective activity relationships detected within a closed feedback system. *Psychophysiology*, 7(3):451–64.

Brown, B. B. (1970b). Recognition of aspects of consciousness through association with EEG alpha activity represented by a light signal. *Psychophysiology*, 6(4):442–52.

Brown, S., Martinez, M., and Parsons, L. (2006). Music and language side by side in the brain: a PET study of the generation of melodies and sentences. *Eur. J. Neurosci.*, 23(10):2791–2803.

Bryan-Kinns, N., Healey, P. G., and Leach, J. (2007). Exploring mutual engagement in creative collaborations. In *Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition*, pages 223–232. ACM.

Bullock, T., Orkand, R., and Grinnell, A. (1977). *Introduction to nervous systems*. WH Freeman San Francisco, San Francisco.

Burgess, A. P. and Gruzelier, J. H. (1997). Short duration synchronization of human theta rhythm during recognition memory. *Neuroreport*, 8(4):1039–42.

Burgess, A. P. and Gruzelier, J. H. (2000). Short duration power changes in the EEG during recognition memory for words and faces. *Psychophysiology*, 37(5):596–606.

Burkett, S., Cummins, J., Dickson, R., and Skolnick, M. (2003). Neurofeedback in the treatment of addiction with a homeless population. In *ISNR 11^{th} annual conference, Houston, September*, pages 18–21.

Buzsáki, G. (2002). Theta oscillations in the hippocampus. *Neuron*, 33(3):325–40.

Buzsáki, G. (2005). Theta rhythm of navigation: link between path integration and landmark navigation, episodic and semantic memory. *Hippocampus*, 15(7):827–40.

Cabeza, R. and Nyberg, L. (2000). Imaging cognition ii: An empirical review of 275 PET and fmri studies. *J. Cogn. Neurosci.*, 12(1):1–47.

Cai, D., Mednick, S., Harrison, E., Kanady, J., and Mednick, S. (2009). REM, not incubation, improves creativity by priming associative networks. *Proceedings of the National Academy of Sciences*, 106(25):10130.

Cajochen, C., Brunner, D. P., Kräuchi, K., Graw, P., and Wirz-Justice, A. (1995). Power density in theta/alpha frequencies of the waking EEG progressively increases during sustained wakefulness. *Sleep*, 18(10):890–4.

Callaway, T. and Bodenhamer-Davis, E. (2008). Long-term follow-up of a clinical replication of the peniston protocol for chemical dependency. *Journal of Neurotherapy*, 12(4):243–259.

Cantero, J. L., Atienza, M., Stickgold, R., Kahana, M. J., Madsen, J. R., and Kocsis, B. (2003). Sleep-dependent theta oscillations in the human hippocampus and neocortex. *J. Neurosci.*, 23(34):10897–903.

Chamorro-Premuzic, T. and Reichenbacher, L. (2008). Effects of personality and threat of evaluation on divergent and convergent thinking. *Journal of Research in Personality*.

Christensen, P., Guilford, J., Merrifield, P., and Wilson, R. (1960a). Alternate uses form B and C.

Christensen, P., Guilford, J., Merrifield, R., and Wilson, R. (1960b). Alternate uses test. *Beverly Hills, CA: Sheridan Psychological Service*.

Ciçek, M. and Nalçaci, E. (2001). Interhemispheric asymmetry of EEG alpha activity at rest and during the wisconsin card sorting test: relations with performance. *Biol. Psychol.*, 58(1):75–88.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences (2nd Edition)*. L. Erlbaum Associates, Hillsdale, New Jersey.

Cohen, J. (1992). A power primer. *Psychol. Bull.*, 112(1):155–9.

Coleridge, S. (1816). Kubla khan, or a vision in a dream. a fragment. poem.

Conners, C. (1969). A teacher rating scale for use in drug studies with children. *Am. J. Psychiatry*, 126(6):884.

Contreras, D., Destexhe, A., Sejnowski, T., and Steriade, M. (1996). Control of spatiotemporal coherence of a thalamic oscillation by corticothalamic feedback. *Science*, 274(5288):771.

Coryell, W. and Noyes, R. (1988). Placebo response in panic disorder. *Am. J. Psychiatry*, 145(9):1138–40.

Costa, P. T. and McCrae, R. R. (1985). *The NEO personality inventory: Manual, form S and form R.* Psychological Assessment Resources, Odessa, Fla.

Creech, A., Papageorgi, I., Duffy, C., Morton, F., Hadden, E., Potter, J., De Bezenac, C., Whyton, T., Himonides, E., and Welch, G. (2008). Investigating musical performance: commonality and diversity among classical and non-classical musicians. *Music education research*, 10(2):215–234.

Crider, A., Shapiro, D., and Tursky, B. (1966). Reinforcement of spontaneous electrodermal activity. *J. Comp. Physiol. Psychol.*, 61(1):20–27.

Csikszentmihalyi, M. (1997). Flow and the psychology of discovery and invention. *HarperPerennial, New York*.

Cycowicz, Y. M., Friedman, D., and Snodgrass, J. G. (2001). Remembering the color of objects: an erp investigation of source memory. *Cereb. Cortex*, 11(4):322–34.

da Silva, F. H., van Lierop, T. H., Schrijer, C. F., and van Leeuwen, W. S. (1973). Organization of thalamic and cortical alpha rhythms: spectra and coherences. *Electroencephalogr. Clin. Neurophysiol.*, 35(6):627–39.

Daum, I., Rockstroh, B., Birbaumer, N., Elbert, T., Canavan, A., and Lutzenberger, W. (1993). Behavioural treatment of slow cortical potentials in intractable epilepsy: neuropsychological predictors of outcome. *J. Neurol. Neurosurg. Psychiatry*, 56(1):94–7.

De Gennaro, L., Ferrara, M., and Bertini, M. (2001). The boundary between wakefulness and sleep: quantitative electroencephalographic changes during the sleep onset period. *Neuroscience*, 107(1):1–11.

DeBeus, R. (2006). Efficacy of attention training for children with adhd: Efficacy of attention training for children with adhd: A randomized double-blind placebo-controlled study. In *ISNR conference, Atlanta, GA, USA*.

deCharms, R. C., Maeda, F., Glover, G. H., Ludlow, D., Pauly, J. M., Soneji, D., Gabrieli, J. D. E., and Mackey, S. C. (2005). Control over brain activation and pain learned by using real-time functional MRI. *Proc. Natl. Acad. Sci. U. S. A.*, 102(51):18626–31.

Delorme, A. and Makeig, S. (2004). EEGlab: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *J. Neurosci. Methods*, 134(1):9–21.

Denney, M. and Baugh, J. (1992). Symptom reduction and sobriety in the male alcoholic. *Substance Use & Misuse*, 27(11):1293–1300.

Di Lazzaro, V., Pilato, F., Saturno, E., Oliviero, A., Dileone, M., Mazzone, P., Insola, A., Tonali, P. A., Ranieri, F., Huang, Y. Z., and Rothwell, J. C. (2005). Theta-burst repetitive transcranial magnetic stimulation suppresses specific excitatory circuits in the human motor cortex. *J Physiol*, 565(Pt 3):945–50.

Dickens, C. (1894). *The uncommercial traveller: and, Pictures from Italy*. Houghton, Mifflin, Boston.

Dietrich, A. (2003). Functional neuroanatomy of altered states of consciousness: The transient hypofrontality hypothesis. *Conscious. Cogn.*, 12(2):231–256.

Dietrich, A. (2004a). The cognitive neuroscience of creativity. *Psychon Bull Rev*, 11(6):1011–26.

Dietrich, A. (2004b). Neurocognitive mechanisms underlying the experience of flow. *Conscious. Cogn.*, 13(4):746–61.

Dietrich, A. and Kanso, R. (2010). A review of EEG, erp, and neuroimaging studies of creativity and insight. *Psychol. Bull.*, 136(5):822–48.

Doepfner, M. and Lehmkuhl, G. (2000). Fbb-hks [rating-scale for hyperkinetic disorder from the diagnostic system for mental disorders in childhood and adolescence according to ICd-10 and DSm-iv (disyps-kj)]. *Gottingen: Hogrefe*.

Doppelmayr, M., Finkenzeller, T., and Sauseng, P. (2008). Frontal midline theta in the pre-shot phase of rifle shooting: differences between experts and novices. *Neuropsychologia*, 46(5):1463–7.

Doppelmayr, M., Klimesch, W., Pachinger, T., and Ripper, B. (1998). Individual differences in brain dynamics: important implications for the calculation of event-related band power. *Biol. Cybern.*, 79(1):49–57.

Drechsler, R., Straub, M., Doehnert, M., Heinrich, H., Steinhausen, H.-C., and Brandeis, D. (2007). 1controlled evaluation of a neurofeedback training of slow cortical potentials in children with attention deficit/hyperactivity disorder (adhd). *Behav Brain Funct*, 3:35.

Dumermuth, G., Lange, B., Lehmann, D., Meier, C. A., Dinkelmann, R., and Molinari, L. (1983). Spectral analysis of all-night sleep EEG in healthy adults. *Eur. Neurol.*, 22(5):322–39.

EEGer Neurofeedback Software, Operator's Manual, V. c. (2005). *EEGer Neurofeedback Software, Operator's Manual, Version 4.1.3c*. EEGer.

Eerola, T. and Toiviainen, P. (2004). Midi toolbox: Matlab tools for music research, university of jyv⊠§skyl⊠§: Kopijyv⊠§, jyv⊠§skyl⊠§, finland.

Egner, T. and Gruzelier, J. (2003). Ecological validity of neurofeedback: modulation of slow wave EEG enhances musical performance. *Neuroreport*, Vol 14 No 9 1 July 2003.

Egner, T. and Gruzelier, J. (2004a). The temporal dynamics of electroencephalographic responses to alpha/theta neurofeedback training in healthy subjects. *Journal of Neurotherapy*, 8(1):43–57.

Egner, T. and Gruzelier, J. H. (2001). Learned self-regulation of EEG frequency components affects attention and event-related brain potentials in humans. *Neuroreport*, 12(18):4155–9.

Egner, T. and Gruzelier, J. H. (2004b). EEG biofeedback of low beta band components: frequency-specific effects on variables of attention and event-related brain potentials. *Clin. Neurophysiol.*, 115(1):131–139.

Egner, T. and Sterman, M. B. (2006). Neurofeedback treatment of epilepsy: from basic rationale to practical application. *Expert Rev. Neurother.*, 6(2):247–57.

Egner, T., Strawson, E., and Gruzelier, J. H. (2002). EEG signature and phenomenology of alpha/theta neurofeedback training versus mock feedback. *Appl. Psychophysiol. Biofeedback*, 27(4):261–270.

Egner, T., Zech, T. F., and Gruzelier, J. H. (2004). The effects of neurofeedback training on the spectral topography of the electroencephalogram. *Clin. Neurophysiol.*, 115(11):2452–2460.

Eisenberg, J. and Thompson, W. (2003). A matter of taste: evaluating improvised music. *Creativity Research Journal*, 15(2):287–296.

Engel, B. and Chism, R. (1967). Operant conditioning of heart rate speeding. *Psychophysiology*, 3(4):418–426.

Fahrion, S. (1999). Human potential and personal transformation. *Subtle Energies and Energy Medicine*, 10:234–234.

Fahrion, S., Walters, E., Coyne, L., and Allen, T. (1992). Alterations in EEG amplitude, personality factors, and brain electrical mapping after alpha-theta brainwave training: A controlled case study of an alcoholic in recovery. *Alcoholism: Clinical and Experimental Research*, 16(3):547–552.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., and Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *J. Cogn. Neurosci.*, 14(3):340–7.

Fine, A., Goldman, L., and Sandford, J. (1994). Innovative techniques in the treatment of adhd: an analysis of the impact of EEG biofeedback training and a cognitive computer generated training. *American Psychological Association, Los Angeles, CA*.

Fink, A., Grabner, R., Benedek, M., and Neubauer, A. (2006). Short Communication Divergent thinking training is related to frontal electroencephalogram alpha synchronization. *Eur. J. Neurosci.*, 23:2241–2246.

Fink, A., Graif, B., and Neubauer, A. C. (2009). Brain correlates underlying creative thinking: EEG alpha activity in professional vs. novice dancers. *Neuroimage*, 46(3):854–62.

Finkelberg, A., Sokhadze, E., Lopatin, A., Shubina, O., Kokorina, N., Skok, A., and Shtark, M. (1996). The application of alpha-theta EEG biofeedback training for psychological improvement in the process of rehabilitation of the patients with pathological addictions. *Biofeedback and Self-Regulation*, 21:364.

Fishbein, D., Thatcher, R., and Cantor, D. (1990). Ingestion of carbohydrates varying in complexity produce differential brain responses. *Clinical EEG electroencephalography*, 21(1):5–11.

Fitzsimons, G. M., Chartrand, T. L., and Fitzsimons, G. J. (2008). Automatic effects of brand exposure on motivated behavior: how apple makes you "think different". *Journal of Consumer Research*, 35(1):21–35.

Fox, S. and Rudell, A. (1968). Operant controlled neural event: Formal and systematic approach to electrical coding of behavior in brain. *Science*, 162(3859):1299.

Friedman, P. (1994). *Friedman Well-Being Scale and Professional Manual: Manual, Questionnaire, Scoring Sheets. Sampler Set*. Mind Garden, Redwood City, Calif.

Fuchs, T., Birbaumer, N., Lutzenberger, W., Gruzelier, J., and Kaiser, J. (2003). Neurofeedback treatment for attention-deficit/hyperactivity disorder in children: a comparison with methylphenidate. *Appl. Psychophysiol. Biofeedback*, 28(1):1–12.

Funderburk, W. (1949). Electroencephalographic studies in chronic alcoholics. *Electroencephalogr. Clin. Neurophysiol.*, 1:369–370.

Funkhouser, J., Nagler, B., and Walke, N. (1953). The electro-encephalogram of chronic alcoholism. *South. Med. J.*, 46(5):423.

Gevensleben, H., Holl, B., Albrecht, B., Schlamp, D., Kratz, O., Studer, P., Rothenberger, A., Moll, G. H., and Heinrich, H. (2010). Neurofeedback training in children with adhd: 6-month follow-up of a randomised controlled trial. *Eur. Child Adolesc. Psychiatry*, 19(9):715–24.

Gevensleben, H., Holl, B., Albrecht, B., Schlamp, D., Kratz, O., Studer, P., Wangler, S., Rothenberger, A., Moll, G. H., and Heinrich, H. (2009a). Distinct EEG effects related to neurofeedback training in children with adhd: a randomized controlled trial. *Int. J. Psychophysiol.*, 74(2):149–57.

Gevensleben, H., Holl, B., Albrecht, B., Vogel, C., Schlamp, D., Kratz, O., Studer, P., Rothenberger, A., Moll, G. H., and Heinrich, H. (2009b). Is neurofeedback an efficacious treatment for adhd? a randomised controlled clinical trial. *J. Child Psychol. Psychiatry*, 50(7):780–9.

Gevins, A., Smith, M. E., McEvoy, L., and Yu, D. (1997). High-resolution EEG mapping of cortical activation related to working memory: effects of task difficulty, type of processing, and practice. *Cereb. Cortex*, 7(4):374–85.

Goldman, R. I., Stern, J. M., Engel, Jr, J., and Cohen, M. S. (2002). Simultaneous EEG and fmri of the alpha rhythm. *Neuroreport*, 13(18):2487–92.

González-Hernández, J. A., Pita-Alcorta, C., Cedeño, I., Bosch-Bayard, J., Galán-Garcia, L., Scherbaum, W. A., and Figueredo-Rodriguez, P. (2002). Wisconsin card sorting test synchronizes the prefrontal, temporal and posterior association cortex in different frequency ranges and extensions. *Hum. Brain Mapp.*, 17(1):37–47.

Gorder, W. (1980). Divergent production abilities as constructs of musical creativity. *Journal of Research in Music Education*, Vol. 28(1):34–42.

Goslinga, J. (1975). Biofeedback for chemical problem patients: A developmental process. *Journal of Biofeedback*, 2:17–27.

Graap, K. and Freides, D. (1998). Regarding the database for the peniston alpha-theta EEG biofeedback protocol. *Appl. Psychophysiol. Biofeedback*, 23(4):265–272.

Gray, C. M. and McCormick, D. A. (1996). Chattering cells: superficial pyramidal neurons contributing to the generation of synchronous oscillations in the visual cortex. *Science*, 274(5284):109–13.

Green, D. and Swets, J. (1966). *Signal detection theory and psychophysics*. Wiley, New York, NY.

Green, E. and Green, A. (1977). *Beyond biofeedback.* Delacorte, New York, NY.

Green, E., Green, A., and Walters, D. (1972). Biofeedback for mind-body self-regulation: Healing and creativity. *Biofeedback and self-control*, pages 152–166.

Green, E., Green, A., and Walters, E. (1970). Voluntary control of internal states: Psychological and physiological. *Journal of Transpersonal Psychology*, 2:1–26.

Green, E., Green, A., and Walters, E. (1974). Alpha-theta biofeedback training. *Journal of Biofeedback*, 2:7–13.

Greenberg, L. M. (1987). An objective measure of methylphenidate response: clinical use of the MCa. *Psychopharmacol. Bull.*, 23(2):279–82.

Grego, F., Vallier, J.-M., Collardeau, M., Bermon, S., Ferrari, P., Candito, M., Bayer, P., Magnié, M.-N., and Brisswalter, J. (2004). Effects of long duration exercise on cognitive function, blood glucose, and counterregulatory hormones in male cyclists. *Neurosci. Lett.*, 364(2):76–80.

Gruzelier, J. (2009). A theory of alpha/theta neurofeedback, creative performance enhancement, long distance functional connectivity and psychological integration. *Cogn Process*, 10 Suppl 1:S101–9.

Gruzelier, J. and Egner, T. (2005). Critical validation studies of neurofeedback. *Child Adolesc. Psychiatr. Clin. N. Am.*, 14(1):83–104, vi.

Gruzelier, J., Egner, T., and Vernon, D. (2006). Validating the efficacy of neurofeedback for optimising performance. *Prog. Brain Res.*, 159:421–31.

Gruzelier, J., Inoue, A., Smart, R., Steed, A., and Steffert, T. (2010). Acting performance and flow state enhanced with sensory-motor rhythm neurofeedback comparing ecologically valid immersive vr and training screen scenarios. *Neurosci. Lett.*, 480(2):112–6.

Guilford, J. (1950). Creativity. *Am. Psychol.*, 5(9):444–54.

Guilford, J. P. (1978). *Alternate uses: form B, form C : manual of instructions and interpretations*. Sheridan Psychological Services, Orange, Calif.

Haarmann, H. J. and Cameron, K. A. (2005). Active maintenance of sentence meaning in working memory: evidence from EEG coherences. *Int. J. Psychophysiol.*, 57(2):115–28.

Haimov, I. and Shatil, E. (2013). Cognitive training improves sleep quality and cognitive function among older adults with insomnia. *PloS one*, 8(4):e61390.

Hall, M. (1977). Theta training: Imagery and creativity. *Beyond Biofeedback (EE Green & AM Green, eds.). Delacorte, San Francisco*.

Hammond, D. (2008). Comprehensive neurofeedback bibliography: 2007 update. *Journal of Neurotherapy*, 11(3):45–60.

Hanslmayr, S., Sauseng, P., Doppelmayr, M., Schabus, M., and Klimesch, W. (2005). Increasing individual upper alpha power by neurofeedback improves cognitive performance in human subjects. *Appl. Psychophysiol. Biofeedback*, 30(1):1–10.

Hardt, J. V. and Kamiya, J. (1978). Anxiety change through electroencephalographic alpha feedback seen only in high anxiety subjects. *Science*, 201(4350):79–81.

Harvey, J. (1994). *These Music Exams*. Associated Board of the Royal Schools of Music Publications., London.

Hasson, U., Nir, Y., Levy, I., Fuhrmann, G., and Malach, R. (2004). Intersubject synchronization of cortical activity during natural vision. *Science*, 303(5664):1634–40.

Hathaway, S. and McKinley, J. (1940). A multiphasic personality schedule (minnesota): I. construction of the schedule. *The Journal of Psychology*, 10(2):249–254.

Haueisen, J. and Knösche, T. (2001). Involuntary motor activity in pianists evoked by music perception. *J. Cogn. Neurosci.*, 13(6):786–792.

Hayashi, M., Ito, S., and Hori, T. (1999a). The effects of a 20-min nap at noon on sleepiness, performance and EEG activity. *Int. J. Psychophysiol.*, 32(2):173–80.

Hayashi, M., Watanabe, M., and Hori, T. (1999b). The effects of a 20 min nap in the mid-afternoon on mood, performance and EEG activity. *Clin. Neurophysiol.*, 110(2):272–279.

Heilman, K. M., Nadeau, S. E., and Beversdorf, D. O. (2003). Creative innovation: possible brain mechanisms. *Neurocase*, 9(5):369–79.

Heinrich, H., Gevensleben, H., Freisleder, F. J., Moll, G. H., and Rothenberger, A. (2004). Training of slow cortical potentials in attention-deficit/hyperactivity disorder: evidence for positive behavioral and neurophysiological effects. *Biol. Psychiatry*, 55(7):772–5.

Hinds, O., Ghosh, S., Thompson, T. W., Yoo, J. J., Whitfield-Gabrieli, S., Triantafyllou, C., and Gabrieli, J. D. E. (2010). Computing moment-to-moment bold activation for real-time neurofeedback. *Neuroimage*.

Hingley, V. D. (1985). *Performance anxiety in music: a review of the literature*. PhD thesis, University of Washington.

Hoedlmoser, K., Pecherstorfer, T., Gruber, G., Anderer, P., Doppelmayr, M., Klimesch, W., and Schabus, M. (2008). Instrumental conditioning of human sensorimotor rhythm (12-15 Hz) and its impact on sleep as well as declarative learning. *Sleep*, 31(10):1401–8.

Hofer-Tinguely, G., Achermann, P., Landolt, H.-P., Regel, S. J., Rétey, J. V., Dürr, R., Borbély, A. A., and Gottselig, J. M. (2005). Sleep inertia: performance changes after sleep, rest and active waking. *Brain Res. Cogn. Brain Res.*, 22(3):323–31.

Holtmann, M., Grasmann, D., Cionek-Szpak, E., Hager, V., Panzner, N., Beyer, A., Poustka, F., and Stadler, C. (2009). Spezifische wirksamkeit von neurofeedback auf die impulsivit
"at bei adhs. *Kindheit und Entwicklung*, 18(2):95–104.

Hommel, B. (1998). Event files: Evidence for automatic integration of stimulus-response episodes. *Visual Cognition*, 5(1):183–216.

Howe, R. C. and Sterman, M. (1972). Cortical-subcortical EEG correlates of suppressed motor behavior during sleep and waking in the cat. *Electroencephalogr. Clin. Neurophysiol.*, 32(6):681–695.

Huang, Y.-Z., Edwards, M. J., Rounis, E., Bhatia, K. P., and Rothwell, J. C. (2005). Theta burst stimulation of the human motor cortex. *Neuron*, 45(2):201–6.

Jasper, H. (1936). Cortical excitatory state and synchronism in the control of bioelectric autonomous rhythms. In *Cold Spring Harbor Symposia on Quantitative Biology*, volume 4, page 320. Cold Spring Harbor Laboratory Press.

Jausovec, N. (2004). Intelligence-related differences in induced gamma band activity. *Int. J. Psychophysiol*, 54:37–37.

Kaiser, D. and Othmer, S. (2000). Effect of neurofeedback on variables of attention in a large multicenter trial. *Journal of Neurotherapy*, 4(1):5–15.

Kalin, N. and Loevinger, B. (1983). The central and peripheral opioid peptides: Their relationships and functions. *Psychiatr. Clin. North Am.*

Kamiya, J. (1962). Conditioned discrimination of the EEG alpha rhythm in humans. *Western Psychological Association*.

Kamiya, J. (1969). Operant control of the EEG alpha rhythm and some of its reported effects on consciousness. *Altered states of consciousness. New York: Wiley*, pages 489–501.

Kasamatsu, A. and Hirai, T. (1966). An electroencephalographic study on the zen meditation (zazen). *Folia Psychiatr. Neurol. Jpn.*, 20(4):315–36.

Kaufman, A. (1990). *K-BIT: Kaufman brief intelligence test*. American Guidance Service, Circle Pines, MN.

Kay, L. M. (2005). Theta oscillations and sensorimotor performance. *Proc. Natl. Acad. Sci. U. S. A.*, 102(10):3863–8.

Keizer, A. W., Verment, R. S., and Hommel, B. (2010a). Enhancing cognitive control through neurofeedback: a role of gamma-band activity in managing episodic retrieval. *Neuroimage*, 49(4):3404–13.

Keizer, A. W., Verschoor, M., Verment, R. S., and Hommel, B. (2010b). The effect of gamma enhancing neurofeedback on the control of feature bindings and intelligence measures. *Int. J. Psychophysiol.*, 75(1):25–32.

Kelley, M. (1997). Native americans, neurofeedback, and substance abuse theory. three year outcome of alpha/theta neurofeedback training in the treatment of problem drinking among dine'(navajo) people. *Journal of Neurotherapy*, 2(3):24–60.

Kishiyama, M. M., Yonelinas, A. P., and Knight, R. T. (2009). Novelty enhancements in memory are dependent on lateral prefrontal cortex. *The Journal of Neuroscience*, 29(25):8114–8118.

Klein, S. and Thorne, B. (2006). *Biological psychology*. Worth Pub, New York, NY.

Klem, G. H., Lüders, H. O., Jasper, H. H., and Elger, C. (1999). The ten-twenty electrode system of the international federation. the international federation of clinical neurophysiology. *Electroencephalogr. Clin. Neurophysiol. Suppl.*, 52:3–6.

Klimesch, W. (1996). Memory processes, brain oscillations and EEG synchronization. *Int. J. Psychophysiol.*, 24(1-2):61–100.

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Research Reviews*, 29(2-3):169–195.

Klimesch, W., Doppelmayr, M., Schimke, H., and Ripper, B. (1997). Theta synchronization and alpha desynchronization in a memory task. *Psychophysiology*, 34(2):169–76.

Klimesch, W., Sauseng, P., and Gerloff, C. (2003). Enhancing cognitive performance with repetitive transcranial magnetic stimulation at human individual alpha frequency. *Eur. J. Neurosci.*, 17(5):1129–33.

Klimesch, W., Sauseng, P., and Hanslmayr, S. (2007). EEG alpha oscillations: the inhibition-timing hypothesis. *Brain Res Rev*, 53(1):63–88.

Koestler, A. (1964). *The Act of Creation*. Macmillan, New York, danube edition.

Kokotsaki, D. and Davidson, J. W. (2003). Investigating musical performance anxiety among music college singing students: a quantitative analysis. *Music Education Research*, 5(1):45–59.

Kotchoubey, B., Strehl, U., Uhlmann, C., Holzapfel, S., König, M., Fröscher, W., Blankenhorn, V., and Birbaumer, N. (2001). Modification of slow cortical potentials in patients with refractory epilepsy: a controlled outcome study. *Epilepsia*, 42(3):406–416.

Kurtzberg, T. R. and Amabile, T. M. (2001). From guilford to creative synergy: Opening the black box of team-level creativity. *Creativity Research Journal*, 13(3-4):285–294.

La Vaque, T., Hammond, D., Trudeau, D., Monastra, V., Perry, J., Lehrer, P., Matheson, D., and Sherman, R. (2002). Template for developing guidelines for the evaluation of the clinical efficacy of psychophysiological interventions. *Appl. Psychophysiol. Biofeedback*, 27(4):273–281.

Lantz, D. L. and Sterman, M. B. (1988). Neuropsychological assessment of subjects with uncontrolled epilepsy: effects of EEG feedback training. *Epilepsia*, 29(2):163–71.

Laufs, H., Krakow, K., Sterzer, P., Eger, E., Beyerle, A., Salek-Haddadi, A., and Kleinschmidt, A. (2003). Electroencephalographic signatures of attentional and cognitive default modes in spontaneous brain activity fluctuations at rest. *Proc. Natl. Acad. Sci. U. S. A.*, 100(19):11053–8.

Lévesque, J., Beauregard, M., and Mensour, B. (2006). Effect of neurofeedback training on the neural substrates of selective attention in children with attention-deficit/hyperactivity disorder: a functional magnetic resonance imaging study. *Neurosci. Lett.*, 394(3):216–21.

Limb, C. and Braun, A. (2008). Neural Substrates of Spontaneous Musical Performance: An fMRI Study of Jazz Improvisation. *PLoS ONE*, 3(2).

Linden, M., Habib, T., and Radojevic, V. (1996). A controlled study of the effects of EEG biofeedback on cognition and behavior of children with attention deficit disorder and learning disabilities. *Biofeedback Self Regul.*, 21(1):35–49.

Lindsley, D. B. (1952). Psychological phenomena and the electroencephalogram. *Electroencephalogr. Clin. Neurophysiol.*, 4(4):443–56.

Logothetis, N. K., Pauls, J., Augath, M., Trinath, T., and Oeltermann, A. (2001). Neurophysiological investigation of the basis of the fmri signal. *Nature*, 412(6843):150–7.

Loo, S. K. and Barkley, R. A. (2005). Clinical utility of EEG in attention deficit hyperactivity disorder. *Appl Neuropsychol*, 12(2):64–76.

Loomis, A., Harvey, E., and Hobart III, G. (1938). Distribution of disturbance-patterns in the human electroencephalogram, with special reference to sleep. *J. Neurophysiol.*, 1(5):413.

Lorr, M., McNair, D., Heuchert, J., and Droppleman, L. (1971). Profile of mood states. *J. Clin. Psychiatry*, 60:89–95.

Lovato, N. and Lack, L. (2010). The effects of napping on cognitive functioning. *Prog. Brain Res.*, 185:155–66.

Lovato, N., Lack, L., Ferguson, S., and Tremaine, R. (2009). The effects of a 30-min nap during night shift following a prophylactic sleep in the afternoon. *Sleep and Biological Rhythms*, 7(1):34–42.

Lowe, F. (1999). How essential is the EEG component of the peniston and kulkosky protocol. *Appl. Psychophysiol. Biofeedback*, 24(2):117–118.

Lubar, J. and Shouse, M. (1976). EEG and behavioral changes in a hyperkinetic child concurrent with training of the sensorimotor rhythm (smr). *Appl. Psychophysiol. Biofeedback*, 1(3):293–306.

Lubar, J. F. (1991). Discourse on the development of EEG diagnostics and biofeedback for attention-deficit/hyperactivity disorders. *Biofeedback Self Regul.*, 16(3):201–25.

Lubar, J. F., Swartwood, M. O., Swartwood, J. N., and O'Donnell, P. H. (1995). Evaluation of the effectiveness of EEG neurofeedback training for adhd in a clinical setting as measured by changes in t.o.v.a. scores, behavioral ratings, and wisc-r performance. *Biofeedback Self Regul.*, 20(1):83–99.

Lubar, J. O. and Lubar, J. F. (1984). Electroencephalographic biofeedback of smr and beta for treatment of attention deficit disorders in a clinical setting. *Biofeedback Self Regul.*, 9(1):1–23.

MacCallum, R. C., Widaman, K. F., Zhang, S., and Hong, S. (1999). Sample size in factor analysis. *Psychol. Methods*, 4:84–99.

Makeig, S. and Jung, T. P. (1996). Tonic, phasic, and transient EEG correlates of auditory awareness in drowsiness. *Brain Res. Cogn. Brain Res.*, 4(1):15–25.

Makeig, S., Jung, T. P., and Sejnowski, T. J. (2000). Awareness during drowsiness: dynamics and electrophysiological correlates. *Can. J. Exp. Psychol.*, 54(4):266–73.

Mann, C., Lubar, J., Zimmerman, A., Miller, C., and Muenchen, R. (1992). Quantitative analysis of EEG in boys with attention-deficit-hyperactivity disorder: Controlled study with clinical implications. *Pediatr. Neurol.*, 8(1):30–36.

Martindale, C. (1977). Creativity, consciousness, and cortical arousal. *Journal of Altered States of Consciousness*.

Martindale, C. (1999). *Handbook of creativity*, chapter Biological Bases of Creativity, pages 137–152. Cambridge Univ Pr, Cambridge, U.K. ; New York.

Martindale, C. and Armstrong, J. (1974). The Relationship of Creativity to Cortical Activation and Its Operant Control. *J. Genet. Psychol.*, 124:311–320.

Maslow, A., Assagioli, R., Crampton, M., Van der Horst, L., Taylor, G., Vargin, J., Haronian, F., Parks, J., and Alberti, A. (1963). *The creative attitude*. Psychosynthesis Research Foundation, Greenville, Del.

Mavromatis, A. (1987). *Hypnagogia: The unique state of consciousness between wakefulness and sleep*. Routledge Kegan & Paul, London; New York.

McCarney, S. and Services, H. E. (1989). *Attention deficit disorders evaluation scale*. Hawthorne Educational Services, Columbia, Mo.

McCormick, D. A. and Huguenard, J. R. (1992). A model of the electrophysiological properties of thalamocortical relay neurons. *J. Neurophysiol.*, 68(4):1384–400.

McCormick, D. A., Wang, Z., and Huguenard, J. (1993). Neurotransmitter control of neocortical neuronal activity and excitability. *Cereb. Cortex*, 3(5):387–98.

Mccrae, R. (1987). Creativity, divergent thinking, and openess to experience. *J. Pers. Soc. Psychol.*, 52(6):1258–1265.

McGraw, K. and Wong, S. (1996). Forming inferences about some intraclass correlation coefficients. *Psychol. Methods*, 1(1):30–46.

McMahon, R. C., Flynn, P. M., and Davidson, R. S. (1985). The personality and symptoms scales of the millon clinical multiaxial inventory: sensitivity to posttreatment outcomes. *J. Clin. Psychol.*, 41(6):862–6.

McNair, D., Lorr, M., and Droppleman, L. (1992). Revised manual for the profile of mood states. *San Diego, CA: Educational and Industrial Testing Services*, 731:732–733.

McPherson, G. E. and Thompson, W. F. (1998). Assessing music performance: Issues and influences. *Research Studies in Music Education*, 10(1):12–24.

Mednick, S. and Mednick, M. (1967a). *Remote Associates Test.* Houghton Mifflin, Boston.

Mednick, S., Mednick, M., and of Michigan, U. (1965). *The Associative Basis of the Creative Process*. University of Michigan, Ann Arbor.

Mednick, S. A. (1962). The associative basis of the creative process. *Psychol. Rev.*, 69(3):220–232.

Mednick, S. A. and Mednick, M. T. (1967b). *Examiner's Manual, Remote Associates Test: College and Adult Forms 1 and 2*. Houghton Mifflin, Boston.

Miller, E. K. and Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annu. Rev. Neurosci.*, 24:167–202.

Millon, T. (1983). Millon clinical multiaxial inventory. minneapolis. *MN: Interpretive Scoring Systems*.

Milner, C. E., Fogel, S. M., and Cote, K. A. (2006). Habitual napping moderates motor performance improvements following a short daytime nap. *Biol. Psychol.*, 73(2):141–56.

Monastra, V. J., Lynn, S., Linden, M., Lubar, J. F., Gruzelier, J., and LaVaque, T. J. (2005). Electroencephalographic biofeedback in the treatment of attention-deficit/hyperactivity disorder. *Appl. Psychophysiol. Biofeedback*, 30(2):95–114.

Moore, J. and Trudeau, D. (1998). Alpha theta brainwave biofeedback is not specific to the production of theta/alpha crossover and visualizations. *Journal of Neurotherapy*, 3(1):63.

Moore, J. P., Trudeau, D. L., Thuras, P. D., Rubin, Y., Stockley, H., and Dimond, T. (2000). Comparison of alpha-theta, alpha and emg neurofeedback in the production of alpha-theta crossover and the occurrence of visualizations. *Journal of Neurotherapy*, 4(1):29–42.

Morikawa, T., Hayashi, M., and Hori, T. (1997). Auto power and coherence analysis of delta-theta band EEG during the waking-sleeping transition period. *Electroencephalogr. Clin. Neurophysiol.*, 103(6):633–41.

Morton, V. and Torgerson, D. J. (2005). Regression to the mean: treatment effect without the intervention. *J. Eval. Clin. Pract.*, 11(1):59–65.

Mueller, S. (2010). A partial implementation of the bica cognitive decathlon using the psychology experiment building LANguage (pebl). *Int. J. Mach. Conscious.*, 2(02):273–288.

Mullholland, T. (1968). Feedback electroencephalography. *Act. Nerv. Super. (Praha)*, 10(4):410.

Muzur, A., Pace-Schott, E., and Hobson, J. (2002). The prefrontal cortex in sleep. *Trends in Cognitive Sciences*, 6(11):475–481.

Naber, D., Bullinger, M., Zahn, T., et al. (1981). Stress effects of beta-endorphin in human plasma: Relationships to psychophysiological and psychological variables. *Psychopharmacol. Bull.*, 17:187–189.

Niedermeyer, E. (2005). 9. the normal EEG of the waking adult. *Electroencephalography: Basic principles, clinical applications, and related fields*, page 167.

Nishida, M. and Walker, M. P. (2007). Daytime naps, motor memory consolidation and regionally specific sleep spindles. *PLoS One*, 2(4):e341.

Nybo, L. and Nielsen, B. (2001). Perceived exertion is associated with an altered brain activity during exercise with progressive hyperthermia. *J. Appl. Physiol.*, 91(5):2017–23.

O'Keefe, J. (1990). A computational theory of the hippocampal cognitive map. *Prog. Brain Res.*, 83:301–12.

Orlandi, M. and Greco, D. (2005). A randomized, double-blind clinical trial of EEG neurofeedback treatment for attention deficit/hyperactivity disorder (adhd). In *ISNR conference*.

Orne, M. and Wilson, S. (1978). On the nature of alpha feedback training. *Consciousness & self-regulation*, 2.

Orne, M. T. and Paskewitz, D. A. (1974). Aversive situational effects on alpha feedback training. *Science*, 186(4162):458–60.

Overall, J., Gorham, D., et al. (1962). The brief psychiatric rating scale. *Psychol. Rep.*, 10(3):799–812.

Papadopoulos, G. and Wiggins, G. (1999). AI methods for algorithmic composition: A survey, a critical view and future prospects. In *AISB Symposium on Musical Creativity*, pages 110–117.

Pascual-Marqui, R. D. (2002). Standardized low-resolution brain electromagnetic tomography (sloreta): technical details. *Methods Find. Exp. Clin. Pharmacol.*, 24 Suppl D:5–12.

Paskewitz, D. A. and Orne, M. T. (1973). Visual effects on alpha feedback training. *Science*, 181(97):360–3.

Passini, F. T., Watson, C. G., Dehnel, L., Herder, J., and Watkins, B. (1977). Alpha wave biofeedback training therapy in alcoholics. *J. Clin. Psychol.*, 33(1):292–9.

Pavlides, C., Greenstein, Y. J., Grudman, M., and Winson, J. (1988). Long-term potentiation in the dentate gyrus is induced preferentially on the positive phase of theta-rhythm. *Brain Res.*, 439(1-2):383–7.

Pearce, M. and Wiggins, G. A. (2002). Aspects of a cognitive theory of creativity in musical composition. In *Proceedings of the ECAI02 Workshop on Creative Systems*.

Peniston, E. (1998). Comments by peniston. *Appl. Psychophysiol. Biofeedback*, 23(4):273–275.

Peniston, E. and Kulkosky, P. (1990). Alcoholic personality and alpha-theta brainwave training. *Medical Psychotherapy*, 3:37–55.

Peniston, E. and Kulkosky, P. (1991). Alpha-theta brainwave neuro-feedback therapy for vietnam veterans with combat-related post-traumatic stress disorder. *Medical Psychotherapy*, 4:47–60.

Peniston, E. and Kulkosky, P. (1999). Neurofeedback in the treatment of addictive disorders. *Introduction to quantitative EEG and neurofeedback*, page 346.

Peniston, E., Marrinan, D., Deming, W., and Kulkosky, P. (1993). EEG alpha-theta brainwave synchronization in vietnam theater veterans with combat-related post-traumatic stress disorder and alcohol abuse. *Advances in Medical Psychotherapy*, 6:37–50.

Peniston, E. G. and Kulkosky, P. J. (1989). Alpha-theta brainwave training and beta-endorphin levels in alcoholics. *Alcohol. Clin. Exp. Res.*, 13(2):271–9.

Petsche, H., Kaplan, S., von Stein, A., and Filz, O. (1997). The possible meaning of the upper and lower alpha frequency ranges for cognitive and creative tasks. *Int. J. Psychophysiol.*, 26(1-3):77–97.

Pfurtscheller, G. and Lopes da Silva, F. H. (1999). Event-related EEG/meg synchronization and desynchronization: basic principles. *Clin. Neurophysiol.*, 110(11):1842–57.

Phelan, S. and Young, A. M. (2003). Understanding creativity in the workplace: An examination of individual styles and training in relation to creative confidence and creative self-leadership. *The Journal of Creative Behavior*, 37(4):266–281.

Picard, B. (2006). Double blind sham study of neurofeedback treatment for children with adhd. In *ISNR conference, Atlanta, GA, USA*, pages 7–10.

Pinker, S. (1999). How the mind works. *Ann. N. Y. Acad. Sci.*, 882(1):119–127.

Plihal, W. and Born, J. (1997). Effects of early and late nocturnal sleep on declarative and procedural memory. *J. Cogn. Neurosci.*, 9(4):534–547.

Plotkin, W. P. and Rice, K. M. (1981). Biofeedback as a placebo: anxiety reduction facilitated by training in either suppression or enhancement of alpha brainwaves. *J. Consult. Clin. Psychol.*, 49(4):590–6.

Poincaré, H. and Halsted, G. B. (1913). *The foundations of science: Science and hypothesis, the value of science, science and method*, volume 1. Science Press, New York.

Pollock, V., Volavka, J., Goodwin, D., Mednick, S., Gabrielli, W., Knop, J., and Schulsinger, F. (1983). The EEG after alcohol administration in men at risk for alcoholism. *Arch. Gen. Psychiatry*, 40(8):857.

Pontifex, M. B. and Hillman, C. H. (2007). Neuroelectric and behavioral indices of interference control during acute cycling. *Clin. Neurophysiol.*, 118(3):570–80.

Pressing, J. (1988). *Improvisation: Methods and Models*, pages 129–178. Oxford University Press, Oxford.

Pucel, J. (1972). Alcohol rehabilitation follow-up questionnaire. Technical report, St. Cloud, MN: Veterans Administration Hospital.

Raichle, M. E. (2009). A brief history of human brain mapping. *Trends Neurosci.*, 32(2):118–26.

Raven, J. (1938). Progressive matrices: A perceptual test of intelligence, 1938, individual form. *London: Lewis*.

Raymond, J., Sajid, I., Parkinson, L. A., and Gruzelier, J. H. (2005a). Biofeedback and dance performance: a preliminary investigation. *Appl. Psychophysiol. Biofeedback*, 30(1):64–73.

Raymond, J., Varney, C., Parkinson, L. A., and Gruzelier, J. H. (2005b). The effects of alpha/theta neurofeedback on personality and mood. *Brain Res. Cogn. Brain Res.*, 23(2-3):287–92.

Rechtschaffen, A. and Kales, A. (1968). *A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects*. U.S. Dept. of Health, Education, and Welfare, Bethesda, Md.

Robbins, J. (2008). *A symphony in the brain: The evolution of the new brain wave biofeedback*. Grove Pr, New York.

Roelofs, S. (1985). Hyperventilation, anxiety, craving for alcohol: a subacute alcohol withdrawal syndrome. *Alcohol*, 2(3):501–505.

Rogers, C. (1954). Toward a theory of creativity. *Etc.*

Ros, T., Moseley, M. J., Bloom, P. A., Benjamin, L., Parkinson, L. A., and Gruzelier, J. H. (2009). Optimizing microsurgical skills with EEG neurofeedback. *BMC Neurosci*, 10:87.

Ros, T., Munneke, M. A. M., Ruge, D., Gruzelier, J. H., and Rothwell, J. C. (2010). Endogenous control of waking brain rhythms induces neuroplasticity in humans. *Eur. J. Neurosci.*, 31(4):770–8.

Ross, L., Lepper, M., Strack, F., and Steinmetz, J. (1977). Social explanation and social expectation: Effects of real and hypothetical explanations on subjective likelihood. *J. Pers. Soc. Psychol.*, 35(11):817–829.

Rossiter, T. (2004). The effectiveness of neurofeedback and stimulant drugs in treating ad/HD: part ii. replication. *Appl. Psychophysiol. Biofeedback*, 29(4):233–43.

Rossiter, T. and La Vaque, T. (1995). A comparison of EEG biofeedback and psychostimulants in treating attention deficit/hyperactivity disorders. *Journal of Neurotherapy*, 1(1):48–59.

Roth, S., Sterman, M., and Clemente, C. (1967). Comparison of EEG correlates of reinforcement, internal inhibition and sleep. *Electroencephalogr. Clin. Neurophysiol.*, 23(6):509–520.

Ruiz, M. H., Jabusch, H.-C., and Altenmüller, E. (2009a). Detecting wrong notes in advance: neuronal correlates of error monitoring in pianists. *Cereb. Cortex*, 19(11):2625–39.

Ruiz, M. H., Senghaas, P., Grossbach, M., Jabusch, H.-C., Bangert, M., Hummel, F., Gerloff, C., and Altenmüller, E. (2009b). Defective inhibition and inter-regional phase synchronization in pianists with musician's dystonia: an EEG study. *Hum. Brain Mapp.*, 30(8):2689–700.

Sauseng, P., Hoppe, J., Klimesch, W., Gerloff, C., and Hummel, F. C. (2007). Dissociation of sustained attention from central executive functions: local activity and interregional connectivity in the theta range. *Eur. J. Neurosci.*, 25(2):587–93.

Sauseng, P., Klimesch, W., Doppelmayr, M., Pecherstorfer, T., Freunberger, R., and Hanslmayr, S. (2005a). EEG alpha synchronization and functional coupling during top-down processing in a working memory task. *Hum. Brain Mapp.*, 26(2):148–55.

Sauseng, P., Klimesch, W., Stadler, W., Schabus, M., Doppelmayr, M., Hanslmayr, S., Gruber, W. R., and Birbaumer, N. (2005b). A shift of visual spatial attention is selectively associated with human EEG alpha activity. *Eur. J. Neurosci.*, 22(11):2917–26.

Sawyer, R. (2000). Improvisation and the Creative Process: Dewey, Collingwood, and the Aesthetics of Spontaneity. *The Journal of Aesthetics and Art Criticism*, 58(2):149–161.

Sawyer, R. K. (2012). *Explaining creativity: The science of human innovation*. OUP USA, Oxford ; New York.

Saxby, E. and Peniston, E. G. (1995). Alpha-theta brainwave neurofeedback training: an effective treatment for male and female alcoholics with depressive symptoms. *J. Clin. Psychol.*, 51(5):685–93.

Schabus, M., Gruber, G., Parapatics, S., Sauter, C., Klösch, G., Anderer, P., Klimesch, W., Saletu, B., and Zeitlhofer, J. (2004). Sleep spindles and their significance for declarative memory consolidation. *Sleep*, 27(8):1479–85.

Schacter, D. (1976). The hypnagogic state: A critical review of the literature. *Psychol. Bull.*, 83(3):452–481.

Scheeringa, R., Bastiaansen, M. C. M., Petersson, K. M., Oostenveld, R., Norris, D. G., and Hagoort, P. (2008). Frontal theta EEG activity correlates negatively with the default mode network in resting state. *Int. J. Psychophysiol.*, 67(3):242–51.

Schreckenberger, M., Lange-Asschenfeld, C., Lochmann, M., Mann, K., Siessmeier, T., Buchholz, H., Bartenstein, P., and Grunder, G. (2004). The thalamus as the generator and modulator of EEG alpha rhythm: a combined PET/EEG study with lorazepam challenge in humans. *Neuroimage*, 22(2):637–644.

Scott, W., Brod, T., Sideroff, S., Kaiser, D., and Sagan, M. (2002). Type-specific EEG biofeedback improves residential substance abuse treatment. In *American Psychiatric Association Annual Meeting*.

Scott, W. and Kaiser, D. (1998). Augmenting chemical dependency treatment with neurofeedback training. *Journal of Neurotherapy*, 3(1):66.

Scott, W. C., Kaiser, D., Othmer, S., and Sideroff, S. I. (2005). Effects of an EEG biofeedback protocol on a mixed substance abusing population. *Am. J. Drug Alcohol Abuse*, 31(3):455–69.

Shapiro, D., Tursky, B., Gershon, E., and Stern, M. (1969). Effects of feedback and reinforcement on the control of human systolic blood pressure. *Science (New York, NY)*, 163(867):588.

Shouse, M. N. and Lubar, J. F. (1979). Operant conditioning of EEG rhythms and ritalin in the treatment of hyperkinesis. *Biofeedback Self Regul.*, 4(4):299–312.

Simonton, D. (1997). Creative productivity: A predictive and explanatory model of career trajectories and landmarks. *Psychol. Rev.*, 104(1):66–89.

Simonton, D. (1999). *Origins of Genius: Darwinian Perspectives on Creativity*. Oxford University Press, USA, New York.

Simonton, D. (2003). Scientific creativity as constrained stochastic behavior: the integration of product, person, and process perspectives. *Psychol. Bull.*, 129(4):475–494.

Singer, W. and Gray, C. M. (1995). Visual feature integration and the temporal correlation hypothesis. *Annu. Rev. Neurosci.*, 18:555–86.

Skinner, B. F. (1937). Two types of conditioned reflex: A reply to konorski and Miller. *The Journal of General Psychology*, 16(1):272–279.

Skok, A., Shubina, O., Finkelberg, A., Shtark, M., and Jafarova, O. (1997). EEG training in the treatment of addictive disorders. *Applied Psychophysiology & Biofeedback*, 22:130.

Smith, M. and Gevins, A. (2004). Attention and brain activity while watching television: Components of viewer engagement. *Media Psychology*, 6(3):285–305.

Speckmann, E. and Elger, C. (1991). The neurophysiological basis of epileptic activity: a condensed overview. *Epilepsy Res. Suppl.*, 2:1.

Spielberger, C., Gorsuch, R., Lushene, R., Vagg, P., and Jacobs, G. (1983). *Manual for the State-Trait Anxiety Inventory (Form Y). 1983, Palo Alto*.

Stanley, M., Brooker, R., and Gilbert, R. (2002). Examiner perceptions of using criteria in music performance assessment. *Research Studies in Music Education*, 18(1):46.

Stennett, R. G. (1957). The relationship of performance level to level of arousal. *J. Exp. Psychol.*, 54(1):54–61.

Steptoe, A. (1982). Performance anxiety: recent developments in its analysis and management. *Musical Times*, 123(1674):537–541.

Steriade, M., Amzica, F., and Nuñez, A. (1993a). Cholinergic and noradrenergic modulation of the slow (approximately 0.3 Hz) oscillation in neocortical cells. *J. Neurophysiol.*, 70(4):1385–400.

Steriade, M., Domich, L., Oakson, G., and Deschênes, M. (1987). The deafferented reticular thalamic nucleus generates spindle rhythmicity. *J. Neurophysiol.*, 57(1):260–73.

Steriade, M., Dossi, R. C., and Nuñez, A. (1991). Network modulation of a slow intrinsic oscillation of cat thalamocortical neurons implicated in sleep delta waves: cortically induced synchronization and brainstem cholinergic suppression. *J. Neurosci.*, 11(10):3200–17.

Steriade, M., Gloor, P., Llinás, R. R., Lopes de Silva, F. H., and Mesulam, M. M. (1990). Report of IFcn committee on basic mechanisms. basic mechanisms of cerebral rhythmic activities. *Electroencephalogr. Clin. Neurophysiol.*, 76(6):481–508.

Steriade, M., McCormick, D., and Sejnowski, T. (1993b). Thalamocortical oscillations in the sleeping and aroused brain. *Science*, 262(5134):679.

Sterman, M. and Wyrwicka, W. (1967). EEG correlates of sleep: evidence for separate forebrain substrates. *Brain Res.*, 6(1):143.

Sterman, M., Wyrwicka, W., and Roth, S. (1969). Electrophysiological correlates and neural substrates of alimentary behavior in the cat. *Ann. N. Y. Acad. Sci.*, 157(Neural Regulation of Food and Water Intake):723–739.

Sterman, M. B. (1996). Physiological origins and functional correlates of EEG rhythmic activities: implications for self-regulation. *Biofeedback Self Regul.*, 21(1):3–33.

Sterman, M. B. and Egner, T. (2006). Foundation and practice of neurofeedback for the treatment of epilepsy. *Appl. Psychophysiol. Biofeedback*, 31(1):21–35.

Sterman, M. B. and Friar, L. (1972). Suppression of seizures in an epileptic following sensorimotor EEG feedback training. *Electroencephalogr. Clin. Neurophysiol.*, 33(1):89–95.

Sterman, M. B., Howe, R. C., and Macdonald, L. R. (1970). Facilitation of spindle-burst sleep by conditioning of electroencephalographic activity while awake. *Science*, 167(921):1146–8.

Sterman, M. B. and Macdonald, L. R. (1978). Effects of central cortical EEG feedback training on incidence of poorly controlled seizures. *Epilepsia*, 19(3):207–22.

Sterman, M. B., Macdonald, L. R., and Stone, R. K. (1974). Biofeedback training of the sensorimotor electroencephalogram rhythm in man: effects on epilepsy. *Epilepsia*, 15(3):395–416.

Stevens, J. (1985). *Search & Reflect*. Community Music, London.

Stoyva, J. and Kamiya, J. (1968). Electrophysiological studies of dreaming as the prototype of a new strategy in the study of consciousness. *Psychol. Rev.*, 75(3):192–205.

Strehl, U., Trevorrow, T., Veit, R., Hinterberger, T., Kotchoubey, B., Erb, M., and Birbaumer, N. (2006). Deactivation of brain areas during self-regulation of slow cortical potentials in seizure patients. *Appl. Psychophysiol. Biofeedback*, 31(1):85–94.

Swanson, J., Nolan, W., and Pelham, W. (1981). The snap rating scale. *Resources in Education*.

Takahashi, M. and Arito, H. (2000). Maintenance of alertness and performance by a brief nap after lunch under prior sleep deficit. *Sleep*, 23(6):813–9.

Tanaka, H., Hayashi, M., and Hori, T. (1996). Statistical features of hypnagogic EEG measured by a new scoring system. *Sleep*, 19(9):731–8.

Tanaka, H., Hayashi, M., and Hori, T. (2000). Topographical characteristics of slow wave activities during the transition from wakefulness to sleep. *Clin. Neurophysiol.*, 111(3):417–427.

Tansey, M. A. (1984). EEG sensorimotor rhythm biofeedback training: some effects on the neurologic precursors of learning disabilities. *Int. J. Psychophysiol.*, 1(2):163–77.

Tansey, M. A. (1985). Brainwave signatures–an index reflective of the brain's functional neuroanatomy: further findings on the effect of EEG sensorimotor rhythm biofeedback training on the neurologic precursors of learning disabilities. *Int. J. Psychophysiol.*, 3(2):85–99.

Tansey, M. A. and Bruner, R. L. (1983). EMG and EEG biofeedback training in the treatment of a 10-year-old hyperactive boy with a developmental reading disorder. *Biofeedback Self Regul.*, 8(1):25–37.

Taub, E. and Rosenfeld, J. (1994). Is alpha/theta training the effective component of the alpha/theta therapy package for the treatment of alcoholism. *Biofeedback*, 22(3):12–14.

Taylor, C. (2005). *These music exams*. Associated Board of the Royal Schools of Music, London.

Thayer, R. E. (1967). Measurement of activation through self-report. *Psychol. Rep.*, 20(2):663–78.

Thesen, S., Heid, O., Mueller, E., and Schad, L. R. (2000). Prospective acquisition correction for head motion with image-based tracking for real-time fmri. *Magn. Reson. Med.*, 44(3):457–65.

Thompson, S. and Williamon, A. (2003). Evaluating evaluation: Musical performance assessment as a research tool. *Music Perception*, 21(1):21–41.

Thompson, W., Diamond, C., and Balkwill, L. (1998). The adjudication of six performances of a Chopin Etude: A study of expert knowledge. *Psychology of Music*, 26(2):154.

Tierney, P. and Farmer, S. M. (2002). Creative self-efficacy: Its potential antecedents and relationship to creative performance. *Acad. Manage. J.*, 45(6):1137–1148.

Timofeev, I. and Steriade, M. (1997). Fast (mainly 30-100 Hz) oscillations in the cat cerebellothalamic pathway and their synchronization with cortical potentials. *J Physiol*, 504 (Pt 1):153–68.

Tornek, A., Field, T., Hernandez-Reif, M., Diego, M., and Jones, N. (2003). Music effects on EEG in intrusive and withdrawn mothers with depressive symptoms. *Psychiatry*, 66(3):234–43.

Torrance, E. (1974). *Torrance Tests of Creative Thinking*. Scholastic Testing Service Bensenville, Ill, Princeton, N.J.

Traut, E. F. and Passarelli, E. W. (1957). Placebos in the treatment of rheumatoid arthritis and other rheumatic conditions. *Ann. Rheum. Dis.*, 16(1):18–22.

Twemlow, S. and Bowen, W. (1976). EEG biofeedback induced self actualization in alcoholics. *Journal of Biofeedback*, 3:20–25.

Twemlow, S., Sizemore, D., and Bowen, W. (1977). Biofeedback induced energy redistribution in the alcoholic EEG. *Journal of Biofeedback*, 3:14–19.

Twemlow, S. W. and Bowen, W. T. (1977). Sociocultural predictors of self-actualization in EEG-biofeedback-treated alcoholics. *Psychol. Rep.*, 40(2):591–8.

van den Pol, A., Wuarin, J., and Dudek, F. (1990). Glutamate, the dominant excitatory transmitter in neuroendocrine regulation. *Science*, 250(4985):1276.

Vernon, D., Egner, T., Cooper, N., Compton, T., Neilands, C., Sheri, A., and Gruzelier, J. (2003). The effect of training distinct neurofeedback protocols on aspects of cognitive performance. *Int. J. Psychophysiol.*, 47(1):75–85.

Vernon, D. J. (2005). Can neurofeedback training enhance performance? an evaluation of the evidence with implications for future research. *Appl. Psychophysiol. Biofeedback*, 30(4):347–64.

Vuust, P., Gebauer, L., Hansen, N. C., Jørgensen, S. R., Møller, A., and Linnet, J. (2010). Personality influences career choice: Sensation seeking in professional musicians. *Music Education Research*, 12(2):219–230.

Wahler, R., House, A., and Starbaugh, E. (1975). Ecological assessment of child problem behaviour. In Lubar and Shouse (1976), pages 293–306.

Wang, C. (1985). Measures of creativity in sound and music. *Unpublished manuscript. Lexington, KY: School of Music, University of Kentucky*.

Wangler, S., Gevensleben, H., Albrecht, B., Studer, P., Rothenberger, A., Moll, G. H., and Heinrich, H. (2010). Neurofeedback in children with adhd: Specific event-related potential findings of a randomized controlled trial. *Clin. Neurophysiol.*

Wapnick, J., Ryan, C., Campbell, L., Deek, P., Lemire, R., and Darrow, A. (2005). Effects of excerpt tempo and duration on musicians' ratings of high-level piano performances. *Journal of Research in Music Education*, 53(2):162.

Wapnick, J., Ryan, C., Lacaille, N., and Darrow, A. (2004). Effects of selected variables on musicians ratings of high level piano performances. *International Journal of Music Education*, 22(1):7.

Watabe, T., Tanaka, K., Kumagae, M., Itoh, S., Hasegawa, M., Horiuchi, T., Miyabe, S., Ohno, H., and Shimizu, N. (1987). Diurnal rhythm of plasma immunoreactive corticotropin-releasing factor in normal subjects. *Life Sci.*, 40(17):1651–1655.

Watson, C. (1972). Relationships of anhedonia to learning under various contingencies. *J. Abnorm. Psychol.*, 80(1):43–48.

Watson, C., Herder, J., and Passini, F. (1978). Alpha biofeedback therapy in alcoholics: an 18-month follow-up. *J. Clin. Psychol.*, 34(3):765–9.

Wechsler, D. (1974). *Wechsler intelligence scale for children-revised*. Psychological Corporation, New York, NY.

Weems, S. A. and Zaidel, E. (2004). The relationship between reading ability and lateralized lexical decision. *Brain Cogn.*, 55(3):507–15.

Wehinger, R. (1970). Ligeti artikulation: elektronische musik.

Weiskopf, N., Scharnowski, F., Veit, R., Goebel, R., Birbaumer, N., and Mathiak, K. (2004). Self-regulation of local brain activity using real-time functional magnetic resonance imaging (fmri). *J. Physiol. Paris*, 98(4-6):357–73.

Wenger, M. A. and Bagchi, B. K. (1961). Studies of autonomic functions in practitioners of yoga in india. *Behav. Sci.*, 6:312–23.

Whishaw, I. Q. and Vanderwolf, C. H. (1973). Hippocampal EEG and behavior: changes in amplitude and frequency of RSA (theta rhythm) associated with spontaneous and learned movement patterns in rats and cats. *Behav. Biol.*, 8(4):461–84.

Whittingstall, K. and Logothetis, N. (2009). Frequency-band coupling in surface EEG reflects spiking activity in monkey visual cortex. *Neuron*, 64(2):281–289.

Williamon, A. (2004). *Musical excellence: Strategies and techniques to enhance performance*. Oxford University Press, USA, Oxford.

Wong, M. (1981). Effects of meditation on anxiety and chemical dependency. *J. Drug Educ.*, 11(2):91–105.

Wyrwicka, W. and Sterman, M. (1968). Instrumental conditioning of sensorimotor cortex EEG spindles in the waking cat. *Physiology & Behavior*, 3(5):703–707.

Yerkes, R. and Dodson, J. (1908). The relation of strength of stimulus to rapidity of habit formation. *J. Comp. Neurol.*, 18:459–482.

Yoo, S.-S. and Jolesz, F. A. (2002). Functional MRI for neurofeedback: feasibility study on a hand motor task. *Neuroreport*, 13(11):1377–81.

Zoefel, B., Huster, R. J., and Herrmann, C. S. (2011). Neurofeedback training of the upper alpha frequency band in EEG improves cognitive performance. *Neuroimage*, 54(2):1427–31.

Zuckerman, M. (1971). Dimensions of sensation seeking. *J. Consult. Clin. Psychol.*, 36(1):45–52.

Zuckerman, M., Lubin, B., and Robins, S. (1965). Validation of the multiple affect adjective check list in clinical situations. *J. Consult. Psychol.*, 29(6):594.