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Review

EEG-neurofeedback for optimising performance. II: Creativity, the performing arts and ecological validity

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ABSTRACT

As a continuation of a review of evidence of the validity of cognitive/affective gains following neurofeedback in healthy participants, including correlations in support of the gains being mediated by feedback learning (Gruzelier, 2014a), the focus here is on the impact on creativity, especially in the performing arts including music, dance and acting. The majority of research involves alpha/theta (A/T), sensory-motor rhythm (SMR) and heart rate variability (HRV) protocols. There is evidence of reliable benefits from A/T training with advanced musicians especially for creative performance, and reliable benefits from both A/T and SMR training for novice music performance in adults and in a school study with children with impact on creativity, communication/presentation and technique. Making the SMR ratio training context ecologically relevant for actors enhanced creativity in stage performance, with added benefits from the more immersive training context. A/T and HRV training have benefitted dancers. The neurofeedback evidence adds to the rapidly accumulating validation of neurofeedback, while performing arts studies offer an opportunity for ecological validity in creativity research for both creative process and product.

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1. Introduction

Neurofeedback is a form of operant conditioning where through immediate feedback the participant learns to self-regulate their neurophysiology. EEG-neurofeedback, arising as an offshoot of biofeedback, has a growing evidence base and now neurofeedback has found acceptance with other brain imaging modalities including fMRI feedback over the past decade (see for review DeCharms, 2008; Ruiz et al., 2013 and for a promising recent clinical implication see Linden et al., 2012), as well as near infrared spectrometry (NIRS; Mihara et al., 2012; Kober et al., 2013) and transcranial doppler sonography (Duschek et al., 2011). Additionally fMRI has been used to monitor the outcome of EEG-feedback (Levesque et al., 2006) with some basic neuroscience reports of EEG-neurofeedback now in conjunction with TMS and fMRI (Ros et al., 2010, 2013). EEG-neurofeedback applications are increasing exponentially both in the optimal performance field (see for review Gruzelier, 2014a) as well as in the clinic (Scott et al., 2005; Sterman, 2000; Gevensleben et al., 2009; Cortoos et al., 2009; Hartmann et al., 2013; Unterrainer et al., 2013), with attention deficit hyperactivity disorder (ADHD) the most popular clinical application (Monastra et al., 2005; Arns et al., 2009; Lofthouse et al., 2012). Developments in understanding the EEG in contemporary affective and cognitive neuroscience have led to innovative protocols including upper-alpha, gamma, frontal midline theta and so on, which have supplemented those drawn from the clinical domain of neurofeedback applications such as sensory-motor rhythm (SMR) and alpha/theta (A/T) training.

Research in the performing arts (Egner and Gruzelier, 2003; Gruzelier and Egner, 2004), along with ancillary neurophysiological studies with musicians (Egner and Gruzelier, 2001, 2004a,b), have played a part in stimulating this renewal of interest in EEG-neurofeedback (Stewart, 2002; Tilstone, 2003), one reason being that the order of magnitude of the enhancement in elite conservatoire music performance was of professional and pedagogic significance. Gains in music performance were associated in two studies with the elevation of theta (4–7 Hz) over alpha (8–12 Hz), termed the alpha/theta (A/T) protocol, and did not occur with faster-wave sensory-motor rhythm (SMR, 12–14 Hz) and beta1 (15–18 Hz) training which had, however, produced gains in the musicians' attention (Egner and Gruzelier, 2001, 2004a,b). Musicality/Creativity was the main performance category enhanced by the A/T training, a protocol originally developed to enhance creativity but without evidence in support (Green and Green, 1977). The result with musicians has inspired a series of performing arts studies (Gruzelier, 2012), with the upshot that this protocol has provided the most replicable results to date, not only regarding artistic performance but within the optimal performance field in general. Gains following A/T training have been found with elite and novice musicians and dancers, seven in all, whereas SMR ratio training has had a beneficial effect mainly on novice artistic performance in five instances, putatively through an impact on lower-level abilities which become automatic in elite performance (Fitts and Posner, 1967).

Creativity, especially creative performance in the arts, will be the focus of this second part of a review on the efficacy and validation of EEG-neurofeedback for optimising function in healthy individuals. Part I of the review (Gruzelier, 2014a) dealt largely with laboratory assessments of cognition and affect. A third article, part III, will consider theoretical and methodological issues as a guide for future studies (Gruzelier, 2014a). A secondary focus of Part II stems from the perspective that assessment of artistic performance provides a window on creativity that has seldom entered the scientific arena and is one which provides ecological validity for the measurement of creativity, the lack of which is of cardinal concern to contemporary researchers on creativity, now briefly considered.

1.1. Ecological validity and the measurement of creativity

Even outside of the Arts the quest for advancing the creative process has never been more pervasive and diverse in world culture ranging from education to the 'creative economy' (Howkins, 2002), and while not lost sight of in the commercial arena with the popularisation of concepts such as lateral thinking (De Bono, 1990) the scientific measurement of creativity over half a century has remained more or less moribund, with little advance on classical cognitive tests such as those of Guilford et al. (1978), Torrance (1974) and Mednick and Mednick (1967) as well as on methods of stimulating creativity (Stein, 1974). Furthermore temporal constructs about the development of the creative process itself date back more than a century when Helmholtz (1826) and Wallas (1926) posited sequential stages of preparation, incubation, illumination and verification. Just how inconclusive and fragmented the creativity field has become has been highlighted by those reviewers who have documented attempts to capture the creative process with brain imaging (Arden et al., 2010; Dietrich and Kanso, 2010).

Contemporary commentators have been united in their advocacy for the need to develop creativity measures. "The most urgent task in front of creativity researchers is to develop ecologically valid measures of creative cognition. . .." (Jausovec and Jausovec, 2011, p. 55). A propos Guilford's alternative uses test (Guilford et al., 1978), a classical measure of divergent thinking, Jausovec and Jausovec go on to quote Dietrich and Kanso (2010, p. 834) "Can we really expect to identify the Michelangelos and Curies of tomorrow by how many innovative uses they can come up with for a brick?"

Assessing live stage performance exemplifies real life validity, and as this review will disclose the potential for enhancement in the performing arts following neurofeedback has related to the multifarious abilities and processes that go to make up stage performance. While these include the domains of technique and communication/presentation, neurofeedback has had a particular impact on creativity in performance with musicians, dancers and actors, and as noted alpha/theta training has produced the larger evidence base of highly replicable gains in performance.

1.2. Why would alpha/theta neurofeedback enhance artistic performance?

Both alpha and theta activity have historically been implicated in the creative process.

1.2.1. Alpha activity and creativity

Whereas the full EEG spectrum from delta to gamma bands has been examined in approaches to understanding creativity (Dietrich and Kanso, 2010), it is alpha activity that has been both a persistent empirical focus (e.g. Martindale and Hines, 1975; Martindale et al., 1984; Jausovec, 2000; Fink and Neubauer, 2006; Grabner et al., 2007) and a theoretical focus as embedded in low arousal and diffuse attention theories of creativity (Mendelsohn, 1976; Martindale, 1999). Further Bazanova and colleagues are undertaking the most comprehensive analysis of features of alpha activity including maximum peak frequency, range width, degree of event-related desynchronisation, and characteristics of alpha spindles (see Bazanova and Vernon, in this issue), which disclose particular alpha band width correlates in relation to creativity assessed with Torrance test measures of fluency, originality and flexibility (Bazanova and Aftanas, 2008).

Alpha formed the basis of an early attempt to explore relations between achieving operant control of eyes-closed alpha power (7–13 Hz, O2-P4) and creativity. Martindale and Armstrong (1974) divided thirty students into high and low creative groups on the basis of the Remote Associates Test (Mednick and Mednick, 1967) and the Unusual Uses Test (Guilford et al., 1978) instructing them to keep a tone on so as to activate a mental state for as long as possible in a single session, and requiring alpha enhancement, which was followed by alpha suppression. The creative groups differed in the dynamics of learning. The high creative group displayed an immediate acquisition of alpha enhancement to 125% of baseline which was sustained without further improvement, and followed this by substantive suppression. The low creative subjects gradually reached the enhancement level of the high creative subjects, and then achieved less than half the suppression of the high creative group. The dynamics of operant control were interpreted as evidence of both a greater facility for focusing attention and flexibility in shifting cognitive strategies in creative individuals putatively underpinning creative thinking.

Alpha was also implicated in a more recent cognitive intervention study ($N = 15$) in which Fink et al. (2006) trained participants in divergent thinking techniques over two weeks (see also Benedek et al., 2006). When comparing a battery of divergent thinking tests before and after training, more ideas were rated as original following training when compared with a non-intervention control group, and contemporaneously there was more frontal alpha following training when compared with the control group.

1.2.2. Theta activity, hypnogogia and creativity

Historical interest in the EEG theta rhythm arose through its potential as an index of hypnogogia (Schachter, 1976), a state about which there has been a wealth of cultural historical documentation that the hypnogogic, reverie or twilight state between waking and sleeping and the converse has induced creative insights (Koestler, 1964, The Act of Creation). Famously the chemist Kekule, who in 1896 claimed to discover the benzene ring through an hypnogogic image of a snake biting its tail, came to become an advocate of hypnogogia 'let us learn to dream gentlemen'. Cocteau conceived the entire scenarios for plays upon awaking. Edison adopted a technique of holding a ball in his hand to maintain the borderline state. While Mozart wrote:

"When I am, as it were, completely myself, entirely alone, and of good cheer-say, travelling in a carriage, or walking after a good meal, or during the night when I cannot sleep; it is on such occasions that my ideas flow best and most abundantly. *Whence* and *how* they come, I do not know; nor can I force them. Those ideas that please me I retain in memory and am accustomed, as I have been told, to hum them to myself. If I continue in this way, it soon occurs to me how I may turn this or that morsel to account, so as to make a good dish of it. . .. All this fires my soul, and, provided that I am not disturbed, my subject enlarges itself, becomes methodised and defined, and the whole, though it be long, stands almost complete and finished in my mind, so that I can survey it, like a fine picture or a beautiful statue, at a glance. Nor do I hear in my imagination the parts *successively*, but I hear them, as it were, all at once (gleich alles zusammen). What a delight this is cannot tell! All this inventing, this producing, takes place in a pleasing lively dream. . . (Holmes, 1912).

1.2.3. The alpha/theta neurofeedback protocol

Informed by evidence that with the progression towards hypnogogia and stage 1 sleep the theta amplitude predominates over alpha (Niedermeyer, 1999), the alpha/theta protocol was evolved to achieve hypnogogia in order to promote creativity and well-being (for review Gruzelier, 2009).

Elmer Green and colleagues first set about reinforcing theta and alpha activity through auditory feedback in a deeply relaxed eyes-closed state in order to facilitate creativity (Green et al., 1971; Green and Green, 1977). Hypnogogic phenomenology as described by Schachter (1976) was successfully achieved, especially when a predominance of theta over alpha was obtained. While month-long practice led to improved well-being and psychological integration with seemingly lasting psychotherapeutic benefit, there were no anecdotal benefits for creative insights.

Subsequently the potential of training alpha and theta for therapy was taken up in controlled studies as a primary part of a mixed modality package with army veterans having diagnoses of alcoholism in conjunction with anxiety/depression (Peniston and Kulkosky, 1989, 1990; Saxby and Peniston, 1995) and also with posttraumatic stress disorder (PTSD; Peniston and Kulkosky, 1991; Peniston et al., 1993). They inferred: "It is as though the patient was capable of integrating past traumatic experiences by coping with previously unresolved conflicts represented in the essential anxiety-free images and memories generated during the theta state of consciousness." This led to formulation of the contemporary A/T protocol and its application with patients and healthy individuals for optimal performance. In drug addiction benefits of neurofeedback with A/T training have been subsequently reported in a trial with stimulant misusers in residential care (Scott et al., 2005), while well-being assessed with the Profile of Mood States (McNair et al., 1992) has been enhanced in withdrawn students in a controlled study (Raymond et al., 2005a). However, the A/T protocol has been especially efficacious in enhancing creative performance. Before reviewing this evidence A/T methodological studies will be considered.

1.2.4. The nature of alpha/theta learning

The trainee is taught to raise posterior theta (4–8 Hz) over alpha (8–12 Hz) amplitude with eyes closed while not falling asleep and with pleasant auditory reinforcement. This is unlike the more conventional neurofeedback training procedure which involves visual feedback on a screen. Typically on eye closure and relaxation the EEG displays high amplitude rhythmic alpha activity and with further deactivation alpha slowly subsides along with theta activity (see Fig. 1), until theta gradually becomes predominant and

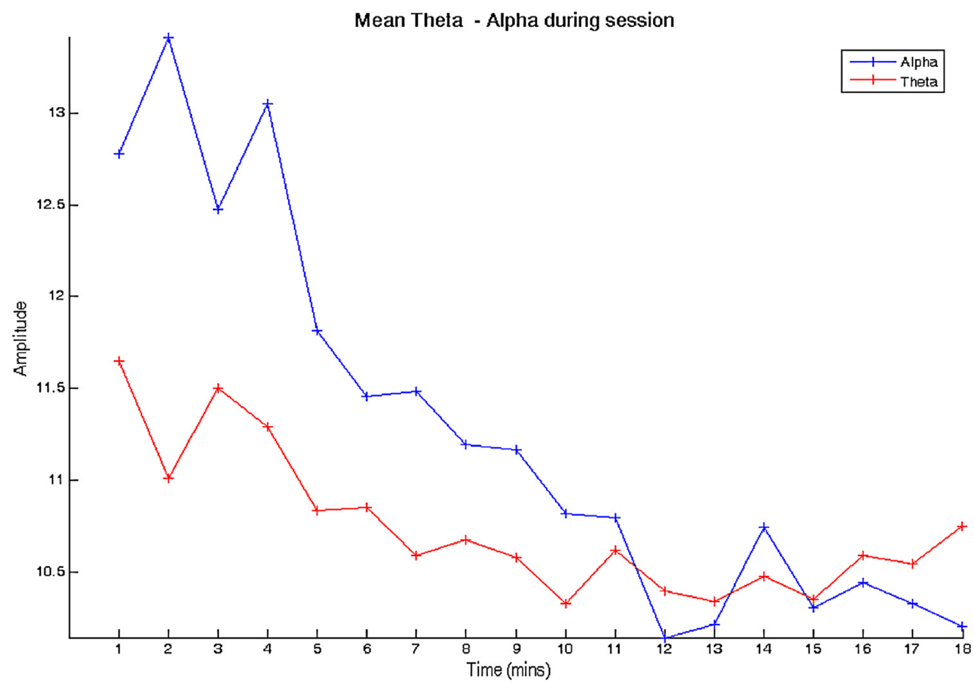

Fig. 1. Mean within-session theta and alpha amplitude (mv) showing theta crossover at 15 min; dancers tested in groups of six (Gruzelier et al., 2013b).

increases typically in conjunction with an increase in delta activity, although theta may increase independently of delta (Gruzelier et al., 2013a). The point when theta activity supersedes alpha activity, the stability of which is subject to individual differences, is called the theta-alpha "crossover", which is commonly associated with alterations in consciousness leading to the onset of early sleep-stage I (e.g. Broughton and Hasan, 1995; Niedermeyer, 1999; De Gennaro et al., 2001). Successful progression is defined by an increase in the theta/alpha (t/a) ratio both within and across sessions. However, because of the brevity of sessions which optimal performance sessions in healthy individuals of necessity usually dictates, the everyday fluctuations in arousal state as participants present for training and which underpin their readiness to enter stage 1 sleep can make day to day across-session t/a ratio progression elusive. Typically the more reliable evidence is obtained from within- rather than across-session changes.

A series of methodological studies has been conducted on A/T training. With the aim of examining whether hypnogogic visualisations were promoted by A/T feedback Moore et al. (2000) contrasted 40-min sessions of training either posterior O2 alpha (8–12 Hz)/theta (4–8 Hz), alpha-only, or EMG feedback, all preceded by thermal biofeedback. Visualisations were found with all interventions and all produced A/T cross-over. Interpretation was compromised by poor compliance from the abstinent substance misuse outpatients ($N = 35$). This precluded meaningful group comparisons leading the authors to examine groups on the basis of pooled sessions rather than subjects, though the data disclosed more than twice the number of sessions in the A/T group, while the calculation of mean t/a ratios did not allow for the independent dynamics of alpha and theta wave production to be considered.

The first evidence of operant control of A/T training arose from an analysis of temporal dynamics where students were randomly assigned to Pz alpha (8–12 Hz)/theta (4–7 Hz) training or to noncontingent sham training consisting of the playback of another subject's session (Egner et al., 2002). Within two weeks five, 15-min sessions preceded by baseline were conducted, and the Thayer Activation/Deactivation Checklist (Thayer, 1967) was administered at the end of each session. In the A/T group there was a linear increase in t/a ratios, an increase not found in the control group. Across-session mean ratios were significantly higher in the contingent group on two/five sessions, underscoring the occurrence of across-session variability. The groups did not differ in their reduced Thayer activation, indicating firstly that the sham procedure was as relaxing as the experimental procedure, with no evidence of possible frustration because of noncontingency through the false feedback. Secondly it was inferred that the t/a short-term relaxation was not captured by the phenomenology of the broad descriptive activation/deactivation assessment, supported by the absence of significant correlation between the t/a ratios and the scales, as will be elucidated by the performing arts studies.

Subsequently temporal dynamics were further explored (Egner and Gruzelier, 2004b) by comparing frontal (Fz) with parietal (Pz) training in view of the broadly different theta correlates from posterior arousal and fronto-limbic theta systems. Also because of evidence that the longer-term outcome two weeks later in the resting EEG was at frontal sites following posterior A/T training, taking the form of reduced frontal beta1 and 2 (Egner and Gruzelier, 2004b). Furthermore there has been widespread current interest in the psychological significance of anterior theta measured from the frontal midline, though in the waking not the hypnogogic state (Inouye et al., 1994; Grunwald et al., 2001; Jensen and Tesche, 2002; Kubota et al., 2001; Missonnier and Deiber, 2006). The dynamics and learning with Pz and Fz training were found to differ. At the conventional posterior site reliable operant control was obtained and dynamics were in line with both deactivation and the signature of the wakefulness-to-sleep transition (De Gennaro et al., 2001), namely a lesser decrease in theta than alpha activity underpinning the increase in the t/a ratio. At the frontal midline site there was an absence of operant control while increments in theta were relatively larger than increments in alpha unlike the waking to sleep transition. The results implicated different generators in the dynamics of A/T training at Pz and Fz. Accordingly A/T training has centred on posterior theta with its associations with lowered arousal.

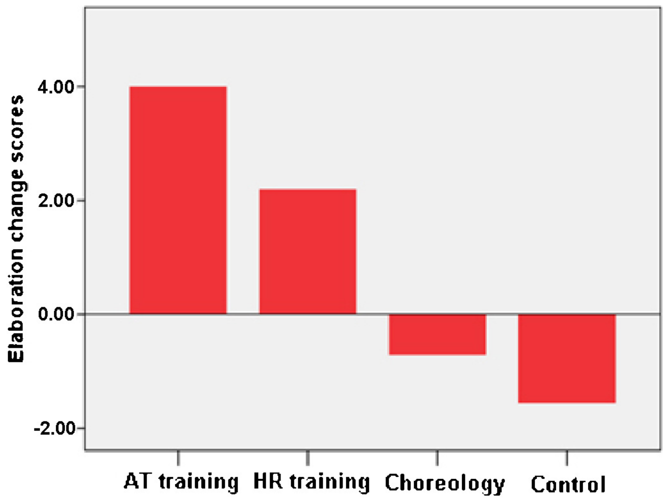

Fig. 2. Mean Guilford divergent thinking change scores for A/T, HRV, choreology and non-intervention control groups ($N = 45$) (Gruzelier et al., 2013b).

1.2.5. A/t and cognitive creativity

In the first controlled attempt to examine the outcome of the A/T protocol on cognitive creativity Boynton (2001) examined the impact of eight, twenty-min, weekly sessions of training with participants ($N = 62$) in groups of two to six requiring them to either increase Pz theta (4–8 Hz) over alpha (8–12 Hz) amplitude or to relax with eyes-closed. Both were supplemented by pre-training lectures, post-session discussions and background music. Cognitive creativity was measured with the Torrance (1974) and Guilford et al. (1978) tests and well-being with the Friedman (1994) scale. There was improvement in creativity and well-being without preferential group changes. No EEG data were reported.

Doppelmayr and Weber (2011) with a primary interest in visuospatial rotation examined the impact of thirty sessions of SMR (C3,4) ratio training compared with theta/beta1 (4.5–7.5/15–21 Hz) training and a control consisting of random 1 Hz bins in the range 6–35 Hz. A battery of cognitive measures included the Verbal Creativity Test (Schoppe, 1975) which provides a creativity index calculated from nine subtests, six of which are related to verbal tasks such as inventing new names, and the other three are titled Unusual Applications, Utopic Situations, and Inventing Nicknames. While SMR training benefitted mental rotation, none of the groups showed improvement in creativity.

An increase in cognitive creativity was found in a study with young contemporary dancers who were randomised to one of four groups, either A/T or heart rate variability (HRV) training, a dance theory comparison group or a non-intervention control group (Gruzelier et al., 2013b). The results on dance performance are outlined in Section 2.3. Following A/T training there was an increase in expressive creativity on the Guilford test (1978) when compared with the comparison groups, see Fig. 2. No changes were found with the Insight test (Dow and Mayer, 2004).

2. Creative music performance

2.1. Elite music performance

The benefits of neurofeedback training for elite music performance as judged by performance experts were first demonstrated in a foundational two-experiment investigation in conservatoire students (Egner and Gruzelier, 2003; Gruzelier and Egner, 2004). As the method was the blueprint for the performing arts studies that followed, and method is the subject of considerable debate in creativity research, it is outlined in some detail. This capitalised

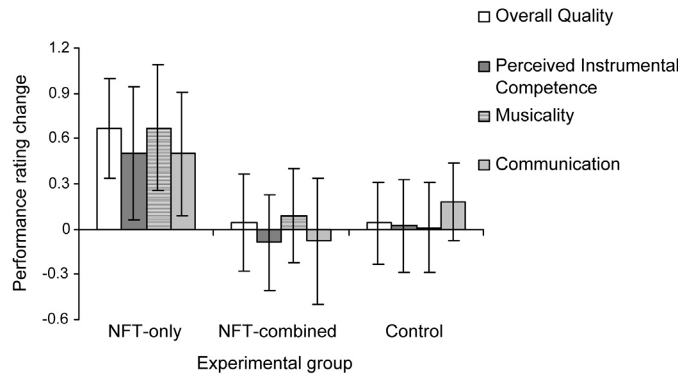

Fig. 3. Mean music performance rating change scores (±S.E.M.) on overall quality and the three music domains showing advantages for the neurofeedback-only group compared with the neurofeedback and additional interventions (NFT-combined) group, and a no-training control group ($N = 36$, Egner and Gruzelier, 2003, study I).

on assessment procedures formalised by the Associated Boards of the Royal Schools of Music (Harvey, 1994) consisting of an overall quality mark and three main categories: Musicality/Creativity, Technical Competence, and Communication/Presentation, which were adapted further with ten sub-scales defined in consultation with instrumental professors (Thompson and Williamon, 2003): Musicality/Creativity subscales were Interpretative Imagination, Expressive Range and Stylistic Accuracy; Technique subscales were Technical Security, Rhythmic Accuracy, and Tonal Quality and Spectrum; Communication/Presentation subscales were Deportment, Emotional Commitment and Conviction, and the Ability to Cope with Situational Stress. Each was marked on a 1–10 scale mapping onto the percentage scales used in the conservatoire. Musicians played two contrasting pieces of their choice from current repertoire for up to 15 min on their first study instrument before a small audience. Video recordings were edited into a random order to blind the raters for group and order of performance and were sent to two external evaluators in the first and three in the second study. Average inter-rater reliability across all evaluation scales was $r = 0.52$ ($p < 0.001$) which was comparable to prior studies of music performance assessment (e.g. $r = 0.53$, Thompson et al., 1998; $r = 0.49$, Wapnick and Ekholm, 1997) and as will be seen the improvements in rated performance correlated significantly with neurofeedback learning attesting to rating reliability. Pre-performance state-anxiety was also assessed (STAI, Spielberger et al., 1983).

Three neurofeedback protocols were contrasted: sensory-motor rhythm (SMR, 12–15 Hz) and beta1 (15–18 Hz) training with theta (4–7 Hz) and beta2 (22–30 Hz) inhibits, and alpha/theta training (A/T, 4–7/8–12 Hz). There were thirty-six volunteers of whom twenty-two took part in SMR/beta1 feedback in ten twice-weekly training sessions of over five weeks. Each session consisted of 15-min of counterbalanced SMR and beta1 protocols. This training course was followed by A/T training also in ten 15-min sessions within a five week period. A random sub-sample of twelve was additionally engaged in mental skills and aerobic fitness training while a third group of fourteen comprised a no-training control group.

Music performance improvements occurred only in musicians who had received neurofeedback training and improvements were in all the three music performance domains, see Fig. 3. In order to tease apart which of the neurofeedback protocols may have been most closely associated with performance enhancement, within- and across-session learning indices for each protocol were calculated, disclosing that a composite A/T learning index and not the SMR or beta1 learning indices correlated positively with improvements in: (i) overall quality, (ii) the three performance domains

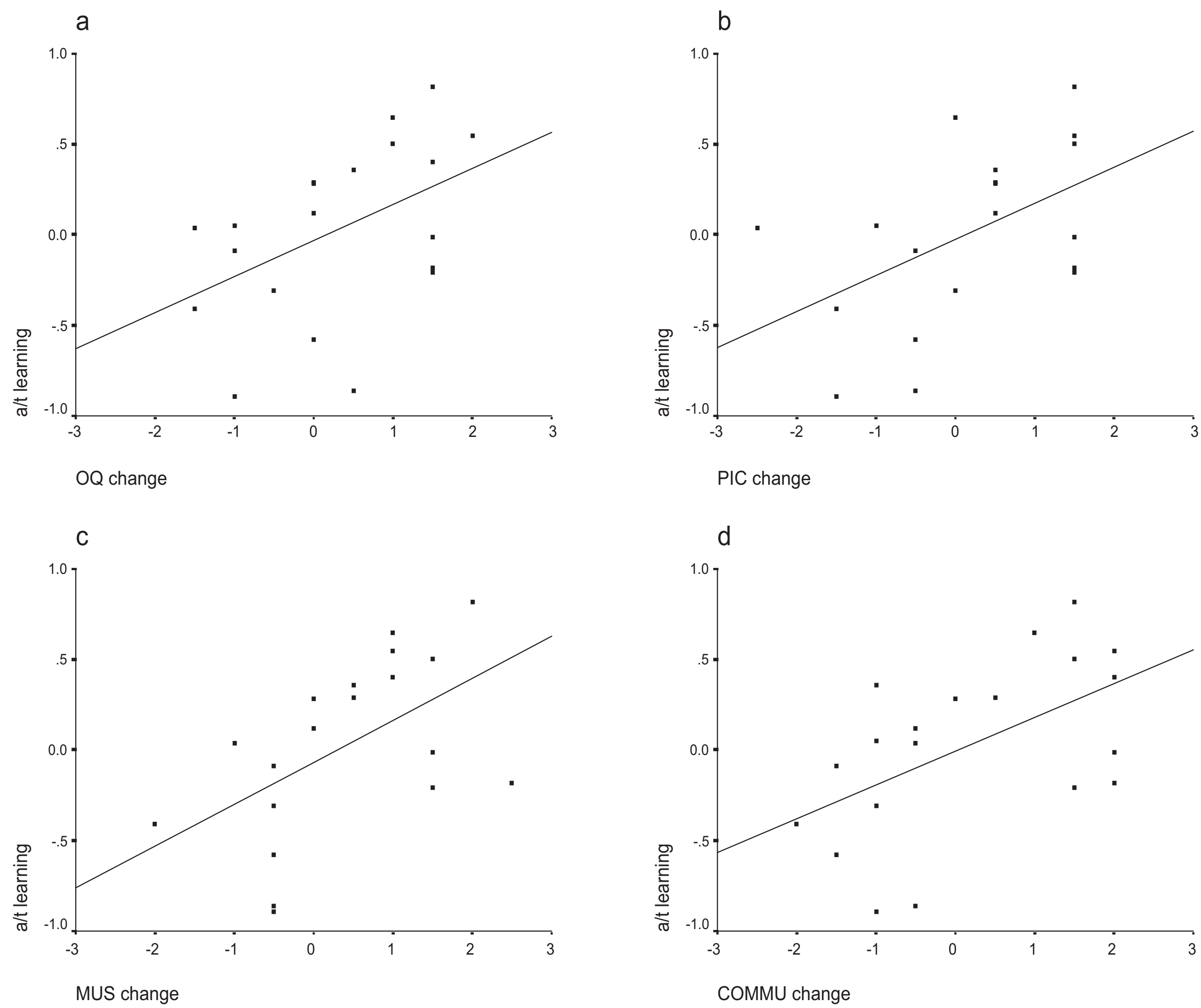

Fig. 4. Lines of best fit for bivariate correlations between A/T learning and music performance rating changes on the main evaluation categories of (a) overall quality [OQ], (b) perceived instrumental competence [PIC], (c) musicality [MUS], and (d) communication [COMMU] ($N = 22$, Egner and Gruzelier, 2003, study I).

($r = 0.47–0.55$, $p < 0.038–0.013$), see Fig. 4, and (iii) the various subcategories ($p < 0.007–0.052$, see Table 1). Differential improvement rates between the experimental groups were not related to pre-performance state anxiety for all interventions disclosed a similar reduction in anxiety between performances.

Table 1
Music performance rating scales with correlations between changes in performance and alpha/theta learning.

	A/T Learning	
	r	*p*
Overall quality	0.47	0.04
Perceived instrumental competence	0.50	0.03
Level of technical security	0.39	0.09
Rhythmic accuracy	0.65	0.00
Tonal quality and spectrum	0.39	0.14
Musicality/musical understanding	0.54	0.02
Stylistic accuracy	0.58	0.01
Interpretative imagination	0.48	0.04
Expressive range	0.53	0.02
Communication	0.55	0.01
Deportment	0.45	0.05
Communication of emotional commitment and conviction	0.51	0.02
Ability to cope with situational stress	0.44	0.05

Edge and Lancaster (2004) in an interpretative phenomenological analysis on a subgroup of musicians found that the reduction in anxiety following fast-wave (SMR/beta1) training had a counterpart in subjective reports which included the introspection "it lets my mind breathe". However, these advantages did not carry over to performance ratings by the experts. This was elucidated further by Thayer (1967) activation ratings which had been obtained after each of the SMR and beta1 training sessions scheduled in a counterbalanced order Gruzelier (2013c). While tiredness increased with both protocols it was only SMR training that facilitated calmness.

In a second investigation (Gruzelier et al., 2002; Egner and Gruzelier, 2003; Gruzelier and Egner, 2004) a constructive replication (Lykken, 1968) was undertaken with an independent-groups design involving random allocation to one of six groups, either A/T ($n = 8$), beta1 ($n = 9$), SMR ($n = 9$), physical exercise ($n = 16$), mental skills ($n = 9$) or Alexander training ($n = 10$; Barlow, 1980) training. There were ten 15-min neurofeedback sessions over 6–8 weeks, while musicians having the other interventions had a similar amount of involvement. In support of experiment 1 the A/T group displayed significant improvements, while the beta1, SMR, Alexander, physical exercise, and mental skills training groups showed no post-training changes. The A/T learning enhancing effects were replicable with respect to all aspects of Musicality/Creativity

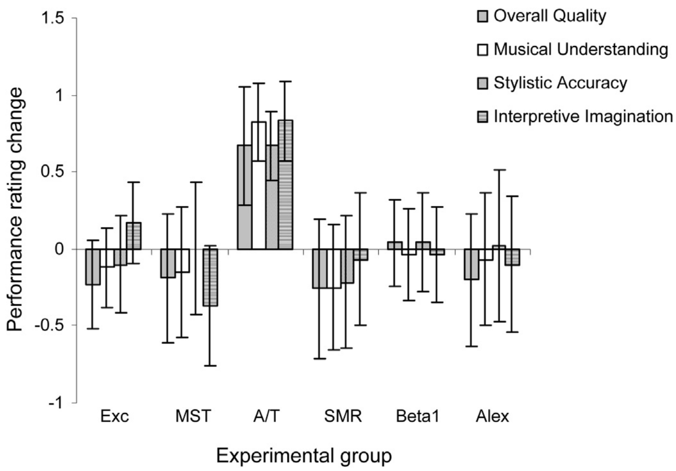

Fig. 5. Mean change scores (±S.E.M.) for the physical exercise (Exc), mental skills training (MST), alpha/theta (A/T), SMR (SMR), beta1 (Beta1), and Alexander Technique (Alex) groups on the main evaluation categories and overall quality showing advantages following A/T training (N = 61, Egner and Gruzelier, 2003, study II).

in performance: Musicality, Stylistic Accuracy and Interpretative Imagination – together with overall quality (see Fig. 5). Here potential benefits for Technique and Communication did not reach significance. The A/T group improvements which ranged between 13.5% and 17%, with a mean improvement rate of 12% across all evaluation scales, were of the order of a class of degree honours, and as such were of pedagogic and professional significance.

In a brief technical report Bazanova et al. (2007) in a single-session contrasted two groups of music academy students (N = 51) who were subdivided as having high or low alpha peak frequency according to an individually adjusted frequency procedure (Klimesch et al., 1993) and to the width of the posterior alpha peak. Recording EEG bilaterally at standard frontal, central, parietal and occipital sites together with frontalis EMG, students first played a 5-min piece of their choice for assessment, practised for 30-min, and then practiced with simultaneous alpha and EMG feedback taking the form of sounds of applause which were heard when an alpha2 power increase was accompanied by a decrease in EMG, after which the music performance was repeated. Three expert observers evaluated their playing on a 10-point scale (Kraus, 1982) which was also completed by the participants. Students were told biofeedback would assist in achieving 'a high quality performance complimented by a feeling of easiness and comfort'. Self-estimation of performance was higher after biofeedback, however, there was no control for expectancy or order of practice conditions. The feedback condition successfully increased alpha power and coherence in both bands and reduced EMG, moreso in the high-alpha group in whom training was said to be the more efficient. The high-alpha students were also said to be rated as superior by the judges. The preferential results for the high-alpha participants have a counterpart in reports elsewhere of superior cognitive performance in high- compared with low-alpha individuals (Bazanova and Vernon, 2013). The outcome was in line with two uncontrolled single case studies (Bazanova and Lubomir, 2006) where successful alpha training led to expert ratings of improved quality of sound, subjective feelings of emotional calm and 'flow' in performance and reduced anxiety.

2.2. Novice music performance

2.2.1. SMR and novice performance

The outcome on creativity in elite musicians (Egner and Gruzelier, 2003) led to a pedagogic initiative to explore the impact on novice musical abilities in both adults and children. Here SMR training was of interest in view of the potentially greater demands in novices on fundamental cognitive processes such as attention, working memory and psychomotor skill. These are processes which SMR training has been shown to enhance (Egner and Gruzelier, 2001, 2004a,b; Vernon et al., 2003; Ros et al., 2009), and coincidental with overall technical gains in microsurgery, SMR training led to a more efficient outcome – faster on task with longer pauses between tasks – resulting in a more modulated performance (Ros et al., 2009); for additional cognitive gains from SMR training see Barnea et al. (2005) and Doppelmayr and Weber (2011). Furthermore in the elite conservatoire musicians SMR training had had a favourable impact on both attention (Egner and Gruzelier, 2001, 2004a,b) and mood (Edge and Lancaster, 2004; Gruzelier, 2013c), sequelae which in the novice may carry over to music performance. The inhibition of sensory-motor cortex following SMR training has facilitated response inhibition in studies with animals and patients with epilepsy Sterman (1996) and altogether the cognitive gains following SMR neurofeedback have been interpreted as reflecting improved regulatory control of somatosensory and sensorimotor pathways leading to a better integration of task-relevant stimuli and more efficient attention (Egner and Gruzelier, 2001; Barnea et al., 2005; Doppelmayr and Weber, 2011).

2.2.2. Novice versus advanced music performance in adults

The efficacy of neurofeedback on novice and elite musical ability (Gruzelier, 2012; Gruzelier et al., 2013c) was examined by recruiting advanced student instrumentalists having novice singing ability and indeed no aspiration to sing. Musical improvisation, both voice and instrumental, was added to investigate further the impact of A/T on creativity in performing (Sawyer, 2000). Both were considered to be at novice level; instrumental improvisation is not conventionally taught in UK conservatoires (Creech et al., 2008). Music students were randomly assigned to A/T (n = 8), SMR ratio (n = 8) or non-intervention control (n = 7) groups. Advanced performance consisted of two prepared instrumental pieces as before, while novice vocal performance was a choice of two unprepared Britten folk songs which were accompanied by a pianist. Instrumental improvisation involved the choice of one theme from a menu while vocal improvisation consisted of Stripsody (Berberian, 1966) where notation was presented as a cartoon-strip on a stave having time and pitch axes, and performed 'as if by a radio sound man who must provide all the sound effects with his voice.' The aim was to facilitate highly expressive and imaginative performance, not requiring trained vocal ability. Evaluation domains were as for the original studies with additional sub-categories, for example Sense of Performance, and Breathing with Music in Mind, Pitch, and Clarity of Diction for singing (see tabulation in Gruzelier et al., 2013a). Performances were filmed and randomised for pre- and post-training order and group with expert raters whose inter-rater reliabilities ranged between r = 0.72 and 0.89. For Communication ratings with the folk song there were in addition lay ratings from three observers (r = 0.81) for the first six students in each of the two neurofeedback groups with categories of Expressivity, Stage Presence and Confidence (Gruzelier, 2012; Gruzelier et al., 2013c).

Firstly, considering the effect of the A/T protocol, as was found in the first of the original studies advanced prepared instrumental playing was enhanced across all three domains of music performance, with affirmative correlations between ratings and within- and across-session learning ratios, especially within-session learning, where the strongest correlation was for the Musicality/Creativity domain (r = 0.89, p < 0.005; Stylistic Accuracy, r = 0.892, p < 0.005; Interpretative Imagination, r = 0.762, p < 0.025; Expressive Range, r = 0.671, p < 0.05). There was also an impact on Communication Overall (r = 0.785, p < 0.01) to include subcategories of Confidence (r = 0.813, p < 0.025), and Sense of Performance

($r = 0.722$, $p < 0.025$). There was a lesser relation with Technique ($r = 0.70$, $p < 0.05$).

Turning to the effect of A/T training on novice abilities, performance gains also extended to the vocal improvisation creativity exercise. These covered the primary creativity rating Interpretative Imagination and Musicality Overall, while there was a more general impact on subscales of Communication/Presentation including Deportment, Emotional Commitment and Conviction, Confidence and Being At-One with Voice. In the Technical domain both Vocal Performance Overall and Tonal Quality improved. There were no correlations between ratings and learning indices. For instrumental improvisation the level of performance was judged to be poor overall with no gains from A/T training.

With the novice singing of folk songs benefits were also strongest in the Musicality/Creativity category, and extended through a higher Emotional Commitment and Conviction rating to Communication. The experts' impression of enhanced Communication was strongly shared with lay judges' ratings of Confidence, Stage Presence and Expressiveness, where there were highly significant advantages following A/T learning compared with SMR learning. The validity of the lay judgements were supported both by their consistency with the ratings of the experts and a high positive correlation between the across-session A/T learning index and the lay Confidence ratings ($r = 0.88$, $p < 0.02$) – there were no correlations between the expert ratings and neurofeedback learning. The apparent transparency of the benefits of A/t training to the lay judges is worth exploring further.

Considering SMR ratio training the outcome was compromised by an absence of learning for the group as a whole, though consideration of individual differences in learning disclosed positive correlations with the rated improvements in novice music performance. In replication of the earlier studies (Egner and Gruzelier, 2003) there was no impact on advanced performance, but regarding novice performance the prediction that Technique would be a likely domain to disclose lower-order process benefits from SMR training was supported. Gains were found for novice vocal technical performance, especially Pitch with the folk song. Furthermore on the basis of correlations in those participants with the better SMR/theta ratio learning across sessions the greater was the impact on instrumental improvisation. This was the piece with which the musicians experienced the greatest difficulty, as inferred from low expert ratings, and could therefore be considered the most likely to show hypothesised benefits of SMR training on performance. The strongest correlations were with Communication, in particular Emotional Commitment ($r = 0.78$, $p < 0.05$) and with a number of suggestive relations at the 10% level impacting on Performance Overall ($r = 0.67$, $p < 0.09$).

2.2.3. Novice music performance in adults

A second study was undertaken of adult novice singing in instrumentalists (Leach et al., 2013; Gruzelier, 2012) with the same pieces and two raters. Here the post-training session was scheduled 10 min after the last training session which had the serendipitous outcome of maximising the demands on sustained attention hypothesised to have a preferential benefit from SMR ratio training, but compromising A/T training given the proximity of the borderline sleep hypnogogic experience to the musical performance. Nineteen undergraduate music students were randomly assigned to alpha-theta (7), SMR ratio (6) and no-training control (6) groups. Inter-rater reliability between the raters was $r = 0.63$ for folk song and $r = 0.71$ for improvisation. In support of the previous study the novice singing of folk songs improved following SMR training with the ratings of Interpretative Imagination and Expressive Range, and there was a positive correlation between within-session learning and Vocal Technique ($r = 0.97$, $p < 0.05$). Vocal improvisation ratings disclosed an improvement in Musicality, though SMR/beta learning correlated negatively with Interpretative Imagination.

Unlike the previous studies (Egner and Gruzelier, 2003; Gruzelier et al., 2013a,c) performance was compromised following A/T training, and in order to test whether the hypothesised proximity to the hypnogogic experience was a likely factor correlations were obtained between the within session theta/alpha ratio in the last session, a reflection of the depth of hypnogogia. Indeed the greater the increase in the theta/alpha ratio and the putative successful attainment of the training goal of hypnogogia the worse were the Communication and Musicality ratings for the folk song, and the post-training rating of Deportment was lower in the A/T group. In keeping with this there was a significant decline in Vocal Technical Competence. Notwithstanding vocal improvisation, which showed a falloff in performance in virtually all scales, also disclosed a positive correlation between the average within-session learning and Oneness with Voice.

2.2.4. Novice music performance in children

Neurofeedback was found to be feasible in a school setting when thirty eleven year olds completed training having been allocated to A/T, SMR ratio or a non-training control group and leaving classes for ten 30-min neurofeedback sessions (Gruzelier, 2012; Gruzelier et al., 2013a). Prepared vocal or instrumental pieces were examined along with creative improvisation, while sustained attention was examined with a task allowing the calculation of an ADHD attention index (TOVA, Greenberg and Kindschi, 1999), and the children's phenomenological report was recorded to compliment the objective assessments. Performances from randomised film clips were rated by three teacher assessors (inter-rater reliability, $r = 0.82$) on 5-point scales covering Creativity (Use of Imagination, Well Structured Performance, Appropriateness to Title, Expression (dynamics and articulation)), Communication (Confidence, Posture, Engagement with the Audience and Enjoyment), and Technique rated for prepared performance only (Vocal Quality, Clarity of Diction and Sense of Pitch, and Control of the Instrument for instrumental playing).

A/T learning, not previously reported in children, proved to be highly effective within sessions, and while SMR/beta2 ratios increased satisfactorily the inhibition of theta was ineffective so that the SMR/theta ratio was unchanged. Following A/T training Technique in prepared performance improved and Communication held up, not showing the falloff observed in the other groups, a possible consequence of the wear and tear of the school term. Improvisation also improved with Musicality/Creativity ratings, but mostly A/T training advantaged Communication in improvised performance, and both domains of improvement were shared with SMR training. As reviewed in Part I (Gruzelier, 2014a) sustained attention was enhanced following A/T training with a highly significant reduction in impulsive errors of commission which would be in keeping with the protocol's facility in inducing relaxation. The exploratory subjective reports at the close of the study disclosed that 19/22 children receiving neurofeedback felt improved well-being at school which could extend to the home while impressions of a positive carry-over to the classroom were volunteered by 8/9 following fast-wave training in relation to science, maths and physical education, and 6/10 following slow-wave training in relation to performing arts, English and maths. The pedaogogic implications are promising.

2.3. Dance performance

Reduction in anxiety (STAI, Spielberger et al., 1983) was found in two uncontrolled case studies with dancers by Singer (2005) following thirty sessions of a broad band 11–16 Hz (T3/4) training with inhibits of 2–7 Hz and 23–38 Hz activity. Anxiety reduction was accompanied by feelings of 'flow' while dancing; objective expert ratings were not obtained. Two controlled investigations have examined dance performance comparing A/T neurofeedback with heart rate variability (HRV) biofeedback. HRV aims to induce a coherent waveform, as can be achieved with slow paced breathing, with reports suggestive of efficacy in female gymnasts, in rehabilitation following myocardial infarction, and in the treatment of panic disorder (Bessel and Gevirtz, 1998; Del Pozo and Gevirtz, 2002; Berger and Gevirtz, 2001). HRV training has been successfully combined with self-hypnosis and osteopathic soft tissue manipulation in a physically and emotionally compromised ballet dancer (Gordon and Gruzelier, 2003).

The first controlled study (Raymond et al., 2005b) involved ballroom and Latin dancers from a competitive university team who performed in male–female pairs and were evaluated individually by two world ranking dance assessors with a scale used for national dance assessments incorporating categories of Technique, Musicality, Timing, Partnering Skill, Performing Flair and Overall Execution. They were randomly allocated to A/T, HRV, and control groups ($N = 6, 4, 8$ after dropouts), and received up to ten sessions of training over four weeks, with a mean of nine sessions. Alpha and theta bands were individually adjusted according to the dominant alpha frequency. Both training groups improved more than the control group in overall execution, despite the disclosure from practice diaries that the controls practised more. Within the categories A/T training improved Timing and HRV improved Technique.

In the second study (Gruzelier et al., 2013c) first years at a dance conservatoire were randomised to one of four groups: A/T, HRV, Choreology, or No-intervention and were examined with a modern dance phrase. Forty-five participated in eight or more 20-min training sessions once a week. To accommodate the curriculum eighteen subjects were trained during 1.5 h in the same room in groups of six. Choreology which involved tutorials on Laban dance theory took place in ten group sessions. Pre- and post-assessments were twelve weeks apart. Dance performance involved a 40-s dance phrase designed by the dance faculty and filmed and rated for artistry and technical performance by four dance experts blind to order and group (inter-rater reliability, $r = 0.56$). As mentioned earlier (Section 1.2.5) cognitive creativity in the form of divergent thinking and insight was assessed respectively with the Alternative Uses Test (Guilford et al., 1978) and Insight Problems (Dow and Mayer, 2004) in order to explore associations with classical measures of cognitive creativity and A/T training in particular. Mood was assessed with the Depression, Anxiety and Stress Scale (Lovibond and Lovibond, 1995).

Whereas there was clear evidence of HRV learning, A/T learning was slower to take place perhaps because the goal of hypnogogia was hampered by the group learning sessions. None of the three interventions improved dance performance, but there was a reduction in Anxiety following HRV training (see Fig. 6) which importantly in the cohort as a whole was associated with improvements in artistry ($r = -0.30$, $p < 0.05$) and technique ($r = -0.25$, $p < 0.05$). As depicted earlier (Fig 2), following A/T training the Unusual Uses expressive creativity elaboration score increased when compared with the no-intervention control group, in line with theory.

2.4. Acting performance

The potential for SMR training to enhance creativity in performance was revisited by examining creative acting performance in sophomores with two methodological innovations especially devised for the context of neurofeedback learning (Gruzelier et al., 2010). In order to facilitate an association between neurofeedback and real-world connections a theatrical performing space as seen from the stage was rendered on the training screen for one

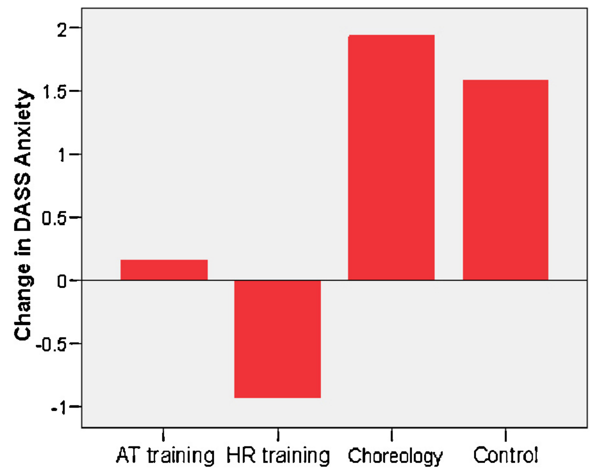

Fig. 6. Mean DASS Anxiety change scores for A/T, HRV, choreology and non-intervention control groups ($N = 45$) (Gruzelier et al., 2013b).

group of actors, while for another the image was seen through 3D glasses in a room where through back projection the actor was surrounded by the same auditorium image in order to enhance presence (Cruz-Neira et al., 1993; Sanchez-Vives and Slater, 2005). Additionally the learned control of brain rhythms was interfaced with the neurofeedback cues which were specifically chosen to signify the actor's control of aspects of the performing space: moderating the lighting in conjunction with SMR amplitude control, and reducing intrusive audience noise with the inhibition of theta and beta2 amplitudes. The ensuing mastery of control and ecological validity were hypothesised to transfer to the control of the acting performance.

Given that sense of control theoretically contributes to the subjective experience of flow, actor self-ratings with a Flow scale were obtained immediately after performing (Jackson and Eklund, 2004). Flow is a psychological construct (Csikszentmihalyi, 1996) describing that optimal experience when the performer is in the 'zone', i.e., totally absorbed in performing, and for them everything comes together. Mastery is central to creative performance, and the sense of control contributes to the subjective experience of flow in performance. The state is itself intrinsically motivating and does not rely on any product or extrinsic reward. It requires an optimal balance between skill, mastery and challenge with immediate feedback about accomplishment. Thus it involves intense concentration without self-consciousness and a feeling of satisfaction, and often the experience of a 'high'. The Flow State Scales (FSS; Jackson and Eklund, 2004) measure nine dimensions: Merging of Action/awareness, Clear Goals, Unambiguous Feedback, Concentration on the Task at Hand, Sense of Control, Loss of Self-consciousness, Transformation of Time, Autotelic Experience and Challenge-skill Balance.

The actors were all fifteen of a class of visiting drama sophomores who over six weeks received either between 7 and 10 sessions of neurofeedback or acted as controls. They were randomised to the two training groups – laptop screen ($N = 6$) or ReaCTor ($N = 5$). Acting performances were rated from filmed studio monologues and Hamlet excerpts performed on the stage of Shakespeare's Globe theatre by three experts from acting conservatoires blind to order and group. The Acting Performance Scale consisted of eleven 10-point scales covering Overall Performance, Voice, Movement, Creativity and Communication: Overall Performance, Vocal Transformation, Vocal Expression, Movement Fluency, Movement Inhabitation, Imaginative Expression, Imaginative Conviction, Imaginative Characterisation, Seamlessly Engaged, At-one with Performance and Well-rounded Performance.

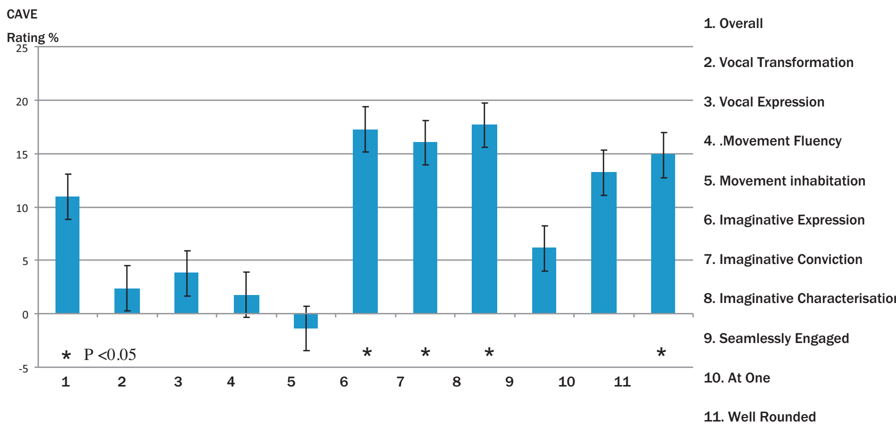

Fig. 7. Percent improvement in acting ratings advantage of ReaCTor over the computer screen training.

Irrespective of training medium (laptop or ReaCTor) those actors who had received neurofeedback experienced higher flow in performance than the controls. However, the more immersive VR procedure had a greater impact on acting performance than the conventional 2D computer screen, even though the same auditorium was depicted. Of the various acting performance domains the greater impact was found to be specific to the creativity in acting domain with the three ratings Imaginative Expression, Conviction and Characterisation – which carried over to the ratings of Overall Performance and Well-rounded Performance (Fig. 7). The preferential effects of the 3D training context had a counterpart in a slight advantage for the more immersive VR context in the speed with which self control of the EEG was learned as depicted in EEG learning curves (see Gruzelier et al., 2010; Gruzelier, 2014b) and with self report introspection on a scale item: "At what stage did you recognise the mental state we were seeking in you?

Of importance for validity and of theoretical relevance to creativity research, in what was the first systematic examination of the subjective experience of the performer about their state during performance following neurofeedback training, the enhancement in the subjective sense of flow-state correlated comprehensively with ratings by the experts for all domains of acting performance (see Table 2). The correlations involved all the categories of acting and were found with five of the Flow scales: Sense of Control, Loss of Self-consciousness, Merging of Action/awareness, Challenge/skill Balance, and Autotelic Experience. The experience of flow in performance was superior in the actors trained with neurofeedback than in the untrained controls.

Table 2
Correlations between the actors' sense of flow post-training and experts' ratings of acting.

Flow scale	Acting rating	r	p
Sense of control	Being-at-one with performance	0.62	0.03
	Vocal expression	0.52	0.07
	Well-rounded performance	0.53	0.07
	% improvement	0.58	0.05
Loss of self-consciousness	Creativity scales factor	0.69	0.03
	Conviction	0.66	0.04
	Movement fluency/inhabitation	0.64	0.05
	Mean of all acting ratings	0.62	0.06
Merging action and awareness	Being-at-one	0.56	0.06
	Vocal scales % improvement	0.60	0.04
	Vocal expression	0.55	0.06
	Imaginative expression	0.53	0.08
Challenge/skill balance	Being-at-one	0.56	0.06
	Well-rounded	0.52	0.08
	Vocal scales	0.53	0.07
Autotelic experience/enjoyment	Vocal Scales	0.57	0.05

3. Summary of neurofeedback outcome and hypotheses on music, dance and acting performance

3.1. Empirical results

3.1.1. Music

There was consistency for the most part between controlled studies of advanced and novice performance involving adults and children.

3.1.1.1. Alpha/theta.

(i) Considering first advanced performance, the reliable finding belonging to all three controlled studies was the gain in Musicality/Creativity following A/T neurofeedback (Egner and Gruzelier, 2003 study I, II; Gruzelier et al., 2013c). In two studies this extended to the domains of Technique and Communication/Presentation, but interestingly in the six-group study where the total sample size was sufficient to allow estimates of co-linearity of the judges between categories, notwithstanding that co-linearity was high (Thompson and Williamon, 2003), the advantage was confined to the Musicality/Creativity domain plus Overall Quality. Furthermore in the third study, where the attribution of feedback mediation was examined by correlating rating-change with neurofeedback learning, the strongest correlation was with the Musicality/Creativity category but extended to Communication and Technique. Whereas in the first study the evidence in favour of A/T feedback had been necessarily only correlational by virtue of the musicians having experienced A/T, SMR and beta1 protocols, allowing for the possibility that this gain may have arisen as a cumulative protocol outcome, this qualification was dispelled through the two subsequent independent group studies where the gain was confined to A/T training. In sum a preferential impact of A/T training on Creativity in musical performance appears reliable in the elite musician with also an impact on Communication and Technique.

(ii) Considering novice performance, advantages following A/T feedback were also found with creative improvisation. Again the advantage was most strongly evinced in the Musicality/Creativity domain with the Interpretative Imagination rating, which as a subcategory of Musicality/Creativity was perhaps the most explicit subcategory rating of creativity (Gruzelier et al., 2013c). However, it extended broadly to Communication subcategories and with a lesser impact on Technique. Musicality was also enhanced with the unprepared song of adults where it also extended to the Communication expert ratings of Emotional Commitment and Conviction, a gain corroborated by lay ratings of Confidence, Stage Presence, and Expressiveness, and with the ratings of increased Confidence correlating positively with A/T learning (Gruzelier, 2012; Gruzelier et al., 2013c). While unprepared adult singing was impaired in a second study, the scheduling of the post-training performances was likely to compromise A/T outcome (Leach et al., 2013).

(iii) Children's musical improvisation was also facilitated by A/T feedback in the Creativity domain, along with Communication (Gruzelier et al., 2013c), while their rehearsed performance gained in ratings of Communication and Technique. Thus in children A/T training could be seen to have an impact on all three music domains in line with the first of the two adult conservatoire studies.

In conclusion, as for elite performance, the preferential effect of A/T training on adult novice performance was on the creativity domain, extending especially with novice singing to communication and with lesser impact on Technique. In children the impact overall was on all three music domains, though without an impact on creativity in their prepared accompanied performance. All told there were six demonstrations of A/T facilitating creativity in elite and novice musical performance, and five demonstrations of an enhancement in Communication, with a striking impact from the perspective of lay judges.

3.1.1.2. Sensory-motor rhythm. A further consistency in advanced rehearsed performance was the lack of benefits attributable to faster-wave training, either in the case of SMR feedback (Egner and Gruzelier, 2003; Gruzelier et al., 2013a), or beta1 feedback (Egner and Gruzelier, 2003), despite the fact that both protocols benefitted the musicians' attention in the laboratory (Egner and Gruzelier, 2001, 2004a,b) and with SMR feedback benefitting calmness during neurofeedback (Gruzelier, 2013c). One implication was that the advanced performer through experience was in control of these processes in performance.

While SMR feedback had not facilitated advanced performance, the hypothesised impact on novice performance by virtue of lower-level process engagement was confirmed in both adults and children:

(i) Adult Vocal Technique was improved, while SMR/theta learning correlated positively with Communication in instrumental improvisation (Gruzelier et al., 2013c).

(ii) Furthermore when music performance followed immediately after training, a putatively more demanding context, the novice vocal performance ratings of Interpretative Imagination and Expressive Range belonging to the Musicality subcategory improved and the gains in Technique correlated with SMR learning (Leach et al., 2013). Adult vocal improvisation also gained in Musicality/Creativity overall but with a negative relation with the Interpretative Imagination subcategory when individual differences were taken in to account (Leach et al., 2013).

(iii) In children SMR feedback did not impact on rehearsed performance, but shared improvements with A/T feedback in both Creativity and Communication in improvisation (Gruzelier et al., 2013a).

In conclusion unlike the lack of impact on elite performance SMR facilitated all domains of assessment of novice musical performance, five instances in all, in support of an influence on lower-level abilities common to music performance in general.

3.1.2. Dance

(i) Both A/T and HRV interventions facilitated ballroom dancing in university competitors in particular timing and technique respectively (Raymond et al., 2005b). In dance conservatoire students a contemporary dance phrase was not improved by the same interventions, nor by dance theory classes (Gruzelier et al., 2013c); most likely the 40-sec dance phrase was not long enough to disclose benefits, aside from practical issues that may have compromised A/T training leading to slower learning.

(ii) Notwithstanding a divergent thinking aspect of cognitive creativity was facilitated by A/T training, while HRV training facilitated a reduction in anxiety, a reduction which in the sample as a whole correlated with improved artistic and technical performance.

3.1.3. Acting

(i) Young actors benefitted from SMR training which incorporated the innovation that the training screens rendered a theatre auditorium and so provided a real world training context. The real world connection was also endorsed through linking features of the auditorium with the control of the EEG spectral training bands, associating learned brainwave control with control over the acting context (Gruzelier et al., 2010).

(ii) Furthermore a higher degree of immersion in the performing space through a 3D CAVE-like environment when compared with a conventional 2D rendition led to higher ratings of Creativity in acting: Imaginative Expression, Conviction and Characterisation, extending to overall Performance Quality.

(iii) Both the SMR groups had higher self-ratings of flow in performance and there were positive correlations between flow and expert ratings of all aspects of acting performance.

3.2. Experimental hypotheses

3.2.1. Alpha/theta hypothesis and creativity in the performing arts

Considering together the different art forms examined, in keeping with the hypothesised link between elevation of the theta/alpha ratio and creativity in music and dance performance there was consistent objective evidence from the ratings of experts. In adults this encompassed Musicality/Creativity, Stylistic Accuracy, Interpretative Imagination and Timing (Egner and Gruzelier, 2003; Raymond et al., 2005b; Gruzelier et al., 2013c; Leach et al., 2013), and in children Creativity in music improvisation including Imagination (Gruzelier et al., 2013b). Outcome in music and dance also included affective and motivational variables which find expression in performance, as seen in the rating categories of Communication and Technique. These included Commitment and Conviction, Confidence, Emotional Expression Sense of Performance and Enjoyment, which in turn had an impact on Deportment, Breathing, Diction, Being-at-one with Performance and Stage Presence. The only inconsistent evidence was where the music performance was scheduled immediately after the final training session (Leach et al., 2013).

3.2.2. SMR hypothesis and novice skills in performance

Evidence in keeping with the hypothesised link between SMR feedback and novice level performance in music and acting was mostly consistent (SMR training has not been examined with dancers). In adult musicians relations were found with Pitch in Vocal Technique and Rhythmic Accuracy, and with Communication in instrumental improvisation through correlations between neurofeedback learning and Emotional Commitment having an impact on Overall Quality (Gruzelier et al., 2013c). Support was also found in the second novice singing study (Leach et al., 2013) for gains in Musicality in both the folk song through the subcategory ratings of Interpretative Imagination and Expressive Range, and in vocal improvisation where in addition to enhanced Musicality feedback learning correlated positively with Vocal technique; though consideration of individual differences disclosed a negative correlation between SMR Ratio learning and Interpretative Imagination. In children SMR feedback led to gains in ratings of Creativity and in Communication in improvised performance, with no impact on rehearsed performance (Gruzelier et al., 2013a). In amateur actors objective ratings also disclosed improvements in the Creativity domain including Imaginative Expression, Conviction and Characterisation extending to Overall Quality and Well-rounded Performance (Gruzelier et al., 2010).

3.2.3. SMR and immersion

The basic premise of neurofeedback is that brain activity will be regulated by the feedback training so that the learned changes and control of brain rhythms will be transferred to the real world. This informed the reasoning that the clear advantage of slow-wave A/T training over SMR training in enhancing advanced artistic performance in the original studies (Egner and Gruzelier, 2003) lay with real world connections made through imaginative visualisation in the eyes-closed reverie, as reflected in the phenomenological report of the pianist (Section 4.1.1 and Gruzelier, 2009). In contrast faster-wave training was conventionally carried out without this real world association being made during training.

The innovation of attempting to forge this connection by rendering a performing space on the training screen and linking the control of EEG bandwidths to control of the performing environment, allowing a transfer of mastery to acting performance and providing the training context with ecological validity (Gruzelier et al., 2010), disclosed benefits for creative acting performance. Additionally increasing the degree of association and transfer by varying the degree of immersion and presence (Sanchez-Vives and Slater, 2005) in the rendered theatrical space through contrasting CAVE-like 3D and 2D computer screen scenarios of the same theatre auditorium rendition advantaged the more immersive training. This was associated both with faster feedback learning, higher creativity ratings (Fig. 7), and higher flow ratings of Sense of Control, Confidence or Challenge-Skill Balance with a tendency to Feel-at-one with Performance through the Merging of Action/Awareness. A more immersive and ecologically relevant training context for SMR learning is worthy of further investigation.

4. Methodology

The studies executed thus far are not blue sky investigations with large groups, large assessment panels of adjudicators, large numbers of sessions, long-term follow-up, numerous comparison and control groups, batteries of assessments, electrophysiological recordings during performance, consideration of individual differences in learning and so on. The optimal performance EEG-neurofeedback field is a long way from engendering large scale investment. For the benefit of future research some methodological features have arisen from these admittedly pioneering studies in the performing arts that are highlighted because of their particular relevance for contemporary considerations in creativity research. More general issues for the neurofeedback field are covered in Part III (Gruzelier, 2014b).

4.1. Assessment

4.1.1. Subjective reports

Subjective reports are a valuable source of evidence that tend to have been neglected in creativity research as a whole (Piffer, 2012). In the first study with musicians introspection was incorporated in an adjunct study when on the basis of a structured interview an interpretative phenomenological analysis was conducted with a subgroup of musicians (Edge and Lancaster, 2004). This provided validation of the hypnogogic experience with A/T training and the calming experience of the SMR/beta1 protocols. Another student, a pianist who early had an international career playing Carnegie Hall as one of a piano duo noted "During the training sessions I feel extremely relaxed and as though my mind is able to freely glide with my creative ideas bringing a new kind of spontaneity and energy to my thought processes. . .. this gives me the opportunity to explore other areas of creativity that were previously unavailable to me as I'm free from the physical act of playing the piano whilst mentally being in the state of a performance. It's an extremely satisfying state to be in as it's almost as though I've been introduced to thinking of nothing, which then takes me to a place where creative possibilities seem boundless" (Gruzelier, 2009). Insights such as this are of heuristic value.

More formal subjective assessment was included in the acting study which was the first involving neurofeedback to examine subjective ratings on validated scales by the participants about their performance following training and completed immediately after they came off stage (Gruzelier et al., 2010). Importantly, not only did those actors who experienced neurofeedback have higher ratings of Flow in performance (Jackson and Eklund, 2004) than controls, but the subjective flow ratings correlated comprehensively with the objective ratings of the three expert judges, as shown in Table 2, and provided additional validation of the effect of neurofeedback on creativity in performance.

Of more general importance is the evidence, also novel, showing the close temporal association between the session in which participants first acknowledged that they reached subjective awareness of achieving self-control of the SMR ratio and when learning reached a plateau. This provides a useful guide for monitoring learning progress and gauging the length of an individualised neurofeedback programme.

4.1.2. Expert evaluation

It is common lore that diversity of opinion characterises the performing arts critic and adjudicator. In fact Fiske (1983) in a commentary entitled his report "Judging musical performances: Method or madness?" There is an acknowledged richness and complexity when experiencing the performing arts, as in the quote from McPherson and Thompson (1998) "lost in a single mark while at the same time lost in the sum of the parts". In formulating a process model of musical assessment they go on to quote Mills (1991) "I recall performances that have over whelmed me, despite there being a handful of wrong notes. I remember others in which the notes have been accurate, and the interpretation has been legitimate, and yet the overall effect has been sterile. A performance is much more than a sum of skills and interpretation (p. 175)", and they quoted Swanwick (1996) who in an example of artistry and technique in ice skating where two very divergent performances give the same overall score concluded: "Such a rich activity cannot be reduced to a single dimension. . .When we conflate several observations we lose a lot of important information along the way. . .. The fudge of adding a category of 'overall' only makes things worse. (p.6)"

The practice of using a panel of experts to judge creativity has been traced by Stein (1974) to Cattell (1906). Amabile (1982) in advocating and demonstrating validity across broad domains, though not exploring the performing arts, has labelled expert evaluation a consensual assessment technique. Even so experience, musical ability, training in adjudication, familiarity with the piece and the instrument have produced mixed outcomes in advanced amateurs to postgraduates ($r = 0.72–0.89$; Gruzelier et al., 2013c).

Interestingly when lay judgement was called on for the singing of familiar folk songs ratings of Stage Presence, Confidence and Expressiveness were higher ($r = 0.81$) than those of the experts and the consistency was reliable: pre-training $r = 0.88$; post-training $r = 0.73$; change between performances $r = 0.77$. Furthermore ratings of Confidence correlated positively with A/T learning, and improvements were highly significant implying transparency in the impact of A/T learning on music performance.

5. Validation

5.1. Ecological validity and implications for creativity research

Neurofeedback studies in the performing arts speak to diverse theoretical and methodological concerns in contemporary creativity research. Theoretical implications include:

(i) Foremost, as posited in the Introduction, they provide a way forward in grappling with the desire for ecological validity in the measurement of creativity (Sternberg, 1985; Runco and Bahleda, 2011), the absence of which some see as a cardinal limitation of what has gone before (Sawyer, 2000; Jausovec and Jausovec, 2011).
(ii) A long standing debate surrounds the measurement of the creative process versus creative product, with the majority of research focusing on creative product and with the lack of research bewailed on the creative process (Martindale, 1999). The approaches reviewed here address assessment of a person's creative process as well as their creative product. Monitoring the learning processes where it culminates in an enhancement of the creative output will illuminate the nature of creative processes.
(iii) A spotlight has been cast on enhancing creativity with a promising methodology provided, when the dominating current interest has been in training working memory to increase intelligence (Jueggi et al., 2008). A question has arisen whether there exists a creativity enhancement factor, one that is generic and applicable to broad domains of creative activity (c.t. Jausovec and Jausovec, 2011). The neurofeedback protocols may address general-purpose processes accessible to everyone and not specific to the creative domain.
(iv) Here transfer from the 'brain training' context to the real world has been realised; such transfer has been viewed sceptically (Owen et al., 2010; Rabipour and Raz, 2012).
(v) The results are of pedagogical significance for the performing arts at both novice and elite levels, while the feasibility of coordinating training within conservatoire and school curricular has been demonstrated.

There are methodological implications:

(i) The studies address through methods of subjective and expert assessment Piffer's (2012) critique, who in finding tests of cognitive creativity and personality scales lacking, reasons that "a person's creativity can only be assessed indirectly (for example with self report questionnaires or official external recognition) but it cannot be measured directly." p. 258.
(ii) They exemplify the value of a broader repertoire of assessment than the Consensual Assessment Technique (Amabile, 1982) by allowing peer assessment and subjective report (Piffer, 2012).
(iii) They allow the trainability of creative processes to be monitored over training sessions through the pattern of training-induced changes in brain activity.
(iv) They provide an advance on the one-shot brain imaging creative-task protocols by monitoring the process of creative enhancement through the comparison of pre- and post-training assessments, as is being done in the fMRI monitoring of the clinical outcome of EEG-neurofeedback (Levesque et al., 2006). Furthermore it is feasible to include the neurofeedback training process in the fMRI scanner (Ruiz et al., 2013), and to include subjective report (Garrison et al., 2013).
(v) The school study provides a first step towards the recommendation of Jausovec and Jausovec (2011) "Further research should extend to more-domain specific creativity training approaches in class-room settings combining neurofeedback with cognitive training. p. 55"
(vi) The use of the performing arts as an avenue for investigating creativity is encouraged.
(vii) They provide pioneering attempts at measurement for development, for measurement of the performing arts is in its infancy, especially acting performance where the conservatoire ethos is that it is beyond measurement?

One final implication is that EEG-neurofeedback, sidelined in the 1970s, has come back from the cold as the exponential growth in publications has shown (Gruzelier, 2014a), and exemplified by its adoption by other imaging modalities. Yet it has not reached the creativity mainstream. Consider that Dietrich and Kanso (2010) in a review of brain imaging, most of which involved the EEG evidence, in launching a repost to the creativity field about the field's fragmentation, failed to include in their review the EEG-neurofeedback studies, cognisant though in their conclusion by saying that "Furthermore, by identifying the basic principles of our ingenuity, researchers might be able to enhance this process in the future, with potentially enormous benefits for society." Consider too that when Jausovec and Jausovec (2011) recommended that from an educational perspective it would be worth studying the trainability of creative processes and the pattern of training induced changes in brain activity they referred to Fink et al. (2010) "as a first step in this direction," overlooking the performing arts evidence, a domain which in itself represents a lacunae for the creativity research field in general with few exceptions (e.g. Fink et al., 2009). This review presents unavoidable evidence of the opportunities and validity of creative performing arts studies, aside from the potential role of neurofeedback.

5.2. Learning indices and mediation of outcome gain

Returning to the main theme of this three-part review, the validity of EEG-neurofeedback, the creativity and performing arts neurofeedback studies supplement the laboratory and field studies in Part I which focussed on cognitive and affective outcomes (Gruzelier, 2014a). More than thirty controlled studies have found gains following neurofeedback training that could not be attributed to nonspecific influences such as practice, motivation, expectancy or generic neurofeedback influences including experimenter engagement. Of those studies twenty-three also documented evidence of neurofeedback learning in the form of learning indices within session, between sessions, or in successive session baselines. Up until very recently learning has been sparsely documented (Gruzelier, 2014a) and in the majority of reports this was left to inference from differential group post-training outcomes in favour of a protocol. However, if there is no evidence of learning the attribution of any outcome advantage from a neurofeedback intervention must be left in doubt in view of the nonspecific factors associated with the process of learning (Enriques-Geppert et al., 2013; Gruzelier, 2014b). There has not been a tradition in the more populous clinical neurofeedback literature to report evidence of whether learning took place though it is a desirable source of validity in proving the impact of feedback learning on outcome gains. In addition, of the twenty-three studies reporting evidence of learning, eight also examined correlations between learning indices and outcome providing nine examples confirming a mediation link between feedback learning and outcome gains in support of causation (Gruzelier, 2014a).

The controlled creativity and performing arts studies reviewed here supplement this evidence. The studies with independent group designs showing differential group advantages in favour of neurofeedback included all three performing arts domains: music (Egner and Gruzelier, 2003 experiments I and II; Gruzelier et al., 2013a,c; Leach et al., 2013), dance (Raymond et al., 2005b; Gruzelier, 2014b), acting (Gruzelier et al., 2010), as well as cognitive creativity (Gruzelier et al., 2013b). Learning indices with affirmative outcome have been reported in all but one of the performing arts studies (Egner and Gruzelier, 2003, study II) as well as the cognitive study (Gruzelier et al., 2013b). Correlations supporting neurofeedback causation in the outcome benefits for creative performance have been reported (Egner and Gruzelier, 2003, study I; Gruzelier et al., 2013c; Leach et al., 2013).

Cognitive creativity neurofeedback studies have been the more preliminary as a whole. Preferential benefit for a measure of divergent thinking was found following A/T feedback in young dancers, when compared with HRV training which reduced their anxiety and controls, a benefit which was unrelated to insight problems and dance performance which was not enhanced by the three interventions including dance theory classes (Gruzelier et al., 2013c). In view of the doubts about the suitability of the brief dance phrase for assessing creativity the independence of the impact of A/T training on cognitive creativity from the impact on creativity in dancing is not considered further. Earlier though, Brennan (1982) with sixty-one female dance majors had found no relations between creative movement tests that she had devised and verbal and figural cognitive creativity tests (Guilford et al., 1978). Doppelmayr and Weber (2011) reported no advantages following thirty sessions of SMR ratio or theta/beta ratio training on cognitive creativity whereas the SMR training improved spatial rotation and RT measures.

Before concluding it should be acknowledged that performance anxiety including stage fright (Steptoe and Fidler, 1987) along with methods with which to moderate stress have been a dominant association in performing arts conservatoires when Psychology comes to mind. Germane to this subjective ratings of pre-performance anxiety (Spielberger et al., 1983) were monitored in the original music conservatoire studies (Egner and Gruzelier, 2003) where anxiety was reduced following all of the six interventions: mental skills, aerobics, Alexander, SMR and beta1 training. However, the gains in creative performance were specific to A/T training and accordingly may not be attributed simply to reduced performance anxiety. In the subsequent study there was no anxiety reduction in any of the groups (Gruzelier et al., 2013c). Of course a relaxed state in the case of A/T encompassing stage I sleep may hold one key to the efficacy of A/T training itself and hence lead to a knock on effect in facilitating creativity in performance, and its promotion of well-being (Peniston and Kulkosky, 1991; Raymond et al., 2005a) and its neurophysiological underpinnings. It has been theorised (Gruzelier, 2009) that in the lower states of arousal the slower waves that then predominate in the EEG allow greater connectedness between brain and memory retrieval networks (e.g. Varela et al., 2001). This in turn allows past learning and new associations to surface and inform performance. As amply documented here neurofeedback performance enhancement goes beyond reduction in performance anxiety.

Certainly anxiety reduction would be an additional gain in the service of creative performance, as shown with contemporary dancers where HRV reduced anxiety (DASS, Lovibond and Lovibond, 1995) and in the total sample anxiety reduction correlated positively with improvement in artistry and technique in dance performance. In support of the notion that A/T training effects may in part be mediated by modified waking arousal levels, we have found that A/T training's impact on spectral EEG topography is characterised by a reduction in fast beta band activity in frontal scalp regions (Egner et al., 2004). Changes in affect are likely to combine with cognitive change, for affect and cognition are inextricably woven into artistic performance.

6. Conclusion

Neurofeedback studies are not for the faint hearted with around four hundred experimental sessions for a modest study of three active groups of ten participants and ten training sessions plus assessments and allowance for replacing drop-outs, etc. Optimal performance field studies are logistically difficult to realise because competing demands on participants may compromise compliance, coordination of the timetables of participants, trainer(s) and expert assessors, and pre- and post-training assessments; further advice for the potential investigator is offered elsewhere (Gruzelier et al., 2013a,b,c). Thus far for purposes of replication protocols in the performing arts have focussed on four: A/T, SMR ratio, beta1 ratio and HRV training. All four had origins and an evidence base with clinical applications. As reviewed in part I other protocols arising from contemporary neuroscience have shown promise: upper-alpha, alpha desynchronisation, gamma and gamma ratio, frontal theta up-training, posterior theta up-training and down-training theta EEG maxima. In an exploratory one-session study upper versus lower alpha amplitude training has been examined with musicians (Bazanova et al., 2007).

The documented gains in artistic performance can join with gains in psychological processes reviewed in Part I which included: sustained attention, orienting and executive attention, the P300b, memory, spatial rotation, RT, complex psychomotor skills, implicit procedural memory, recognition memory, perceptual binding, intelligence and wide ranging aspects of mood and well-being. The correlational evidence with musicians and actors between neurofeedback learning indices and the performance gains evaluated by experts combines with evidence in Part I for mediation links with sustained attention, P300b, working memory, mental rotation, motor procedural learning, psychomotor skills, fluid intelligence and anxiety in performance.

As expressed in Part I a multitude of methodological and theoretical issues have been disclosed by these emergent studies, issues that will be considered in Part III along with mechanisms. To repeat a closing sentiment from Part I, there is now sufficient evidence validating the role of EEG-neurofeedback in enhancing function to dispel the lingering vestige of prejudice against the value of this EEG methodology. Surely, with the evidence reviewed here on creativity and the performing arts, and the methodological advantages for elucidating the creative process and product there is nascent potential too for the field of creativity research.

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