Enhancing imaginative expression in the performing arts with EEG-neurofeedback

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Chapter 21

Enhancing imaginative expression in the performing arts with EEG-neurofeedback

John Gruzelier

21.1 **Introduction**

The application of electroencephalography (EEG)-neurofeedback to the performing arts in the UK began 10 years ago with our Leverhulme Trust funded project in collaboration with the Royal College of Music (RCM) with the aim of exploring the relevance for music performance of interventions from the field of sports psychology. This followed a BBC documentary called 'Losing It' in which Britain's Olympic gold medallists explained how on one occasion they won a medal while in similar competitions in close proximity they were less successful, yet they were at the same level of expertise and fitness. One popular explanation for the discrepancy was that they were in 'The Zone' when they won. The project was called 'Zoning In', and neurofeedback was contrasted with mental skills training and a programme of fitness training. The Zone is a popular term for a 'flow' state, which is a psychological construct (Csikszentmihalyi, 1996) describing that optimal experience when the performer is totally absorbed in performing and everything comes together, often associated with a 'high'. The resultant neurofeedback results have helped provide crucial evidence for validation of the largely forgotten field of EEG-biofeedback, and helped provide a stimulus for validation studies in optimal performance, educational, and clinical domains.

We have earlier (Gruzelier & Egner, 2004) acquainted a music readership with an introduction to neurofeedback in a chapter describing our RCM studies, the first two of the seven studies to be reviewed here, and readers are referred to that chapter. In brief, neurofeedback (earlier termed biofeedback) is a form of instrumental learning where through the feedback in real-time of the brain's electrical activity, participants learn to regulate it through reinforcers and the reinforcing consequences of mastering a skill, and so may transfer the learned state to the real world. The procedure was originally called biofeedback, a term now reserved for control of the peripheral nervous system, while neurofeedback refers to control of the central nervous system. There is a close association between the spectrum of EEG rhythms and arousal state, though alignment with arousal is merely a convenient simplification, and the precise cognitive and affective correlates of EEG activity are a central focus of cognitive neuroscience.

For didactic purposes, EEG spectral neurofeedback protocols may be divided into slow- versus fast-wave training, e.g. alpha/theta (A/T), and sensory-motor rhythm (SMR) training. The former, when conducted with eyes closed with auditory reinforcement, encourage states of deep relaxation, whereas fast wave training is conducted with eyes open while reinforcement is provided on a computer screen. Slow-wave neurofeedback aims to train the elevation of theta amplitude (5–8 Hz) to be higher than alpha amplitude (8–11 Hz), and is done by presenting pleasing sounds such as waves gently crashing on the beach or a babbling brook, contingent on the production of theta and alpha. The relative reward contingencies are gradually changed to maximize the theta-to-alpha ratio (see Egner and Gruzelier (2004b) for the temporal dynamics of the training protocol). With fast-wave training, operant contingencies determined that reward (i.e. points on a computer screen): these were contingent upon increments in either say SMR (12–15 Hz) or beta1 (15–18 Hz) without concurrent rises in frequencies lower and higher in the EEG spectrum.

Nowadays, neurofeedback training has enhanced attention, memory, learning, micro-surgical skills, mental rotation, intelligence, sleep, and well-being in healthy participants (Egner & Gruzelier, 2001, 2004a; Vernon et al., 2003; Barnea et al., 2005; Raymond et al., 2005a; Hanslmayer et al., 2005; Hoedlmoser et al., 2008; Ros et al., 2009; Keizer et al., 2010a, b; Zoefel et al., 2011), while in the clinic, controlled studies have shown efficacy inter alia for epilepsy (Rockstroh et al., 1993; Sterman, 2000), attention deficit hyperactivity disorder (ADHD: Arns et al., 2009; Gevensleben et al., 2009), autism (Mirjam et al., 2009), and insomnia (Cortoos et al., 2009). The slow-wave applications have included anxiety reduction, mood elevation, creativity, addiction, and post-traumatic stress syndrome, while fast-wave applications have included attention, perceptual-binding, learning, memory, mental-rotation, intelligence and skilled psychomotor performance, ADHD, autism, and insomnia. Studies of underlying mechanisms are beginning (Ros et al., 2010).

Of central relevance to musical imagination, A/T training has consistently enhanced interpretative imagination in the performing arts, and in fact the A/T protocol originated to enhance creativity (Green & Green, 1977), though this was lost sight of when pioneering attempts were unsuccessful (for review see Gruzelier, 2009). There had been extensive historical anecdotes that hypnagogia has facilitated creative associations in various cultural spheres (Koestler, 1964), while theta was considered to be an EEG marker of hypnagogia. Since then the production of theta with eyes closed has been shown to accompany states of deep relaxation close to sleep, meditation and hypnosis (Vaitl et al., 2005). As described by Schachter (1976), hypnagogia produces spontaneous visual, auditory, and kinaesthetic images, unusual thought processes and verbal constructions, and symbolic representations of ongoing mental and physiological processes.

21.2 **Zoning in: advanced music performance**

In the first of two studies (Egner & Gruzelier, 2003: Gruzelier & Egner, 2004), of the 36 students who participated, 22 were trained on two neurofeedback protocols (SMR and beta1) commonly used as tools for the enhancement of attention, followed by the deep relaxation A/T protocol. A random sub-sample of 12 of the neurofeedback group was additionally engaged in a 10-weekly regime of physical exercise as well as mental skills training derived from sports psychology. A third group of 14 consisted of scholastic grade- and age-matched no-training controls. The aim was to compare a mixed neurofeedback package with the same package with and without aerobic fitness and mental skills training.

In order to assess music performance, the mark scheme of the Associated Boards of the Royal Schools of Music (ABRSM; Harvey, 1994) was adapted, consisting of three main categories: technical competence, musicality, and communication, with ten further sub-categories (Thompson & Williamon, 2003). The 13 rating categories (see Table 21.1) were marked on a 1–10 scale which mapped directly onto the percentage scales frequently used in educational contexts. Pre-performance state-anxiety was assessed using an anxiety inventory (STAI; Spielberger et al., 1983). Before a panel of instrumental professors the participants gave recitals of up to 15 minutes. Video recordings were edited into a random order and sent to two external evaluators in the first study and three in the second. The same methodology is used in the subsequent performing arts studies in

Table 21.1 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	0.51	0.02
~~Commitment and conviction~~		
Ability to cope with situational stress	0.44	0.05

the remainder of the chapter, with modifications as indicated. Readers should consult the empirical papers of the studies for methodological details.

The neurofeedback-only group was judged to have improved, while no improvements were found in the others (Figure 21.1). Improvement was found in all three domains: musicality, technique, and communication. The EEG in each protocol was correlated with changes in ratings in all 22 musicians receiving neurofeedback. Interestingly, an A/T training learning index correlated highly positively with improvements in each of the three domains: technique, musicality and communication (Figure 21.2). The full list of correlations is shown in Table 21.1 where it can be seen there were significant associations with A/T learning in virtually all subcategories. Neither the SMR

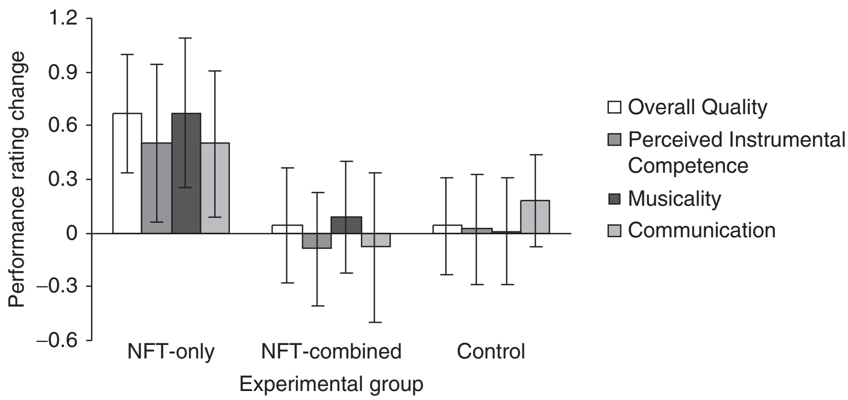

Fig. 21.1 Mean music performance rating change scores (± s.e.m.) on the main evaluation categories and overall quality for neurofeedback-only (NFT-only), neurofeedback and additional interventions (NFT-combined), and a no-training control group showing advantages for the neurofeedback-only group.

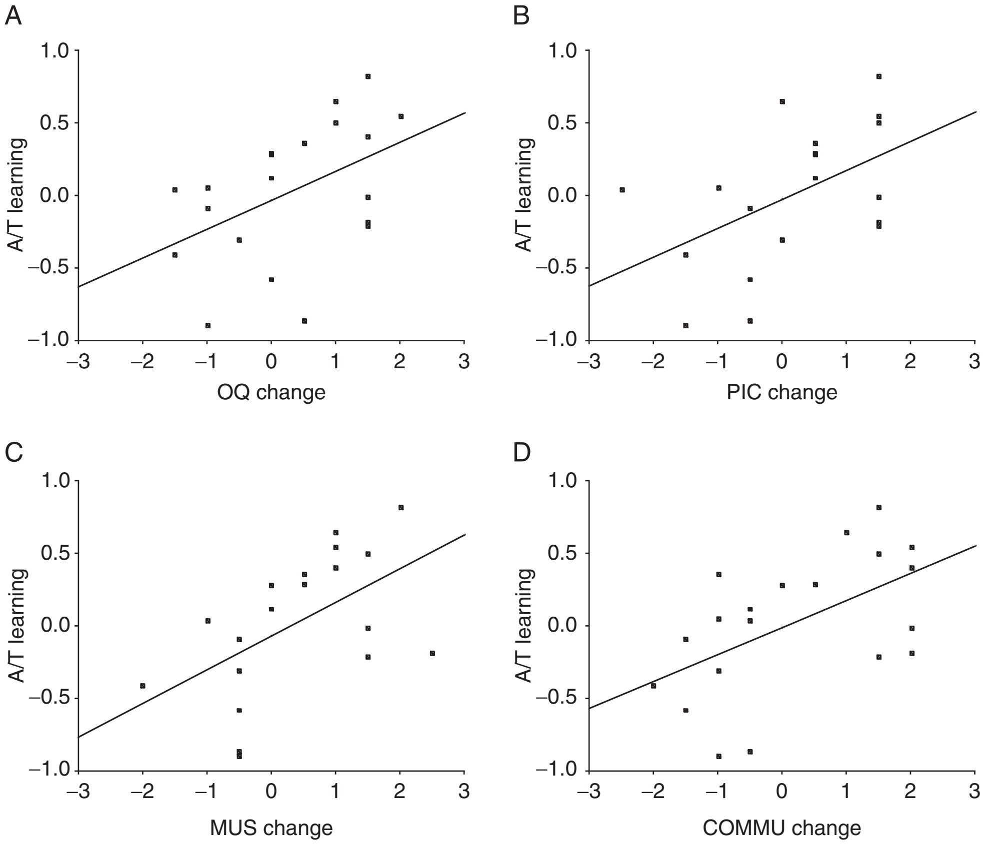

Fig. 21.2 Lines of best fit for bivariate correlations between A/T learning and music performance rating changes on the main evaluation categories of (A) Overall quality [OQ], (B) Perceived instrumental competence [PIC], (C) Musicality [MUS], and (D) Communication [COMMU].

nor the beta1 learning indices correlated with changes in music performance. Furthermore, differential improvement rates between the experimental groups were not related to pre-performance anxiety, which improved in all groups. The reduction in anxiety following fast-wave (SMR/beta1) training was supported by an interpretative phenomenological analysis (Edge & Lancaster, 2004). Fast-wave training was described as relaxing; as one said it 'lets my mind breathe'. However, these advantages did not carry over to performance ratings by the experts.

In a second investigation a constructive replication was undertaken with an independent-groups design (Gruzelier et al., 2002; Egner & Gruzelier, 2003; Gruzelier & Egner, 2004) involving a different cohort of 61 students who were randomly allocated to either A/T, SMR, or beta1 neurofeedback, physical exercise, mental skills, or the Alexander technique. The Alexander technique is widely used in performing arts conservatoires and involves a system of kinaesthetic education to avoid excessive postural tension.

In support of the first study, the A/T group displayed significant improvements. The beta1, SMR, Alexander, physical exercise, and mental skills training groups showed no post-training changes (Figure 21.3). A/T enhancing effects were replicable, particularly with respect to the parameters of musicality—stylistic accuracy and interpretative imagination—together with overall quality. As before, all groups tended to report less anxiety. Together, these results could be

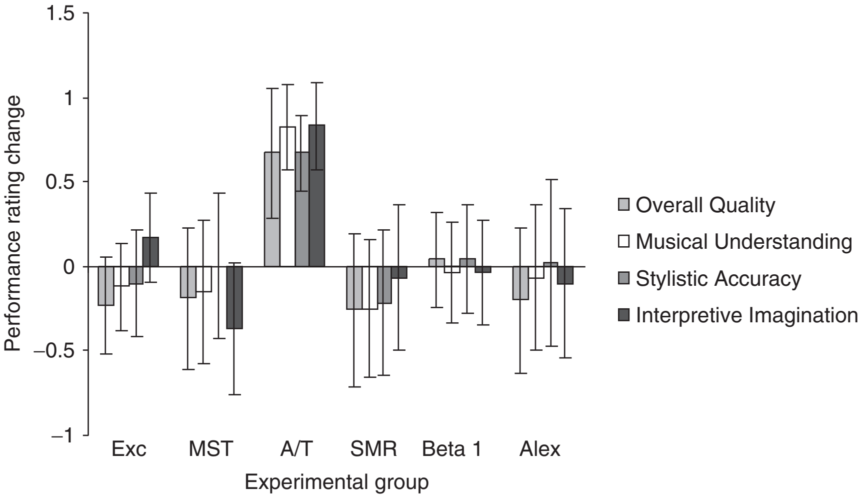

Fig. 21.3 Mean change scores (± s.e.m.) for the physical exercise (Exc), mental skills training (MST), alpha/theta (A/T), SMR (SMR), beta1 (Beta1), and Alexander Technique (Alex) groups on the main evaluation categories and overall quality showing advantages following A/T training.

interpreted as indicating that A/T training led to improvements, especially on attributes of artistic expression including interpretative imagination, which in turn improved performance overall. This was consistent with an impact on creativity. The increments in the ratings of the three experts represented average A/T group improvements of between 13.5% and 17%, with a mean improvement rate of 12% across all evaluation scales. This was equivalent to more that one class grade and was clearly of professional significance. In the year that followed the completion of the research neurofeedback training was offered as an option in the RCM curriculum.

In neither RCM study could the effects be accounted for by invoking practice, motivational, or generic neurofeedback factors. An explanation based simply on generic relaxation can also be discounted, on the grounds that in both studies A/T training was not associated with a greater decrease in pre-performance anxiety than was obtained in other groups. Additionally, a mental skills training group, which engaged in extensive relaxation training, showed no performance improvements. That the effects of A/T training may not necessarily be reflected in self-reported relaxation phenomenology was shown in a study in which appraisal, by medical students, of subjective arousal states with Activation-Deactivation scales (Thayer, 1967) did not differ between an accurate feedback and a mock feedback condition. Both were reported to be equally relaxing, even though significantly different EEG alpha/theta signatures were observed such that accurate feedback led to an increase in the theta/alpha ratio which was not observed with mock feedback (Egner, Stawson & Gruzelier, 2002).

21.3 **Novice versus advanced musical performance**

The promising outcome of neurofeedback training on music performance led to support from NESTA (the National Endowment for Science, Technology and the Arts in the UK), with the chosen over-riding goal of the impact on novice musical ability in both young adults and children. If successful, the pedagogic implications would be considerable and would not be limited to the very talented.

In adults, the strategy was adopted of examining novice singing ability in conservatoire instrumentalists in whom advanced instrumental performance was also rated. Given the impact on musical creativity, aside from examining musical ability with well-known pieces, improvisation was included with both voice and instrumental playing. Again we contrasted alpha/theta slow-wave training with fast-wave training but here focusing on SMR training, not beta1 training, for of the fast wave protocols, SMR training had the more generic benefits for laboratory measures of attention in the music students, as reviewed in the next section. We hypothesized firstly, that slow-wave training would enhance the three domains of music performance assessment; secondly, as SMR training had produced subjective reports of mental relaxation in musicians, and in other contexts had produced benefits in sustained concentration, working memory, learning, mental rotation and perceptual-motor skills, as referenced above, that SMR training should benefit music performance, which perhaps would be disclosed with novice abilities, here vocal performance.

Twenty-four music students from London universities were randomly assigned to one of three experimental groups: A/T, SMR or non-intervention controls. All were instrumentalists with a wide range of instrumental ability from advanced amateur to postgraduate, but with a singing ability at novice level and, indeed, a reluctance to sing. Music performances consisted of a choice of two unprepared Britten folk songs and self-selected prepared instrumental pieces. Vocal improvisation consisted of *Stripsody* (Berberian, 1966), in which notation was presented as a cartoon-strip on a stave with 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. Instrumental improvisation involved the choice of one theme from a menu of topics. Evaluation was essentially as for the RCM studies, with additional scales for singing.

Neurofeedback successfully fulfilled the chief NESTA aim of a potential impact on novice musical ability. Both A/T and SMR neurofeedback protocols were found to enhance the novice singing ability of folk songs. A/T training had an impact on the musicality and communication categories, but not in technique. In contrast, SMR training for the first time disclosed suggestive evidence of enhancing music ability to some extent, and interestingly this was only with novice performance and was in the domain of technique, improving pitch and to some extent rhythmic accuracy and diction. Both protocols would therefore have a place in training musical ability, and in addition were seen to have complementary effects on novice performance—A/T having an impact on musicality and communication and SMR an impact on technique. Indeed, the impact of A/T on communication was observable to lay people as disclosed in their ratings of expressivity, confidence and stage presence.

As a secondary aim, improvisation was examined as a direct test of the impact of neurofeedback on creativity in performance. Vocal improvisation with *Stripsody* was enhanced following A/T in all domains, but most particularly regarding communication in performance. There was no advantage from SMR training with *Stripsody*. Instrumental improvisation was not influenced by neurofeedback, and was at a low level of ability (which may have been a function of our choice of material). Thirdly, we provided a further replication of the advantage of A/T training for higher level instrumental ability and this was found in all domains—musicality, communication, and technique, in replication of the first RCM study. Here as before there was no advantage for SMR training.

Thus, considering these various studies, A/T training showed consistent benefits for music performance in all three performance domains, in both advanced instrumental playing and novice singing. Interestingly, for the first time, SMR training was found to be beneficial, but only with technique in the low level novice singing ability measured with the Britten folk songs. This impact on novice ability, as will be seen below, chimes with the success of SMR training in children, but before considering the child studies ancillary studies on cognition and affect with musicians, university students and trainee doctors will briefly be outlined in view of the relevance for outcome in general but especially with children.

In conclusion, the NESTA aim of determining whether neurofeedback could have wide-ranging impact on musical education was vindicated through its efficacy with novice performance, aside from the demonstration of a further highly reliable impact of A/T on mature performance.

21.4 Attention, memory, perceptual-motor skills, and mood

In interpreting the benefits of A/T neurofeedback training with the RCM musicians it was noted that reduction in anxiety was an unlikely explanation, as was the case for improvements in attention per se. Germane to the latter, the students in both RCM studies had been examined for changes in laboratory measures of attention. It was the fast-wave training, the neurofeedback protocol which had not benefited music performance, which benefited attention, whereas effects of A/T training on attention were less clear.

One measure of attention was a widely used go/no-go continuous performance task (Greenberg & Kindschi, 1999) in which two types of errors can be incurred—errors of omission (failing to respond to a target stimulus), and errors of commission (erroneously responding to a non-target stimulus), which are held to reflect inattentiveness and impulsiveness respectively. A global attention index derived from signal detection theory (Green & Swets, 1966), termed 'd prime' (d') took into account both error types by expressing a ratio of hit rate to false alarm rate.

In the first RCM study we established that 10 sessions of beta1 and SMR neurofeedback led to highly significant improvements in commission error rates (Egner & Gruzelier, 2001). Learning indices of how well the students had learned to enhance the targeted EEG rhythms were correlated with changes in error rates in order to explore the linkage between the process of learned EEG self-regulation and reduction in impulsive mistakes. Considering here only the influence of SMR training, it was found that the relative success at enhancing the SMR was highly positively correlated with reduced commission errors, which in turn had an impact in elevating d'. The same attention task has been widely used to validate treatment outcomes in ADHD, disclosing following fast-wave neurofeedback improvements in d', commission and omission errors and reaction time variability (Monastra et al., 2005). It was therefore doubly relevant for our study with children.

SMR training has been found to enhance semantic working memory (Vernon et al. 2003), while SMR training of trainee eye surgeons performing a simulated cataract operation has resulted in a more efficient, modulated performance as indexed by both consultant surgeon subjective ratings of filmed performance and objective timed measures (Ros et al., 2009), and, importantly, has been shown most significantly with the more difficult perceptual-motor tasks. Attention, memory, and perceptual-motor abilities are all engaged in music performance, especially at a novice level. In the affective domain, we found that mood measured by the *Profile of Mood States* (McNair et al., 1992) was enhanced in socially withdrawn medical students (Raymond et al., 2005a). Students were randomized to either contingent or non-contingent (mock) A/T training, receiving 10 sessions in all. After A/T training participants rated themselves as significantly more compassionate, agreeable, elated, confident and energetic whereas controls were more compassionate but less energetic.

Both fast and slow-wave neurofeedback training therefore have an impact on cognitive and affective processes that theoretically might advance artistic performance. This is aside from the putative advantage of hypnagogia-induced creativity, the aim of A/T training—mechanisms for which will be elaborated in the final section.

21.5 Neurofeedback training of musical ability in children

The aims of the NESTA programme were to examine the effects of training on music performance in schoolchildren aged 11 years: on their application in the classroom as well as on well-being at school and at home, and above all the feasibility of neurofeedback within the school curriculum. Alongside rehearsed music performance we examined creative musical improvisation, while attention was examined with the sustained attention test, as for the RCM studies and the 'gold standard' measure of treatment outcome in the ADHD field for monitoring intervention success. The efficacy of neurofeedback in treating ADHD has now been the subject of sufficient studies to warrant a meta-analysis, confirming its efficacy across various neurofeedback protocols (Arns et al., 2009). As a subsidiary aim of our study it was of interest to determine the incidence of ADHD levels of inattention in the school and the efficacy of neurofeedback in moderating them.

The study was conducted at the ARK Evelyn Grace Academy, Brixton, London in the autumn term of 2009 (Gruzelier et al., 2011b) with 33 11-year-olds selected on three criteria: musical potential, behavioural issues, or a combination of the two. Music performances included either a vocal or instrumental solo piece of their choice as practised in class, and a vocal or instrumental improvisation on the theme of *the sea* pre-training or *a storm* post-training following 2 minutes of preparation. Performances were filmed, randomized for order and group and then rated by four teacher assessors in two joint rating sessions on items covering creativity, communication and technique.

Prepared vocal or instrumental performance showed improvement in technique following A/T training—consisting of vocal quality, clarity of diction and sense of pitch, and for instrumental playing control of the instrument. There were also benefits following A/T training with the communication category, consisting of ratings of confidence, posture, engagement with the audience, and enjoyment. Here there was no impact on creativity, nor any improvement in the other groups following SMR training, as was the case with controls. Creative improvisation did improve with both neurofeedback groups on a creativity subscale, whereas the control group declined, giving a highly significant advantage to neurofeedback training, and despite a relative advantage to the control children at baseline. Creativity included use of imagination, well structured performance, appropriateness to title, and expression (dynamics and articulation). The communication category scale showed an even more striking advantage to neurofeedback training for both A/T and SMR, whereas there was a significant decline in the controls. Communication was based on ratings of engagement with the audience and enjoyment in performance.

On the attention test there was a highly significant slowing in mean reaction times in the course of the study, attesting to the tiredness observable in all groups at the end of term; this was especially noticeable as the study began when children were fresh after the long summer vacation. The decline did not occur in reaction time variability, implying that it was unrelated to attention per se: this inference was supported by a highly significant improvement in the global attention index d', mainly reflecting a decrease in commission errors (impulsive responding). This improvement was found to follow neurofeedback training only, with a highly significant reduction in errors of commission following A/T, and a tendency towards improvement in the SMR group.

At the close of the study a structured questionnaire was administered; 19/22 children from the training groups felt improved well-being in the school context, and this could extend to the home. Impressions of a positive carry-over to the classroom situation were volunteered by eight children following fast-wave training and six following slow-wave training. Music performance aside, self-report impressions of a positive impact on academic subjects included science, maths, physical education, performing arts, and English.

In summary, rehearsed musical performance was enhanced by slow-wave training for the categories of technique and communication with subscales of confidence, posture, engagement, and enjoyment, as shown in our conservatoire studies. The category of creativity/musicality was not enhanced as it was in the adult studies, although creativity as indexed by musical improvisation was enhanced to a highly significant degree. Interestingly, in children this was achieved with both slow-wave and fast-wave training, as was the enjoyment in creative improvisation as communicated to the raters. Thus fast-wave training had an impact with children as it did with novice as distinct from advanced music performance in adults. This was despite the fact that reaction times were slower at the end of the study, validating the behavioural impression gained that the children were tired at the end of the school term, yet music performance following neurofeedback was buffered from the wear and tear of the school year. Similarly, improvements in attention were observed despite the fact that there was a high incidence (19/33) of children whose attention was within the ADHD range; evidence from the clinical ADHD field would recommend that more than double our ten training sessions would be necessary to fully improve attention for such a level of impairment. This indicates how valuable neurofeedback training would be as an integral part of the curriculum planning, quite aside from the benefits for music. The logistics of implementing the neurofeedback training proved eminently viable in the school setting, given the excellent collaboration from the staff and an expert timetabling schedule such that children did not miss the same subject too often. The ARK academies have expressed interest in embedding neurofeedback training in the curriculum in the future.

21.6 **Dance performance**

Two studies have examined advanced dance performance, the first with competitive university ballroom and Latin dancers at Imperial College London (N = 18; Raymond et al., 2005b), and the second with freshers at the Labin dance conservatoire (N = 64) (Gruzelier et al., 2011a). In both these studies A/T neurofeedback was compared with heart rate variability (HRV) biofeedback training. HRV aims to induce a coherent waveform as can be achieved with slow paced breathing. Both neurofeedback interventions facilitated ballroom dancing in competitors who went on to win the UK championship. Dancers performed in male–female pairs but were evaluated individually by two qualified dance assessors with a scale used for national dance assessments with categories of technique, musicality, timing, partnering skill, performing flair, and overall execution.

Both training groups improved more than the control group in overall execution, while on the subscales A/T training improved timing and HRV improved technique. Contemporary dance was not improved. Here the 40 second dance phase, performed in groups of five, may not have been long enough to disclose benefits, and compliance with training was such that weekly sessions were missed, which we have shown may compromise the outcome (Ros et al., 2009). Notwithstanding, cognitive creativity assessed with the *Alternative Uses Test* (Guilford, 1967) was facilitated by A/T training, and HRV facilitated reduction in anxiety as measured with the *Depression, Anxiety and Stress Scale* (Lovibond & Lovibond, 1995).

21.7 **Acting performance**

With the support of the European Union's *Future and Emerging Technologies* initiative we revisited the effect of SMR training on creative performance with a technical innovation that gave the neurofeedback training context ecological relevance. Instead of the conventional screen which depicts brain wave changes by histograms moving up and down, or computer games unrelated to the training goals of enhancing performance, a theatre auditorium was rendered on the computer screen. This was an image of the Vanburgh Theatre, Royal Academy of Dramatic Art (RADA), as seen by the actor from the stage. Its ecological relevance would putatively allow for more effective transfer to the real world. We reasoned that the clear advantage with elite performance for A/T training over SMR training may lie in the fact that real world connections were made through imaginative visualization in the eyes-closed reverie. As one musician had expressed:

> 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: p. 105.)

We also drew on theory from Visual Reality (VR) Presence research (Sanchez-Vives & Slater, 2005), which studies the illusion of being in a place facilitated by surrounding VR immersive images via CAVE-like and head-mounted displays (Cruz-Neira et al., 1993). The auditorium image was rendered in the ReaCTor (at University College London), where in a cave-like context, the actor was surrounded by the auditorium image and experienced it in three dimensions through glasses. We hypothesized that the more technically immersive ReaCTor would prove to be superior in transfer than the conventional computer screen approach to SMR training, although both media would be effective in enhancing creative performance.

Of further theoretical relevance for creative performance was the innovation of interfacing the learned control of brain rhythms with feedback which signified mastering the control of aspects of the performing space. Enhancement of SMR was represented by changes in the auditorium lighting, and inhibition of theta and high-beta by a reduction in intrusive audience noise. Mastery is central to creative performance, and the sense of control contributes to the subjective experience of flow. Flow is the psychological construct (Csikszentmihalyi, 1996) mentioned in the Introduction which describes that optimal experience when the performer is totally absorbed in performing, and for them everything comes together. 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. It therefore involves intense concentration without self-consciousness, a feeling of satisfaction, and often the experience of a 'high'. Thus the learned control of brain rhythms was designed to be contingent on control of the computer rendered performing space, and the ensuing mastery was hypothesized to transfer to acting performance.

The performers' subjective flow state was examined with the *Flow State Scales* (FSS) of Jackson and Eklund (2004), which measure nine dimensions of flow: 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. In view of the relative brevity of the performances it was not anticipated that there would be evidence for unambiguous feedback or for transformation of time, the two scales which require a deep experience (Tenebaum et al., 1999).

All 15 members of a class of American drama sophomores on semester placement in London received neurofeedback or acted as controls (Gruzelier et al., 2010). Students were randomized 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 scales covering overall performance and categories of voice, movement, creativity and communication. The 11 scales were as follows: overall performance, vocal transformation, vocal expression, movement fluency, movement inhabitation, imaginative expression, imaginative conviction, imaginative characterization, seamlessly engaged, at-one with performance, and well-rounded performance.

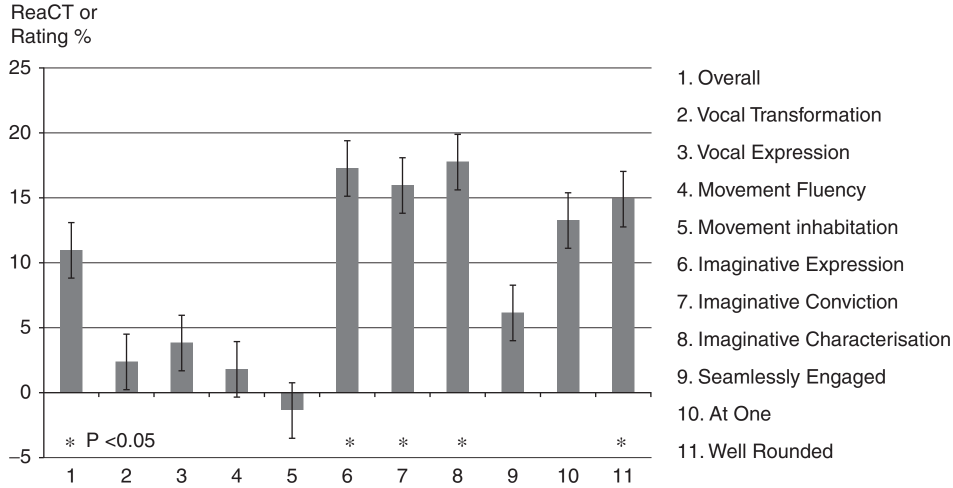

Fig. 21.4 Percentage improvement in acting advantage following training with the ReaCTor over the computer screen.

Learned control of brain activity was achieved with both training procedures. There was a slight advantage to the more immersive VR context in providing a learning curve asymptote of the SMR/theta ratio about a session earlier, coincidentally with identification of by the actor of ‘At what stage did you recognize the mental state we were seeking in you?’. The VR procedure also had a greater impact on acting performance: the results are shown in Figure 21.4. It is noteworthy that of the various acting performance domains, improvements were found to be specific to creative acting performance—imaginative expression, conviction, and characterization—which carried over to ratings of acting performance overall and well-rounded performance.

Irrespective of training medium (laptop or ReaCTor) actors who had received neurofeedback experienced a higher flow state in performances on the Globe stage and studio than the controls, as shown in Figure 21.5. Advantages to neurofeedback were seen on flow ratings of sense of control, confidence or challenge-skill balance and there was a tendency with feeling-at-one with performance through the merging of action/awareness. Of importance for validation were the numerous positive correlations (see Table 21.2) between flow and the expert ratings of improvement or performance at the study end. The correlations involved all categories of acting performance 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.

In conclusion, in this exploratory study (N = 15) demonstrable benefits for acting performance were disclosed as the result of fast-wave SMR training in an ecologically valid training context, the theatre auditorium, hypothesized to facilitate transfer to creative performance. The immersive three-dimensional (3D) VR properties were superior to the two-dimensional (2D) properties, even though the same auditorium was depicted, as was also reflected in the speed of learning the self-control of brain rhythms, and as was seen in the expert rating of acting performance. This was especially true of the imaginative aspects of acting. Notwithstanding, the experience of flow in performance was superior in the actors trained with neurofeedback than in the untrained controls. Furthermore, enhancement in the subjective sense of flow state correlated comprehensively with ratings in all domains of acting performance by the experts. This was the first systematic examination of the subjective experience of the performer about their state during artistic performance as a result of neurofeedback training.

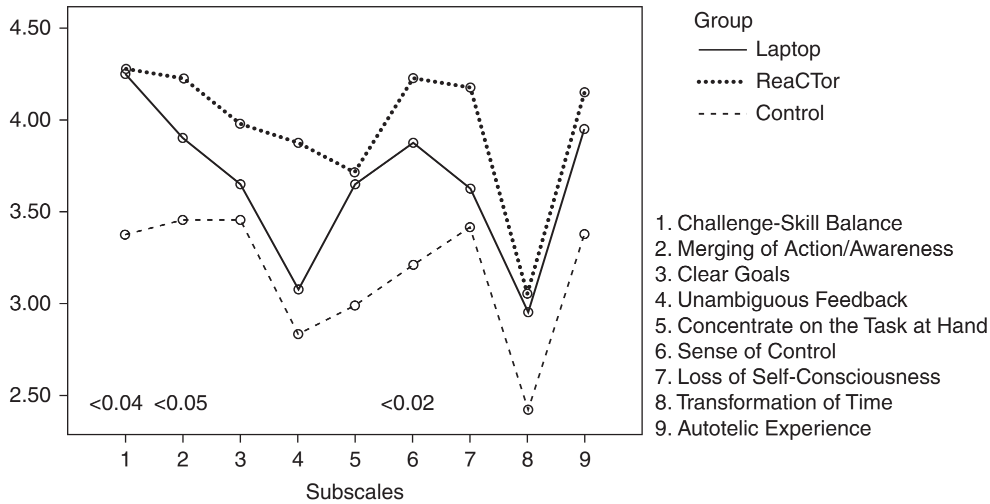

Fig. 21.5 Flow state self-ratings averaged for *Hamlet* excerpts and monologues indicating superior flow with neurofeedback training.

21.8 **Synthesis: methodology and mechanisms**

21.8.1 **SMR neurofeedback**

Through our studies of novice performance in young adults and children, and our study with actors in which the SMR training context was made relevant to performance, we may have resolved

Table 21.2 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 & 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

the initial puzzle that SMR training did not benefit music performance in the RCM studies even though the musicians acknowledged subjective benefits, and it improved their attention in laboratory assessments post-training (Egner & Gruzelier, 2001, 2004a), quite aside from its clear and germane cognitive benefits in other avenues of investigation (Vernon et al., 2003; Raymond et al., 2005a; Hanslmayer et al., 2006; Arns et al., 2009; Ros et al., 2009; Keizer et al., 2010a, b). The fact that lower level abilities and not higher level abilities were facilitated by SMR may indicate that its role in inducing a relaxed modulated attentional style has more impact in the novice than in the advanced performer; the latter has already through practice and experience mastered attentional requirements in rehearsed performance.

Notwithstanding, the acting study did demonstrate advantages from SMR training for adult advanced level artistic performance. Here the innovation of giving the neurofeedback training context ecological validity was the likely explanation for the striking relevance to artistic outcome. This raises the important issue of the transfer of the learned control of brain rhythms to the real world. It does not necessarily mean transfer of the mental state achieved in neurofeedback training to performance; no one would perform incisively in a state of borderline sleep induced by A/T training, for example.

Instead, with A/T training, it is proposed that the learning involves associations between the highly connected brain state achieved through hypnagogia with the world of performance (Gruzelier, 2009), either unconsciously (since all participants volunteered with the aim of improving their artistry), or through creative visualization. But in SMR training the transfer of the brain state that is achieved through training is more pertinent, for the outcome was successful in actors when there were direct links between training and outcome contexts, here achieved by the rendering of the theatre auditorium. Furthermore, the outcome was superior with the greater immersion allowed by the 3D CAVE-like environment compared with the 2D rendition. That the SMR training involved control of the acting space—auditorium lighting and intrusive audience noise—was putatively also salient. The success of this study on the outcomes of objective expert ratings and subjective flow state ratings, as well as the high degree of interrelationship between objective and subjective ratings, is especially worthy of replication and extension to other participant domains. The fact that the impact was on the creativity category of performance ratings, extending to performance overall, is especially relevant to the theme of this book.

It was also the case that in actors all three dynamics of the SMR EEG protocol—the increase in SMR, and the decrease in both theta and high beta—were brought under learned control. Another potentially important issue concerns the relations of the three EEG bands to outcome. The reduction in high-beta activity reduction is of fundamental importance in SMR training. It indexes an activated state associated with over-arousal and anxiety, and indeed a reduction in fast beta band activity in frontal scalp regions was found to be the long-term outcome of A/T training in our original studies with musicians (Egner, Zech, & Gruzelier, 2003).

In our study with children, analysis of the EEG recordings disclosed that reduction in high beta was the main dynamic achieved in SMR training. However, the reduction in eyes-open theta is also important. It has not always been recognized that there are several kinds of theta, and that theta in eyes-closed and eyes-open states are different. The study of experienced meditators mediating to a blissful state exemplifies the positive hedonic tone associated with eyes-closed theta (Aftanas & Golocheikine, 2001). In contrast, eyes-open theta may be associated with negative affect, as disclosed in a recently conducted single-case study of treatment with psychotherapy and SMR and A/T training with a student suffering anhedonia, depression, cognitive confusion and psychological disintegration following long-term drug misuse. Treatment was effective~~, and it was successful in outcome.~~ It is noteworthy that there were significant correlations between practitioner ratings of the mental state across the ten sessions and the eyes-open theta recorded during SMR training. These were in the direction of the *poorer* the mental state, the *higher* the eyes-open theta amplitude. Thus, training down eyes-open theta in SMR and training up eyes-closed theta have some complementary effects.

These findings suggest the way forwards with SMR training includes: 1) to give the training context ecological validity; 2) to harness the control of the brain state to the control of the performance arena—the theatre for performing artists and the schoolroom for school children; 3) to ~~ensure control of all the EEG dynamics by~~ monitor~~ing~~ learning curves of the enhancement of SMR amplitude and the reduction in adjacent slow and fast wave activity.

21.8.2 **Alpha/theta neurofeedback**

Consistency has been the hallmark of the impact of A/T training on the domain of artistry in music and dance performance. In adults this encompassed musicality, stylistic accuracy, interpretative imagination and timing, and in children creative music improvisation including imagination (Egner & Gruzelier 2003; Raymond et al. 2005b; Gruzelier et al., 2011b). 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, confidence, emotional expression, and enjoyment, which in turn had an impact on deportment, breathing, diction and stage presence.

The type of creativity traditionally associated with hypnagogia involves making new cognitive associations between items already stored in long-term memory. It has been demonstrated through learning and memory studies in animals that the slower rhythms alpha and theta carry information over long-distance distributed connections (von Stein & Sarntheim, 2000). Novel cognitive associations may require the integration of distributed neural networks and hence the value of hypnagogia in inducing slow wave activity and allowing for the long distance neural connections which underpin the creative associations to be made. Consistent with this, a study of creative thinking has confirmed an increase of anatomically widely distributed coherence of EEG oscillations, especially amongst the low end of the spectrum (Petsche, 1996). In meditation, theta power and low alpha power have been shown to dominate the EEG spectrum along with increased theta coherence between distal electrodes in the topographical EEG (Aftanas & Golocheikine, 2001). 'Accordingly, . . . it is hypothesised that creative cognitive associations arise from integration through the co-activation by slow wave activity of distributed neural networks, for which the relaxed hypnagogic state is especially conducive' (Gruzelier, 2009). This was further exemplified by the results with the test of cognitive creativity with the contemporary dancers following A/T training. Incidentally, while we refer to A/T 'training', this does not imply the need for higher centres to regulate lower centres to achieve the hypnagogic state, say through directed attention. In hypnagogia, as with hypnosis, there is an uncoupling of prefrontal processes, which in hypnosis accompanies the letting-go stage (Gruzelier, 1998, 2006; Egner et al., 2005; Oakley et al., 2007).

The breadth of impact of A/T training on performance comes as no surprise in view of the extensive theta correlates in animal and human studies. These include theta as a carrier of mnemonic processes which have pervasive influences on attention, effort and sensory-motor regulation, and with a role in the mediation of emotion, motivation, effort, and arousal circuits in limbic and cortico-reticular systems. Artistic performance requires integration and expression of past learning and expertise, imbuing this in performance, and communicating this to the audience with artistry. In putting their life experience into their creative performance, performing artists must draw on whole brain connections. Theta therefore is an ideal candidate for this integrating role. It is further proposed that these wide ranging influences of A/T training have a counterpart in theta's widely distributed neural connections, and would be in keeping with theta's role in mediating distributed circuitry in the brain giving rise to neural and psychological integration (Gruzelier, 2009).

21.9 Scientific and pedagogical implications

These validation studies have wide ranging scientific and pedagogical implications.

They have contributed to putting EEG-neurofeedback back on to the map of contemporary cognitive and affective neuroscience. The Society of Applied-Neuroscience (see http://www.applied-neuroscience.org) has been established for basic scientists and practitioners to achieve this aim, and to place neurofeedback within a broader scientific context. University-based research on neurofeedback and the adjunct field brain-computer interface is now widespread throughout Europe, and British universities include Bangor, Canterbury Christ Church, Goldsmiths, Greenwich, Imperial College London, The Open University, and University College London. University-based training and certification training courses are now an imperative, least the premature dismissal of this field that occurred in the 1970s, a classic case of 'throwing the baby out with the bathwater', is revisited due to the field being brought into disrepute through the spawning of practitioners with dubious qualifications.

While this chapter has focused on applications in the performing arts most activity in the field is clinical, and here the most widespread application is ADHD. Sufficient controlled studies have now been conducted in this field to warrant a meta-analysis, which has concluded firm evidence for an impact on inattention and impulsivity in children (Arns et al., 2009). The scale of grant funding has realized multicentre ADHD studies in Germany (Gevensleben et al., 2009). The most long-standing clinical validation concerns epilepsy (review by Sterman, 2000), to include recovery or reduction in anticonvulsant medication in chronic intractable patients (Rockstroh et al., 1993), but neurology has remained indifferent. Many other conditions have been treated beneficially and evidence is accumulating from controlled trials such as insomnia and autism (Cortoos et al., 2009; Mirjam et al., 2009).

Controlled evidence for optimal performance and educational applications is growing rapidly. Among young adults behavioural and electrophysiological evidence, including gamma rhythm feedback, of performance advantages have accrued from controlled studies of attention, memory, learning, sleep, feature binding and intelligence, mental rotation and emotion (Barnea et al., 2005, 2006; Egner & Gruzelier, 2001, 2004a; Hanslmayer et al., 2005; Hoedlmoser et al., 2008; Keizer et al., 2010a,b; Raymond et al., 2005a; Vernon et al., 2003; Zoefel et al., 2011). In educational settings we demonstrated that trainee eye surgeons achieved a more efficient and modulated performance in a simulated cataract operation (Ros et al., 2009). Our study with 11-year-olds (Gruzelier et al., 2011a, in preparation) aside from music performance, benefited sustained attention, and with subjective impressions by the children of carryover to classroom subjects, the school and family life. The academy school now seeks to embed neurofeedback training in the curriculum. The fact that so many of this mixed race and immigrant population were within the ADHD range in their attention itself discloses an important role for neurofeedback in facilitating academic performance. The University of Malta is also planning school studies in the light of these results.

Thus far the studies reported here are the only ones in the performing arts, although a large scale study with opera singers to include functional magnetic resonance imaging (fMRI) is under analysis in Germany (Kleber et al., 2008, 2010). Sporting applications lack controlled evidence, though there are anecdotal reports of successful teams in European football and the winter Olympics having been trained in neurofeedback, and a single case study has been reported (Pop-Jordanova & Demerdzieva, 2010). Neurofeedback capabilities have been demonstrated with fMRI (Rota et al., 2009; Scharnowski et al., 2004; Yoo & Jolesz, 2002; Yoo et al., 2004), while fMRI has been used both to elucidate the basic processes involved in EEG-neurofeedback (Ros et al., 2010) and to monitor training (Levesque et al., 2006).

Altogether, the pedagogical implications of the validation evidence speak for themselves. As evinced by the rapid acknowledgement from commentators (Stewart, 2002; Tilstone, 2003), and rapid access by the scientific readership for our neurofeedback article on microsurgery performance in trainee eye-surgeons (Ros et al., 2009), which received a highly accessed tag after publication and was in the top ten most viewed publications in its journal for a year after publication, while the A/T theoretical article (Gruzelier, 2009) was the most down-loaded article from its journal in 2009. The outcome on music performance was part of a 6-month neurobotics exhibition for the public at the Science Museum, South Kensington, London, 2007–2008. Although there are numerous scientific questions to address, the accumulating evidence base is already strong, and this is manifestly inspiring scientists and policy-makers to take up the challenge.

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