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Beneficial outcome from EEG-neurofeedback on creative music performance, attention and well-being in school children

J.H. Gruzelier*, M. Foks, T. Steffert, M.J.-L. Chen, T. Ros

Department of Psychology, Goldsmiths, University of London, Lewisham Way, New Cross, London SE14 6NW, UK

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ABSTRACT

We earlier reported benefits for creativity in rehearsed music performance from alpha/theta (A/T) neurofeedback in conservatoire studies (Egner & Gruzelier, 2003) which were not found with SMR, Beta1, mental skills, aerobics or Alexander training, or in standby controls. Here the focus was the impact on novice music performance. A/T and SMR training were compared in 11-year old school children along with non-intervention controls with outcome measures not only of rehearsed music performance but also of creative improvisation, as well as sustained attention and phenomenology. Evidence of effective learning in the school setting was obtained for A/T and SMR/beta2 ratios. Preferential benefits from A/T for rehearsed music performance were replicated in children for technique and communication ratings. Benefits extended to creativity and communication ratings for creative improvisation which were shared with SMR training, disclosing an influence of SMR on unrehearsed music performance at a novice level with its greater cognitive demands. In a first application of A/T for improving sustained attention (TOVA), it was found to be more successful than SMR training, with a notable reduction in commission errors in the children, 15/33 of whom had attention indices in the ADHD range. Phenomenological reports were in favour of neurofeedback and well-being benefits. Implementing neurofeedback in the daily school setting proved feasible and holds pedagogic promise.

1. Introduction

Building on our earlier demonstration in elite conservatoire musicians of professionally significant enhancements in music performance following neurofeedback (Egner & Gruzelier, 2003; Gruzelier & Egner, 2004). Here we have carried out a series of studies in the performing arts (Gruzelier, 2012), we have set out to examine whether neurofeedback would enhance novice-level music performance, in children aged 11 years with sessions conducted during school time.

1.1. Neurofeedback

Neurofeedback is a form of operant conditioning where the change in a physiological parameter is fed back to the participant in real time so that through their monitoring of feedback and adjusting their mental state they may learn to regulate it. It was originally called biofeedback, a term now tending to be reserved for the peripheral nervous system, wheres neurofeedback typically involves electrocortical parameters such as the electroencephalogram (EEG). As awareness of neurofeedback's potential grows it is being applied to other forms of brain imaging such as functional magnetic resonance imaging (fMRI) and near infrared tomography (NIRS), developments which are included in this journal special issue on Neurofeedback. There is an allied field of brain–computer interface (BCI) in neurological rehabilitation which via the feedback of brain rhythms aims to circumvent the spinal and motor system (Birbaumer, Murguialday, & Cohen, 2008). The widest application of EEG-neurofeedback is in the treatment of clinical disorders among which attention deficit hyperactivity disorder (ADHD) has accrued the largest clinical evidence base (for a meta analysis see Arns, de Ridder, Strehl, Breteler, & Coenen, 2009). A second domain concerns optimising functions in non-clinical populations, focussing on improved attention, memory, creativity, perceptual-motor skills, sports and the performing arts (for review see Gruzelier, in preparation). The present study contributes to a third domain, education, as do our performing arts conservatoire studies (Gruzelier, 2012). The promise of neurofeedback through the accumulation of validation studies is now encouraging the investigation of underlying mechanisms (e.g., Ros, Munneke, Ruge, Gruzelier, & Rothwell, 2010). An introduction to the history of neurofeedback is included in the special issue (XXX).

EEG-neurofeedback most commonly involves learned control of the EEG spectrum of rhythms which follows an arousal continuum: low arousal/slow rhythms such as delta and theta to high arousal/fast rhythms such as beta and gamma. Traditionally the

* Corresponding author. Tel.: +44 020 7 9197635; fax: +44 020 7 919 7873.
E-mail address: j.gruzelier@gold.ac.uk (J.H. Gruzelier).

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implications for attention and performance within the delta to high beta (beta2) range have followed the classical inverted-U curve. This has historically guided the choice of neurofeedback protocols for the enhancing and inhibiting of bands within the spectrum, though new approaches are being pioneered (for a review see Gruzelier, in preparation), while the recording of slow cortical potentials offers an alternative approach in some situations (e.g., Mayer, Wyckoff, & Strehl, 2013). As in our original music studies we compared in children the relative efficacy of training slower versus faster wave bands, here alpha/theta (A/T), versus the sensory-motor rhythm (SMR) band, the former putatively associated with creativity (Gruzelier, 2009) and well-being (Peniston & Kulkosky, 1991; Raymond, Varney, & Gruzelier, 2005) and the latter with motor quiescence coupled with a relaxed focus of attention (Sterman, 1996). To further explain the reasons for this selection of protocols and research design we consider briefly aspects of our two original studies. For more introductory and detailed accounts for the reader unfamiliar with the application of psychophysiology to the performing arts see Gruzelier and Egner (2004) and Gruzelier (2012) that were invited for a music readership.

1.2. Neurofeedback protocols and music studies

In applying to London Royal College of Music 2nd to 5th year students a number of interventions from Sports Psychology, including mental skills training, aerobic fitness, the Alexander technique and three neurofeedback protocols, the one that proved to be uniquely effective was A/T training. Elite music performance in the two controlled studies (Egner & Gruzelier, 2003) that involved a constructive replication (Lykken, 1968) was enhanced by more than one class of honours according to expert raters using scales which mapped directly on to conservatoire assessments (Harvey, 1994; Thompson & Williamon, 2003a). These findings stimulated scientific and pedagogic interest (Stewart, 2002; Tilstone, 2003) and the funding of a research programme to explore novice music performance in adults (Gruzelier et al., submitted for publication; Leach, Holmes, Hirst, & Gruzelier, in preparation), and in children as outlined here.

1.3. Alpha/theta and creativity

The A/T protocol was the one that was found to benefit music performance. It had been first designed by Green and Green (1977) to induce a state of hypnogogia (the border between sleeping and waking) which at the time was thought to be associated with creative ideas (Koestler, 1964) and to be indexed by the EEG's theta rhythm (Schachter, 1976). The training procedure involved relaxing with eyes closed and listening for pleasant sounds which reward both the occurrence of theta activity and the adjacent higher alpha band, the latter being a common counterpart of eye closure. The aim is to vary reward thresholds in order to raise the amplitude of theta over the amplitude of the more prevalent alpha, but without the occurrence of sleep heralded by delta waves. Its first successful outcome was as the primary component of a mixed treatment programme aimed at alleviating anxiety in alcoholic veteran soldiers and subsequently with soldiers having alcoholism as well as Post Traumatic Stress Disorder (PTSD) (Peniston & Kulkosky, 1991), and more recently mood was enhanced in withdrawn students (Raymond, Varney, et al., 2005).

In our music conservatoire controlled investigations the ability to learn to increase the theta/alpha ratio in the first study correlated significantly with the quality of music performance overall and with each of the three domains of performance: perceived instrumental competence, musicality/creativity, and communication, as well as subcategories including interpretative imagination. In contrast the SMR and beta1 neurofeedback protocols were unrelated to music performance as were aerobic fitness and mental skills training, the other interventions. The A/T protocol was also uniquely effective in the second study which involved a new cohort of musicians from the same conservatoire (Gruzelier, Egner, Valentine, & Williamon, 2002; Gruzelier & Egner, 2004). This study had an independent-groups design where musicians were randomly allocated to either A/T, SMR, or beta1 neurofeedback, to physical exercise, to mental skills, or to the Alexander technique widely used in performing arts conservatoires in order to avoid excessive postural tension through a system of kinaesthetic education. In support of the findings of the first experiment the evaluations of three assessors disclosed that the A/T group displayed significant improvements, while the other groups showed no post-training changes. The replicability of the A/T learning enhancing effects were seen particularly with the parameters of musicality – stylistic accuracy and interpretative imagination, together with the overall quality of the performance. The results from the two studies were interpreted as indicating that A/T training led to improvements, especially in attributes of artistic expression including interpretative imagination, which in turn contributed to an improved overall performance. Subsequently the A/T protocol was applied to competitive ballroom dance performance (Raymond, Sajid, Parkinson, & Gruzelier, 2005), cognitive creativity in contemporary dancers (Gruzelier et al., in press) and creative acting performance in second year acting students (Gruzelier, Inoue, Steed, Smart, & Steffert, 2010). Here the question we address is: Would there be similar benefits from A/T training in eleven year old children?

There is an issue that hovers in the background when Psychology comes to mind in connection with performing well in conservatoires and beyond. 'Anxiety in performance' is typically the foremost and often the sole association. For this reason it is noted that all interventions reduced pre-performance anxiety, as was the case in the second study, so that the enhancement in music performance that was found to be specific to A/T training could not be attributed solely to underlying anxiety reduction. A relaxed state however, may hold the key to the efficacy of neurofeedback in facilitating creativity in performance. 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), allowing past learning and new associations to surface and inform performance. A/T training has also been shown to promote well-being (Peniston & Kulkosky, 1991; Raymond, Varney, et al., 2005).

1.4. SMR and attention

The other neurofeedback protocol selected for the school children enhances the SMR amplitude. This protocol rewards through points on a computer screen increases above baseline in the amplitude of the SMR (12–15 Hz) without concurrent rises in theta (4–7 Hz) and high beta (22–30 Hz; beta2). The rhythm is recorded over sensory-motor cortex, is under ventral-basal thalamic control and is augmented in states of motor quietude, so that enhancing it reduces restlessness and motor impulsivity promoting a relaxed focus of attention and sustained concentration (Sterman, 1996). It has had fruitful application in the treatment of ADHD (Arns et al., 2009; Fuchs, Birbaumer, Lutzenberge, Gruzelier, & Kaiser, 2003; Gevensleben et al., 2009; Linden, Habib, & Radojevic, 1996; Lubar, Swartwood, Swartwood, & O'Donnell, 1995; Rossiter & Lavque, 1995; Strehl et al., 2006). The ADHD evidence was apposite given the incidence of behaviour disorder in our school with its mixed race and immigrant population situated in a south London police ward with the highest crime rate in the UK.

Aside from the fact that a second neurofeedback group would act as a control for nonspecific influences such as practice, motivation, or generic neurofeedback factors, there were other possible benefits that putatively could arise from SMR learning. In 'optimal performance' studies SMR training has had a positive impact on attention, memory, visuo-motor skills, mental rotation and creative acting performance (Barnea, Rassis, & Zaidel, 2005; Doppelmayr & Weber, 2011; Gruzelier et al., 2010; Ros et al., 2009). In fact this evidence base also includes ancillary studies of attention involving the conservatoire musicians (Egner & Gruzelier, 2001, 2004), which aside from demonstrating benefits in cortical evoked potential attention paradigms, included a continuous performance test widely used to assess attention in ADHD, the Test of Variables of Attention (TOVA; Greenberg & Kindschi, 1999). Accordingly we applied the same test in our school study. We hypothesised that such basic cognitive processes as attention, memory and visuo-motor skills may be apposite for the underpinnings of novice music performance in a way that they are not required in the well honed performance of elite musicians.

1.5. Creative improvisation and mood and feasibility

Finally, as an innovation to further inform the impact of the A/T protocol on creativity in music performance we introduced creative improvisation with both the children and the adults in our replication studies (Gruzelier et al., submitted for publication; Leach et al., in preparation) in addition to the pieces of music prepared in advance from their current repertoire. Additionally there was evidence that both our chosen neurofeedback protocols have had benefits for mood; following A/T training students were more composed, agreeable, happy, energetic and confident (Raymond, Varney, et al., 2005), while SMR training increased self-ratings of calmness (Gruzelier, 2013). It was therefore of interest whether the children would report feelings of improved well-being in school and at home as well as improved application in the classroom.

In conclusion, the main implication we have addressed in the present report is whether the benefits of neurofeedback would extend to novice musical abilities as found in children? The methodology and the design were based on our original studies taking into account the logistics of conducting the study within a school in a single term, notably the availability of the children who were timetabled to leave selected classes for the half-hour sessions. Availability limited the number of neurofeedback protocols to two, the number of training sessions to ten, and the sample size to thirty-three allowing for a non-training control group; a total of more than 350 test sessions. We compared the A/T and the SMR protocols for their potential impact on both prepared performance following rehearsal in class and unprepared creative improvisation. Sustained attention was examined with a test widely used in the ADHD field and one measured in our music conservatoire studies. The children's phenomenological report was also recorded to compliment the objective assessments.

2. Participants

33 11-year olds from the ARK Evelyn Grace Academy, Brixton, South London were randomised to 10 sessions of A/T training, SMR training or to a non-training control group (11 in each). Children were selected on three criteria: musical potential as gauged by the music teacher, referral for special educational needs, or a combination of the two, for which groups were balanced as well as for sex. In addition the Eysenck Personality Scale for Children (Eysenck & Eysenck, 1994) was administered and disclosed no group differences on any of the scales: Extraversion, Neuroticism, Psychoticism, Antisocial Behaviour and the Lie scale. There were three drop outs with one child changing school and two others staying away from school towards the end of term, all in the neurofeedback groups. This reduced the numbers to 9 in the SMR group and 10 in the A/T group giving: SMR 5m, 4f; A/T 5m, 5f, Control 6m, 5f.

3. Methods and design

3.1. Neurofeedback

Neurofeedback was carried out with a Neurocybernetics (Encino, CA) EEG Biofeedback System and ProComp (Thought Technology Ltd; Montreal, Quebec) differential amplifier Signal was acquired at 160 Hz, and A/D converted to extract frequency band components. For SMR training amplitude measures in the filter-bands beta (22–36 Hz), SMR (12–15 Hz) and theta (4–7 Hz) were transformed online into graphical feedback representations together with reward points displayed on a screen and gained whenever the trainee enhanced SMR without concurrent rises in theta and beta, and were instructed to adjust their mind to let that happen. The active scalp electrode was placed over sensory-motor cortex at Cz, the standard placement for the sensory-motor rhythm with the reference placed on the left and the ground electrode on the contralateral earlobe respectively. Artefact rejection thresholds were set for each subject individually to suspend feedback when eye movements or other motor activity would cause gross EEG fluctuations. The aim was to train a relaxed focus of attention during which eyes were open.

For A/T training children relaxed with their eyes closed and listened via headphones to auditory feedback representations of ongoing changes in relative theta (4–7 Hz) and alpha (7–10 Hz) power (bands widths selected for children) with an active electrode at Pz, a standard placement for measuring alpha and theta with eyes closed. The reason for the protocol being undertaken with eyes closed was because the aim was to create a state of hypnogogia which is a state of deep relaxation, the border between waking and sleeping (Gruzelier, 2009). Sounds of waves gently breaking on the shore were associated with theta and a babbling brook with alpha. When participants' alpha was higher than theta power the brook sound was heard, and when theta was higher than alpha the sound of waves. Each band also had an amplitude threshold, and suprathreshold bursts of alpha or theta were rewarded by a high- or low-pitched gong sound respectively. These thresholds were set manually and updated such that alpha and theta amplitudes were over the threshold 50–70% and 25–40% respectively. The participants were instructed to relax deeply and listen to the pleasant sounds which would occur more frequently as they relaxed more deeply, but to try not to fall asleep.

3.2. Outcome assessments

Music performances were designed by the school's head of music and consisted of (1) a familiarisation of performing to camera and warm up, (2) a solo piece of their choice as practised in class, either vocal or instrumental, (3) an improvisation either vocal or instrumental on the theme of *the sea* pre-training or *a storm* post-training, and given 2 min preparation with paper and pencil if required. Performances were filmed by JG, and then randomised as to order (pre/post) and group and rated by four teacher assessors, who were blind to group membership, in two joint rating sessions. One rater had missing data being unable to keep pace with the group of raters in the film rating sessions, reducing the inter-rater reliability, and was therefore excluded. 5-point ratings were obtained on items covering the three domains as for the adult studies for the rehearsed performance providing scales of Creativity/Musicality, Communication and Technique and for improvisation Creativity and Communication; technique at such a novice level was considered inappropriate. Creativity was based on

Table 1
Means and standard deviations of dependent variables not influenced by training.

Variables	Mean (standard deviation)				Statistics (Group × Time)	
	Group				F	P
	Time	A/T	SMR	Control		
Rehearsed						
Music Creativity	Pre	6.43(1.32)	6.56(1.17)	6.82(0.97)	0.83	0.45
	Post	6.43(1.07)	5.78(1.19)	6.48(1.34)		
TOVA RT	Pre	357.56(59.65)	370.57(71.82)	367.80(57.50)	0.01	0.99
	Post	387.67(61.55)	401.29(86.96)	396.10(84.97)		
TOVA RTV	Pre	120.56(36.78)	133.14(45.03)	102.20(32.97)	0.24	0.79
	Post	132.11(37.62)	135.86(55.23)	105.20(30.66)		
TOVA Omissions	Pre	0.023(0.014)	0.021(0.018)	0.011(0.017)	0.14	0.87
	Post	0.026(0.024)	0.023(0.038)	0.022(0.049)		
d-Prime (d′)	Pre	3.48(0.83)	3.80(1.12)	4.59(1.22)	0.06	0.95
	Post	3.87(0.92)	4.14(1.18)	4.79(1.54)		

the following four ratings: use of imagination, well structured performance, appropriateness to title, and expression (dynamics and articulation). Communication consisted of ratings of confidence, posture, engagement with the audience and enjoyment. Technique for singing consisted of vocal quality, clarity of diction and sense of pitch, and for instrumental playing control of the instrument.

The pre/post assessments also included the TOVA-7 (Greenberg & Kindschi, 1999) widely used in the ADHD field (Arns et al., 2009). The TOVA contains two classes of stimuli, “targets” which require the subject to respond as quickly and accurately as possible (e.g., by pushing a response switch), and “non-targets”, which require the subject to refrain from responding. Two types of errors can be incurred on such a task, 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 further attention measure derived from signal detection theory (Green & Swets, 1966) is termed “perceptual sensitivity” or “d-prime”, and takes into account both of these error types by expressing a ratio of hit rate to false alarm rate. In addition an ADHD Attention Index (Leark et al., 1999) was calculated which in addition to d-prime takes into account response time and response time variability and it enables each child’s performance to be compared with the profile of an ADHD sample. However, reaction times were increased in all groups equally, interpreted as a reflection of a build up of tiredness with the passage of the school term, such that any change in this measure was compromised.

The Strengths and Difficulties Questionnaire (Goodman, 1997) was to be completed by teachers, covering a range of behaviour with subscales of emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems, and prosocial behaviour. Poor compliance by the teachers at the study end precluded analysis.

At the end of session 10 the trainer MF asked the child two open-ended questions: Whether they found the sessions helpful? Whether they would do it again? In other words, did they enjoy doing it.

The study was accomplished with 30/33 children, who completed 10 sessions of neurofeedback training. Children were successfully scheduled to leave classes one at a time to complete the pre and post training assessments and the half-hour training sessions. One strategic issue must be flagged up before continuing in order to fully appreciate the results. It became apparent that as the post-training assessment time approached at the end of the autumn term before the Xmas break we were dealing with very different children from those at the time of the pre-training assessments when the children were full of spirits, in a new school setting and fresh after the long summer vacation. Conceivably this may have compromised the interventions to some extent; the tiredness that accrued in the course of the term may underpin the significantly longer reaction times as will be seen in the whole sample at the end of term.

4. Results

Inter-rater reliability was assessed with Cronbach’s alpha. There was high consistency between the 3 raters ($r > 0.822$). Importantly the balanced randomisation according to musical ability, and behaviour disorder which might have been reflected in sustained attention, was successful. One way ANOVAs on baseline assessments indicated no statistical differences between the groups either in music performance or on the TOVA, though on average the control group was superior at improvisation, but not significantly so ($p > 0.26$). The group differences in outcome following neurofeedback were examined with repeated measures ANOVA (Group × Time) followed by paired *t*-tests. Results are either shown in Figs. 3–7 where there were noteworthy group effects, or in Table 1 if there were no group differences.

4.1. Neurofeedback learning

It is critical for validation in neurofeedback research that learning has been shown to take place. Here there was clear evidence of A/T learning within sessions in the correlation between amplitude and period within sessions ($r = 0.756$, $p = 0.001$), as shown in Fig. 1a, and a trend for between-session learning in the correlation between session number and amplitude ($r = 0.174$, $p = 0.102$) shown in Fig. 1b. As has been customary in our studies whereas the course of within-session learning follows a positively accelerated curve, across-session A/T learning tends not to be as regular (Linear R Square = 0.291, $F(1, 8) = 3.28$, $p = 0.108$). We suspect that this may be due to wide variations in day to day arousal levels; children spontaneously reported irregularities in night’s sleep. There was also on average an increase in the delta/theta ratio within the last half of sessions ($r = 0.704$, $p < 0.001$), as may occur if the children went beyond hypnogogia towards sleep, but this diminished across sessions ($r = -0.084$).

Within-session SMR learning with theta and beta2 inhibits was effective with regard to the within-session increase in the SMR/beta2 ratio, seen in Fig. 2a in the dotted line: correlation between ratio and period number, $r = 0.211$, $p = 0.079$. This was not the case with the SMR/theta ratio (Fig. 2a solid line, $r = -0.032$). A similar picture was provided by across session ratio changes as shown in Fig. 2b for the SMR/beta2 ratio (SMR/beta2 $r = 0.244$, $p = 0.036$; SMR/theta, $r = -0.121$).

In summary, there was good evidence in support of A/T learning, in keeping with our other optimal performance studies. On the other hand whereas the SMR/beta2 ratio was increased this was not

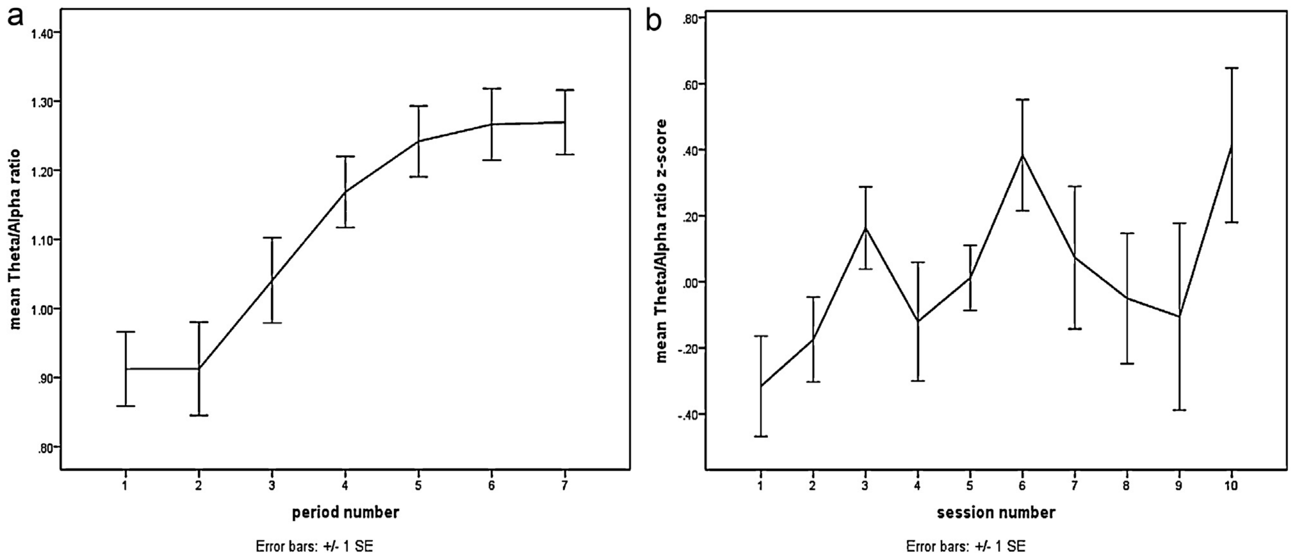

Fig. 1. (a) Within session theta/alpha ratios across seven 3 min periods, and (b) ratios across the ten sessions.

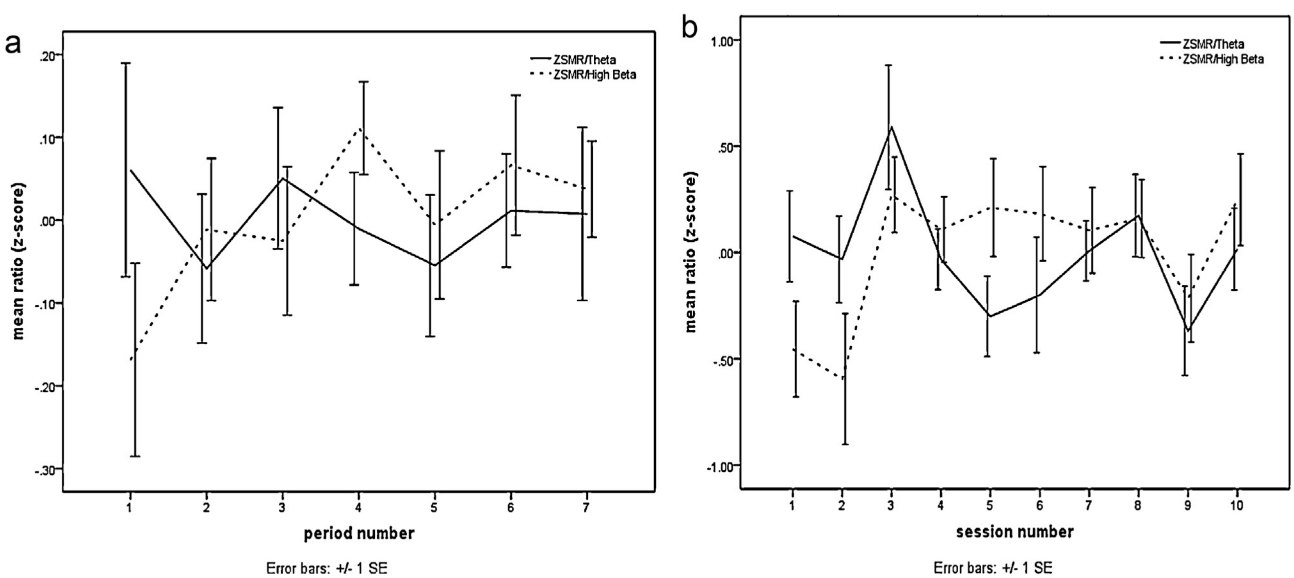

Fig. 2. (a) Within session SMR/beta2 ratios across seven 3 min periods, and (b) ratios across the ten sessions.

the case with the SMR/theta ratio militating against the potential impact of SMR ratio training.

4.2. Music performance

4.2.1. Rehearsed performance

As shown in Fig. 3, prepared vocal or instrumental performance showed improvement in Technique ratings following A/T training which approached significance, with no improvement in the other groups as shown by a significant Group × Time interaction and paired t-tests for each group comparing pre and post-training assessments (Group × Time $F(2, 27) = 3.313$, $p = 0.05$; A/T $t(9) = 2.18$, $p = 0.057$; SMR $t(8) = 0.39$; control $t(10) = 0.89$). There was also a suggestion of benefits with Communication ratings following A/T training, as can be seen in Fig. 4, in so far as Communication held up whereas it declined in the other groups (Group × Time $F(2, 27) = 2.802$, $p = 0.078$). The decline approached significance in the SMR group ($t(8) = -2.08$, $p = 0.07$). There were no statistical effects with the Creativity ratings (Table 1).

4.2.2. Improvisation

As shown in Fig. 5, creative improvisation on average improved on the Creativity scale with both neurofeedback groups compared with controls (Group × Time ($F(2, 27) = 6.224$, $p = 0.006$),

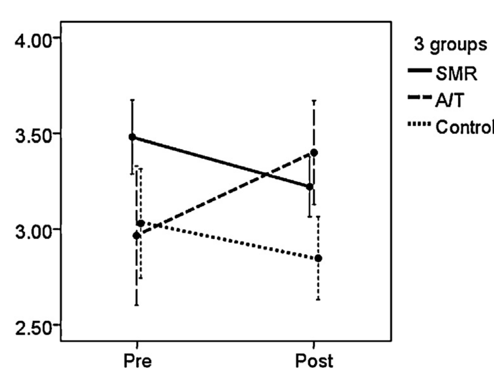

Fig. 3. Improvement in ratings of Technique in prepared performance following alpha/theta training compared with the other groups.

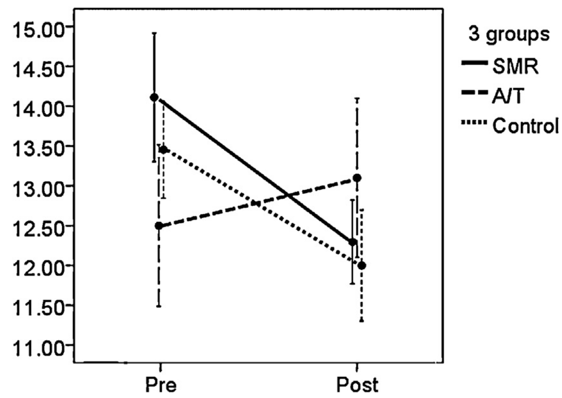

Fig. 4. A decline in Communication in the SMR and control groups not seen in the A/T group.

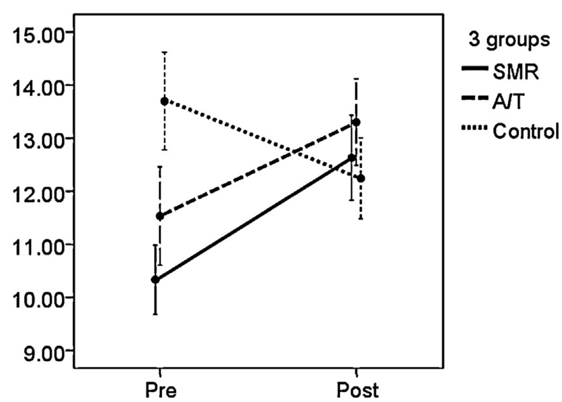

Fig. 5. Improvisation Creativity subscale showing improvements following neurofeedback.

significantly so with the SMR group whereas the control group declined to an extent just short of significance (A/T $t(9) = 1.70$, $p = 0.122$; SMR $t(8) = 2.18$, $p = 0.014$; control $t(10) = -2.16$, $p = 0.056$). This was despite a non-significant advantage to the control children at baseline.

The Communication subscale showed an even more striking advantage to neurofeedback training (Group × Time $F(2, 27) = 11.326$, $p = 0.001$) with significant improvement in both groups (A/T $t(9) = 2.57$, $p = 0.03$; SMR $t(8) = 3.00$, $p = 0.017$), whereas there was a significant decline in the controls ($t(10) = 2.92$, $p = 0.015$). Results are shown in Fig. 6.

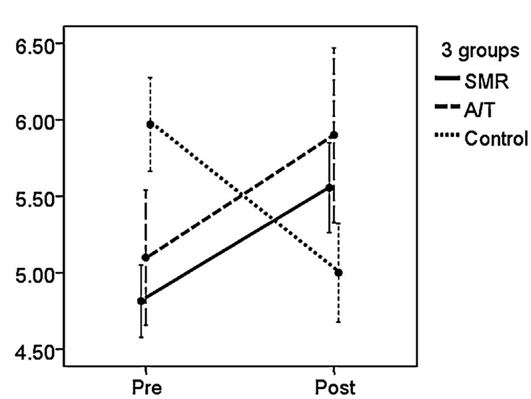

Fig. 6. Improvisation Communication subscale showing improvements following neurofeedback and a decline in controls.

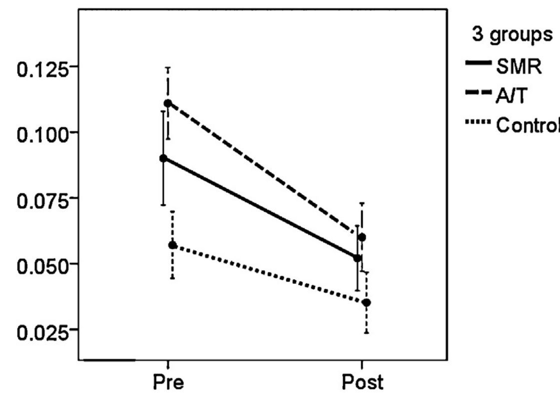

Fig. 7. Reductions in errors of commission %; greater in the A/T group than in controls.

4.3. Attention

On the attention test invalid performances such as overly long inattention or frequent anticipatory responses as determined by the TOVA-7 manual (Greenberg & Kindschi, 1999) reduced numbers to 7 SMR, 9 A/T and 10 controls. There was a highly significant slowing in response time in the course of the study ($F(1, 23) = 8.03$, $p = 0.009$), compatible with tiredness observable in the children at the end of term. This amounted to an 8% slowing from 365 to 395 msecs and was disclosed equally in all the groups, see Table 1. The decline did not occur in reaction time variability (Table 1).

There was a non-significant ($F = 1.58$) increase in d-prime the global attention measure, with an increase from $X = 3.99$ to $X = 4.30$. This largely reflected a decrease in commission errors ($F(2, 26) = 20.36$, $p = 0.001$; A/T $t(8) = 4.47$, $p = 0.002$; SMR $t(6) = 1.98$, $p = 0.095$; controls $t(9) = 1.71$, ns), and this was greater for the A/T group compared with the controls ($t(19) = 1.77$, $p < 0.05$), as shown in Fig. 7. There was also a non-significant increase in omission errors for all groups ($F = 0.51$) reflecting inattention, as shown in Table 1.

Using TOVA-7 scores, scores of < -1.80 place children in the suggestive ADHD category. 10 children were classified as ADHD at baseline and 10 children post-training comprising 5 of whom were so categorised at baseline. This gave a total of 15 of those who remained in the study with valid performances. Adding the 4 with invalid performances due to inattention and in accord with the TOVA manual 19/33 children were classifiable by their attention performance as being in the ADHD category so far as their attention was concerned.

4.4. Training session questionnaire

Excerpts from the questionnaire are shown in Table 2. The main conclusions were as follows. Of the 11 children assigned to SMR training all but two, one of whom withdrew from the school, and one who had eye problems looking at the screen, experienced a positive outcome. This ranged over school performance, life at home and in the classroom, and well-being, mood and concentration. Descriptors for mood and well-being included energetic, good, happy, peaceful, relaxed, calm, confident, sleeping better; Academic descriptors included concentration, focus, multi tasking, and better application in maths (4), science (5), and physical education (2).

All but one assigned to A/T training enjoyed the sessions, though that child admitted to improved sleep at night. Positive effects were reported on well-being, including sleep and mindset, and behaviour in class. Descriptors included relaxing, happy, good, and put aside worries. Nine of them experienced the desired hypnogogic imagery in at least some of the sessions. 6 referred to a carryover to school

Table 2
Subjective reports from the children 1–11 in each of the neurofeedback groups.

SMR Training
1. Enjoyed sessions, felt more energetic and good; finds maths and science easier to focus on. "Helps me focus better in class".
2. Withdrew from school. Behaviour problems.
3. Happy, peaceful, relaxed, good, sleepy. Feels relaxed afterwards. Can feel it outside the session, especially in maths.
4. Can concentrate better in class. Withdrew from school.
5. Had persistent eye trouble looking at screen, tired. Relieved it was over.
6. "I've got more focus in science, maths and PE, and at home."
7. Focussed, calm, "science is getting easier". "Yes it's very relaxing".
8. Identified the state "It goes with thinking positive things, but it is the feeling not the thought". Calm, focussed. Improvement in science. "Will practise the SMR feeling". Yes, feels focus has improved and is keen to improve it more. Concentration has improved in Kick Boxing training."
9. "Can focus on more things at once, like multitasking. Can write notes and still hear what the teacher's saying. Talking less and getting hardly any verbal warnings now compared with before."
10. "Will practise the 'neutral' feeling." "Is doing better in class and sleeping better."
11. Focus is better in maths and science. "Yes, because it helped me focus more. And I join in at home (speak up) so I feel more confident."

A/T Training
1. Imagery of beach, forest with stream, 'Lord of the Rings', adventure things, cartoon animals with big heads, big golden drum covered in sand. Relaxing.
2. Imagery of skimming stones on water, but mostly no imagery. Said there had definitely been a difference with music performance.
3. Sea and seashells, on the whole had worries. Yes, coming out of lessons and having a chance to relax means I can go back to my lessons with a different mindset".
4. Did not relax satisfactorily throughout course of training. "I go to sleep quicker at night – just a bit. The sessions are boring, it's hard to keep my eyes closed."
5. Imagery on a boat travelling, indoor swimming pool, underwater stunts, the shape of the water took me to a slide, dreamt of being a fashion designer modelling her own creations, huge shells. Felt very happy. "Yes, I think that when I sing at home I can hold the notes for longer."
6. Imagery of swimming in the ocean with dolphins and fishes, watching the film 'Fame', a big cup over flowing with water, floating, sky diving. "Yes, lets you go inside your head and put aside your worries."
7. Imagery of a dance movie, raindrops, acting performance, being in High School Musical with Zac, visualising performance in Of Mice and Men. Felt good, relaxed.
8. Imagery of swimming pool outside in the sunshine, on a boat searching for something, thunder storm, dream of whether to be a footballer or rapper. "Yes, my music is better, and my maths and English."
9. Imagery of an office with a wall of windows, a sky scraper and he was the boss, a normal day in school, sense of supernatural power and family and friends shared the power. "Yes, it is relaxing, and I get less verbal warnings when I go back to class afterwards."
10. Imagery of being a celebrity in a show and family did not have to work, my brother on stage, images of baby cousin. "Yes, it is a new experience – think it helped me with my performance as Buttons."
11. Imagery of being rocked to sleep, singing songs in head. Withdrew from school.

and/or music performance. In contrast to SMR training, references were made to Arts, Performance and Humanities with 4, and with one to maths.

5. Discussion

To our knowledge this is the first formal report of a controlled neurofeedback study in a school setting, where through a careful timetabling exercise one at a time children left their scheduled classes for their half-hour sessions, an exercise ensuring that no particular classroom subject was compromised. The self-reports of the children indicated that they enjoyed neurofeedback training and felt that it had positive contributions overall for their well-being. From an objective scientific standpoint there were positive outcomes. Before being considered in more detail these were as follows:

1) The beneficial outcome of A/T neurofeedback on music performance endorsed its value, extending the earlier studies with elite performers to children who were novice performers and supporting the impact on creativity in performance, evidence that was extended to creative improvisation.
2) For the first time SMR training was found to enhance music performance and this was found with creative improvisation. This disclosure was attributed to the novice status of the performers, along with improvisation being the more challenging of the two music assessments in so far as it was unprepared and required effortful, sustained concentration in the way that a practised piece of music does not.
3) Sustained attention benefitted from both protocols, but moreso from A/T training, reducing impulsive errors of commission.
4) There was evidence of neurofeedback learning through learning curves, contributing to the validation of the behavioural outcome of the interventions.

5.1. Alpha/theta and music performance

Some of the benefits we had seen in conservatoire students (Egner & Gruzelier, 2003) were demonstrable in children. In musicians we had examined self-selected, prepared, mainly instrumental performances. These had been found to be uniquely enhanced by A/T training when compared with up to five other interventions, and the improvements were of professional significance in that they were on average equivalent to more than one class of degree honours. These were seen across the three domains of music evaluation: musicality/creativity, technique and communication, but especially with musicality/creativity.

In the prepared performances of children improvements were found with ratings of Technique, while there was a preferential outcome in favour of A/T training with ratings of Communication which held up, not showing the falloff observed in the other groups that was a possible consequence of the wear and tear of the school term. Technique encompassed vocal quality, clarity of diction and sense of pitch, while Communication encompassed confidence, posture, engagement with the audience and enjoyment. Turning to musical improvisation there was an improvement in the Musicality/Creativity ratings which encompassed the use of imagination, a well structured performance, creative expression and appropriateness to title. But mostly A/T training advantaged Communication. The benefits for improvisation were shared with SMR training which contrasted with the decline in the control children.

Thus in children A/T training could be seen to have an impact on the three music domains: technique, musicality and communication, in line with the first of the two conservatoire studies, whereas in the second conservatoire study the gains were in musicality/creativity (Egner & Gruzelier, 2003). Inter-rater reliability ($r > 0.822$) was higher than in our conservatoire studies ($r = 0.52$ ($p < .001$) where reliability had been comparable to prior studies of music performance assessment (e.g., $r = 0.53$, Thompson, Diamond, & Balkwill, 1998; $r = 0.52$, Gruzelier & Egner, 2004).

5.2. SMR and novice music performance

This is the first report of a beneficial outcome for music performance from SMR training and the second report where SMR training has been shown to benefit creative performance. In the children this benefit was seen in musical improvisation, but was not found with the more advanced of the two pieces the prepared music performance, which had been rehearsed in class and declined in all but those receiving A/T training. It is noteworthy that creative improvisation was the more challenging of the two music assessments in so far as it was unprepared and required complete effortful, sustained concentration. SMR training was not found effective in the original music studies despite its efficacy in increasing self-reported calmness, both in a phenomenological analysis of individual student interview reports (Edge & Lancaster, 2004) and in ratings of within-session arousal change (Gruzelier, 2013).

SMR training was first found effective in enhancing the creative performance in sophomore actors (Gruzelier et al., 2010). There were two methodological innovations devised for the training context which may have facilitated this. These concerned the ecological validity of both the training context and the feedback cues for facilitating learned-control.

Contemporaneously our programme of research exploring the potential gains for novice music performance has found additional support for the utility of SMR training from adults by comparing novice and advanced music abilities in the same university students (Gruzelier et al., in press; Leach et al., in preparation). What resonance has this for what was found with the school children? In the first of these adult studies, whereas the advantage of A/T training for higher level instrumental ability was replicated, as before (Egner & Gruzelier, 2003) as it had been in children, there was no impact of SMR training on advanced performance. On the other hand the adults' novice singing of folk songs was improved by both SMR and A/T protocols, with A/T training having an impact on ratings of Musicality and Communication whereas SMR training enhanced Technique, improving pitch and to some extent rhythmic accuracy and diction (Gruzelier et al., in press). Again lower level abilities were improved by SMR training in adults as they were in children, benefits shared with A/T training in both cases. In an extension of this, in the second study (Leach et al., in preparation) the scheduling of the post-assessment music performances was within only 10 min of the last training session, placing greater demands on sustained attention in music performance. Again SMR training benefited performance through the putative call on basic lower-level cognitive processes.

From the response to SMR training from the school study and the two with novice singing in university instrumentalists, it would appear that the training of lower-level abilities involved in novice performance would be in keeping with evidence of the positive impact of SMR on attention, memory, visuo-motor skills as well as the creative acting performance of amateur actors (Barnea et al., 2005; Doppelmayr & Weber, 2011; Gruzelier et al., 2010; Gruzelier, in preparation; Ros et al., 2009; Vernon et al., 2003). Additionally this may have facilitated a relaxed, modulated attentional style (Egner & Gruzelier, 2001, 2004; Gruzelier, 2013; Ros et al., 2009). This is in contrast to the elite performer who has already through practice and experience mastered the fundamental cognitive requirements by rehearsal.

5.3. Alpha/theta, SMR and attention

What had not been anticipated was the enhancement following A/T training for sustained attention assessed with the TOVA. Here the significant impact of A/T training on attention was due to a highly significant reduction in errors of commission, a reduction in impulsive responding which would be in keeping with the protocol's facility in inducing relaxation in the school setting. Indeed there was no previous evidence to inform us whether children could reach a state of hypnogogia in relatively brief sessions in the midst of the school day. Thus the elevation of theta over alpha with eyes closed and auditory feedback in a state of deep relaxation was a new venture with children. As the learning curves and subjective reports disclosed, it was highly effective, and it was enjoyed. Up until now only those protocols that engaged children with neurofeedback learning via computer screens, as with SMR, beta1 and slow potential training, had been applied to improve sustained attention (e.g., Strehl et al., 2006).

SMR training did not have the anticipated benefit that might have been expected from the ADHD evidence (Arns et al., 2009), and from its efficacy with the TOVA and event-related potential indices of attention in our music conservatoire studies (Egner & Gruzelier, 2001, 2004). There was only a tendency towards improvement in errors of commission (SMR, $p < 0.095$, c.t., A/T, $p < 0.002$). However, two factors may have been responsible for this. Firstly, the successful increase in the SMR/beta2 ratio did not have a counterpart with an increase in the SMR/theta ratio. Secondly, the ADHD attention index from the TOVA-7 manual placed 15/33 children in the ADHD category so far as their attention was concerned (see Gruzelier, 2012 for group distributions); ADHD treatment plans would require thirty or more sessions in contrast to the ten sessions here. Clearly the positive impact of A/T training on attention warrants further investigation.

5.4. Subjective reports

The exploratory subjective reports at the close of the study disclosed that 19/22 children receiving neurofeedback felt improved well-being in the school context and this could extend to the home. Impressions of a positive carry-over to the classroom were volunteered by eight following fast-wave training and six following slow-wave training. Self report impressions of a positive impact on academic subjects included science, maths, physical education in the case of SMR training, and in the case of A/T training performing art, English and maths. It is of interest that impressions of change in school subjects differed between the training groups. Validation through alignment with school performance would be worthwhile in the future.

5.5. Learning curves

Documenting that learning has taken place is a fundamental requirement and too often in the earlier reports was left to inference from post-training outcomes (for review see Gruzelier, in preparation). 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 factors such as practice, motivation, experimenter engagement and other nonspecific factors. Often a comparative neurofeedback group allows control for some of these factors, but notwithstanding one needs to know whether learning took place. In a majority of clinical reports with ADHD for example learning curves and separate ratios have not been provided leaving validation of earning unknown.

Contrary to what might have been anticipated, namely the challenge to quickly induce borderline sleep between classes in the midst of the school day, arrangements proved highly conducive for A/T learning in the hands of the experienced practitioner. This was demonstrated by the significant ($p < 0.001$) A/T within-session learning curves. In fact at first the children went deeper than desired, indexed by an increase in the delta/theta ratio, but with training they learned to remain outside of a delta predominance. A/T learning curves both within and across sessions were in line with those of successful studies with adults. In fact the within-session group curve depicted highly satisfactory learning when compared with other adult studies (Gruzelier et al., in press; Ros et al., 2009). The irregularity in the between-session curve was typical of the majority of our studies, and has been attributed to the wide variation in day by day baseline arousal levels when adjusting to the laboratory and with the goal of quickly entering hypnogogia.

SMR learning was on the whole not as effective. The favourable impact on improvisation was despite the fact that for reasons unknown a reduction in the SMR/theta ratio was not realised compared with the reduction in beta2. However, the reduction in beta2 is salient. beta, especially Beta2, has been associated with anxiety/over-arousal (Begic, Hotujac, Jokic-Begic, 2001; Pollock & Schneider, 1990), and a reduction in frontal beta was the long term EEG outcome of A/T training in our original studies with musicians (Egner, Zech, Guzelier, 2004). A reduction in beta2, when taken in conjunction of SMR training's putative role in inhibiting sensory-motor cortex (Sterman, 1996), is compatible with the outcome of instilling a more relaxed attention style, with likely benefits for the cognitive processes inherent in lower-level novice performance.

5.6. Implications for the future

5.6.1. Alpha/theta with children

To our knowledge this is the first report of the A/T protocol applied to children. The school children responded with enthusiasm and with one exception experienced no difficulty despite many of them having attention within the ADHD range. One implication is that this may provide a new treatment approach or adjunct, especially for ADHD. Surely a major issue is how to reduce the number of sessions required with neurofeedback to improve its cost effectiveness. Practitioners may give eighty or more sessions to achieve lasting effects. Multi-modal treatment approaches are a likely solution (Thompson & Thompson, 2003b). Conceivably A/T sessions before and/or interspersed with faster-wave feedback or SCP protocols may facilitate a reduction in the number of sessions conventionally required for this disorder. Furthermore the highly significant improvement in errors of commission along with the positive subjective reports of the children coming from diverse social backgrounds indicate how valuable neurofeedback training could be as an integral part of the curriculum planning in an educational context.

5.6.2. Feasibility of neurofeedback in schools

The study demonstrated that neurofeedback training within a school curriculum was feasible, and that this may include controlled investigations for research purposes. Though the study was not a joint venture between the investigators and the school as the earlier music study had been, it had the full support of the headmaster and the head of music who helped with the design, scheduling and running of the music performances. At the same time the research was not embedded in the school, one consequence of which was the lack of teacher compliance with their ratings. Experience across our applied studies suggests that it is highly desirable, if not essential, to have the institution in which the research is done as a responsible partner in the project, regime change notwithstanding.

The full support of the collaborating institution is also advisable at a practical level for the logistics of conducting controlled trails within institutions with healthy participants is considerable (see Gruzelier et al., in press for a dance conservatoire study). Firstly, limitations of subject availability means that the duration of a ten-session training study with pre- and post-assessments is likely to span a term. Furthermore it is desirable in order to avoid long gaps between sessions as would occur with vacations which may retard neurofeedback learning (see the hospital study of Ros et al., 2009, with eye surgeons), so that the course of training should fit within a term. Secondly, beginning a study after the long summer vacation and the children's refreshment, though we had no choice, with hindsight might be avoided. An alternative approach to counteract the end of term effect would be to train throughout the second term with the pre- and post-assessments programmed at the end of terms one and term two respectively. Given that this handicap materialised in the course of the study the improvements that were disclosed following neurofeedback could be seen to be all the more noteworthy.

5.6.3. Conclusion

The mostly positive outcomes from our study merit replication to extend their implications, increase the evidence base, and to explore the generality of the findings. At this stage of the development of the neurofeedback field resources are scant and allow only small scale studies. There are constraints too imposed by conducting intervention studies in the everyday life of educational institutions which pose challenges for scientific enquiry including availability of participants, which are often overlooked by commentators accustomed to the relative convenience of basic-laboratory as distinct from applied studies.

The research endorses the value of neurofeedback for the field of optimal performance, and applications to the performing arts in particular (Gruzelier, 2012, in preparation), here extended to music performance in children. The impact on creative performance vindicates the historical development of the A/T paradigm in order to enhance creativity (Green & Green, 1977). Benefits for creative performance in children and adults aside, assessments of creativity in performance in the Arts signals a fresh and much needed approach, for creativity research at large is mainly caught in the limbo of assessment measures which have not advanced in half a century (Gruzelier, in preparation); this approach provides ecological validity.

Evidence is provided that SMR training is also appropriate when performance skills are at an elementary level, with the ability to instate a sustained, relaxed attentional style and improve processes fundamental to novice performance such as focussed and sustained attention (Egner & Gruzelier, 2001, 2004), memory (Barnea et al., 2005; Hoedlmoser et al., 2008; Vernon et al., 2003), and perceptuo-motor skills (Ros et al., 2009; see Gruzelier, in preparation for review).

A/T training, music performance aside, was highly effective in reducing errors of commission in sustained attention and it was experienced as pleasurable by 19/22 children, of whom 15 were classifiable with an ADHD-like attention profile on the basis of the TOVA. This demonstration, in what was a first application of A/T with children, is worthy of careful examination in future studies. It also supports the inclusion in the school curriculum of structured time out sessions for relaxation as is being investigated with other approaches such as mindfulness (Burke, 2010; Napoli, Krech, & Holley, 2005; Semple, Reid, & Miller, 2005), yoga (Peck, Kehle, Bray, & Theodore, 2005; Galantino, Galbavy, & Quinn, 2008) and Tai Chi (Wall, 2005). This should be a Zeitgeist.

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