



Replication of elite music performance enhancement following alpha/theta neurofeedback and application to novice performance and improvisation with SMR benefits

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ARTICLE INFO

Article history:

Received 20 February 2013

Accepted 4 November 2013

Available online 11 November 2013

Keywords:

Neurofeedback

Alpha/theta

SMR

Music

Creativity

Improvisation

ABSTRACT

Alpha/theta (A/T) and sensory-motor rhythm (SMR) neurofeedback were compared in university instrumentalists who were novice singers with regard to prepared and improvised instrumental and vocal performance in three music domains: creativity/musicality, technique and communication/presentation. Only A/T training enhanced advanced playing seen in all three domains by expert assessors and validated by correlations with learning indices, strongest with Creativity/Musicality as shown by Egner and Gruzelier (2003). Here A/T gains extended to novice performance – prepared vocal, improvised vocal and instrumental – and were recognised by a lay audience who judged the prepared folk songs. SMR learning correlated positively with Technical Competence and Communication in novice performance, in keeping with SMR neurofeedback's known impact on lower-order processes such as attention, working memory and psychomotor skills. The importance of validation through learning indices was emphasised in the interpretation of neurofeedback outcome.

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1. Introduction

1.1. Historical background

Neurofeedback involves the feedback in real time of a physiological parameter where putatively through operant learning principles the participant adjusts their mental state and performance in the service of learning to control their brain activity. This ability for self-regulation dates back to the 1960s (Kamiya, 1962, 1969; Miller, 1969; Sterman, Wyrwicka, & Roth, 1969) and the classical conditioning of the EEG before that (Jasper & Shagass, 1941; Loomis, Harvey, & Hobart, 1936). 'Neurofeedback' has been ascribed when the feedback involves central nervous system indices such as the electroencephalogram (EEG), while an earlier term 'biofeedback' has become reserved for the feedback of peripheral nervous system measures. Despite early indication of the clinical promise of this discovery (Lubar & Shouse, 1976; Sterman & Friar, 1972), especially for epilepsy (see Sterman, 2000 for review), the potential of CNS biofeedback was lost sight of through some failed replications (Dworkin & Miller, 1986; Plotkin & Rice, 1981),

likely coupled with the sceptical antagonism often associated with clinical over statement and premature popularisation in society-at-large as instrumentation initiatives created a band wagon. This was not the case with biofeedback for peripheral nervous system measures. However, neurofeedback (EEG-biofeedback) was kept alive in research in North America, notably in the field of attention deficit hyperactivity disorder by Lubar (1991) influencing a band of dedicated practitioners (Othmer & Othmer, 2007; Thompson & Thompson, 2003), while in Europe there was extensive research with slow cortical potential (SCP) neurofeedback (Birbaumer, Elbert, Canavan, & Rockstroh, 1990; Elbert, Rockstroh, & Birbaumer, 1984; Rockstroh, Elbert, & Birbaumer, 1993).

Encouraged by experience at firsthand from an SCP neurofeedback programme for schizophrenia (Gruzelier et al., 1999; Hardman et al., 1997), a collaborative music conservatoire opportunity was embraced combining with the pedagogic aim of enhancing music performance the scientific aim of validating neurofeedback. To further this cause we carried out a number of ancillary studies (Egner & Gruzelier, 2001; Egner, Zech, & Gruzelier, 2004; Egner, Strawson, & Gruzelier, 2002, 2004; Vernon et al., 2003) which sought and obtained additional evidence of validity. These joint aims and the music outcome stimulated interest (e.g., Stewart, 2002; Tilstone, 2003), and inclusion in a six-month Robotics exhibition in the Science Museum, South Kensington, London, and the funding of a

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research programme to explore the application of neurofeedback to novice-level music abilities of which the present report is one of three from the programme (Gruzelier, Foks, Steffert, Chen, & Ros, 2013; Leach, Holmes, Hirst, & Gruzelier, 2013). Their design and methodology were based on the original studies which are now introduced keeping a general readership in mind. For more introductory and detailed accounts for the reader unfamiliar with the application of psychophysiology to the performing arts see Gruzelier and Egner (2004) or Gruzelier (2012) invited for a music readership.

1.2. The formative music study

Originally two year-long studies were undertaken investigating a range of interventions with potential for improving music performance in a music conservatoire, three interventions of which involved neurofeedback (Egner & Gruzelier, 2003). In the first the neurofeedback protocols were used as a package and in the second they were compared in an independent group design as a constructive replication (Lykken, 1968).

It must be understood that neurofeedback protocols are not equivalent, a misunderstanding sometimes made when reviewers of treatment outcomes lump them together and claim erroneously on the basis of a single protocol 'that neurofeedback does not work'. Historically the choice of EEG spectrum protocols has been governed by the implications of an arousal continuum inherent in the EEG-spectrum together with the inverted-U relation between arousal and performance in the delta to high beta (beta2) range, implications which informed our original choices for the music studies.

Three protocols were compared: two faster-wave protocols – sensory-motor rhythm (SMR) and beta1, commonly used to enhance attention (Arns, de Ridder, Strehl, Breteler, & Coenen, 2009), and slow-wave A/T training which involved elevating the theta/alpha EEG ratio in an eyes-closed hypnagogic, reverie or twilight state while remaining awake, originally designed to facilitate creativity (Green & Green, 1977) and found helpful in elevating mood (e.g., Peniston & Kulkosky, 1991; Raymond, Sajid, Parkinson, & Gruzelier, 2005). The faster-wave protocols involved rewarding through points on a computer screen increases above baseline in either beta1 (15–18 Hz) in one protocol, or SMR (12–15 Hz) in the other protocol, without concurrent rises in theta (4–7 Hz) and high beta (22–30 Hz; beta2). With A/T training, participants relaxed with their eyes closed and listened via headphones to auditory feedback in the form of pleasant sounds that were associated with ongoing changes in theta (5–8 Hz) and alpha (8–11 Hz) power.

In the first study the evidence based on the ratings of two experts was correlational. Each musician's learning indices for the A/T, SMR and beta1 protocols, reflecting their success at increasing the various ratios, disclosed that the better the musician was in increasing the theta/alpha ratio the greater was their improvement in music performance whereas there was no relation with the other protocols. Nor was there any impact on music performance from mental skills and aerobic fitness interventions. The correlations with A/T training were found across the three domains of music performance – Musicality/Creativity, Technical Competence and Communication/Presentation, and included virtually all the domain subcategories, including Interpretative Imagination ratings. In the constructive replication with a different cohort of sixty-one students (Egner & Gruzelier, 2003; Gruzelier & Egner, 2004; Gruzelier, Egner, Valentine, & Williamon, 2002) the same A/T protocol was found to be uniquely successful in enhancing performance. There A/T was compared with five other interventions: beta1, SMR, physical exercise, mental skills, or the Alexander technique which is widely used in performing arts conservatoires and

in sport in order to avoid excessive postural tension through a system of kinaesthetic education. In support of the first experiment the evaluations of three assessors disclosed significant improvements in the A/T group, while the other groups showed no changes. Here the A/T learning enhancing effects were replicable, particularly with respect to the parameters of Musicality – Stylistic Accuracy and Interpretative Imagination, together with the Overall Quality of performance. This provided support for the creativity hypothesis outlined in Section 4 (Green & Green, 1977; Gruzelier, 2009) whereas other attempts had been inconclusive (Boynton, 2001; Moore et al., 2000).

The constructive replication and the correlations with learning indices provided important sources of validation. Furthermore by virtue of the fact that the scales mapped directly on to conservatoire assessments (Thompson & Williamon, 2003), the improvements could be seen to be equivalent to more than one class of honours. The outcome was clearly of pedagogic and professional significance, while the constructive replication and correlations with learning indices provided important sources of validation.

1.3. Novice versus elite music performance

Here we set out to examine two of the neurofeedback protocols, A/T and SMR training. The aim was to replicate the differential effects of the two protocols on elite performance, and concurrently investigate whether there would be a preferential advantage for A/T with novice-level performance while SMR's impact on basic cognitive processes might facilitate music performance. By choosing conservatoire instrumentalists who had no singing experience we could examine in the same person advanced versus novice music performance by rating their instrumental playing as well as their singing. This was also important for validity, for by showing a dissociation within an individual, here between the impact on novice versus elite abilities, instead of relying on group differences which might be attributed to chance individual differences, evidence was strengthened by being disclosed within individuals. This dissociation methodology has been important for validation in Neuropsychology in the cause of localisation (Kinsbourne, 1971; Teuber, 1955).

While on the basis of the original results A/T training was a clear choice for inclusion, SMR training was selected for its putative potential in playing a role in improving performance at a novice level. Conceivably the greater demands on fundamental cognitive processes which SMR training has been shown to enhance such as focussed and sustained attention, working memory, and psychomotor skills (Egner & Gruzelier, 2001; Egner, Zech, & Gruzelier, 2004; Ros et al., 2009; Vernon et al., 2003) might impact on novice performance which has greater demands on attention, memory and skill compared with playing compositions once they have been rehearsed. Indeed there is growing evidence (see Gruzelier, 2013a for review) for benefits from SMR training in healthy participants with a range of higher-order processes beyond attention, working memory and visuospatial skills including recognition memory in children (Barnea, Rassis, & Zaidel, 2005), mental rotation (Doppelmayr & Weber, 2011) and creative acting performance in sophomores (Gruzelier, Inoue, Steed, Smart, & Steffert, 2010). Benefits have also extended to relaxation (Gruzelier, 2013a) and have facilitated a more modulated performance (Ros et al., 2009). This evidence supplements the clinical benefits of SMR training for attention in ADHD (Arns et al., 2009; Fuchs, Birbaumer, Lutzenberger, Gruzelier, & Kaiser, 2003; Gevensleben et al., 2009; Linden, Habib, & Radojevic, 1996; Lubar, Swartwood, Swartwood, & O'Donnell, 1995; Rossiter & LaVaque, 1995; Strehl et al., 2006). Furthermore in the conservatoire musicians, studies ancillary to the music performance investigations disclosed that the faster-wave protocols had a favourable impact on attention (Egner & Gruzelier,

2001; Egner, Zech, & Gruzelier, 2004) and in the case of SMR training on aspects of mood (Gruzelier, 2013b). Similarly in an interpretative phenomenological analysis of a subsample of the musicians (Edge & Lancaster, 2004) fast-wave training was described as relaxing; as one musician said it “lets my mind breathe”. But these advantages did not carry-over to the elite music performance as assessed by the experts.

1.4. Creative improvisation

As a further innovation we have added creative music improvisation. This was in order to extend the evidence from the expert ratings of enhanced creativity in performance following A/T training from the two original studies. This might provide a further source of evidence where A/T training may play a role in enhancing creativity. Improvisation, being unprepared, was additionally seen as another facet of novice-level performance where SMR training may also have an impact. Improvisation was examined for both instrumental and vocal performance.

1.5. Summary of aims

In conservatoire instrumentalists with a wider range of ability than in our previous studies and with novice singing ability A/T and SMR training were compared for their ability to improve both advanced and novice-level music performance in the same individuals. Advanced playing was examined as before with rehearsed instrumental performance of pieces of their choice from their current repertoire. Novice performance was examined through their singing ability of well known folk songs. In addition creative improvisation was examined, at a novice level, in both instrumental and singing ability. It was hypothesised, that as before A/T training would facilitate music performance at both advanced and novice levels, whereas SMR training would primarily have an impact on novice performance.

In the cause of validation neurofeedback learning curves were obtained both within sessions and across sessions: see Gruzelier (2013c) for a review of the role of learning indices in the validation of neurofeedback for optimal performance. Relations were also sought between learning and performance through correlational analysis.

2. Methods and design

2.1. Subjects

24 music students (10 females) with a mean age of 26 years (s.d. 9.20) from Trinity College of Music, RCM, Goldsmiths, Guildhall and Kings College volunteered. Taking into account gender and class of instrument they were randomly assigned as they entered the study to one of three experimental groups: A/T ($n=8$), SMR ($n=8$) or non-intervention controls ($n=8$) with one subsequent control dropout. All were instrumentalists having passed grade 8 with a novice singing ability. They included seven pianists, four guitarists, three flautists, two violinists and bassists, a percussionist, oboist, cellist, clarinettist, and trumpeter. According to years of education a wide range of instrumental ability was represented from advanced amateur to postgraduate, wider than in the original studies for they were drawn not only from conservatoires but also from university music departments who do not require elite performance. Frequency distributions of pre-training instrumental musical ability disclosed no group differences and shared the same medians.

2.2. Outcome assessments

2.2.1. Music performance

Advanced music performances consisted of two prepared instrumental pieces of their own choice and played for about 3 min. Novice performances consisted of three performances: (1) Instrumental improvisation, which involved the choice of one theme from a menu including first steps on the moon, a busy market place, a tearful farewell, walking in the forest, etc., for which they were given 2-min to prepare and played for no more than 3-min. (2) A choice of two popular Britten folk songs, with 15-min to prepare and sung for approximately 3-min with a piano accompaniment. (3) Vocal improvisation, consisting of Stripsody (Berberian, 1966) where notation was presented as a cartoon-strip on a stave with time and pitch axes, and with instructions to perform ‘as if by a radio sound man who must provide all the sound effects with his voice.’ This was done without vocal preparation and was sung for 2-min with a different section on retest. The aim was to facilitate highly expressive and imaginative performance, not requiring trained vocal ability. All performances were performed before a small audience.

Evaluation was based on the procedures of Egner and Gruzelier (2003). The assessment of music performance has been formalised in the UK with a mark scheme of the Associated Boards of the Royal Schools of Music (Harvey, 1994). This consists of an Overall Quality mark and three main categories: Technical Competence, Musicality, and Communication. This scheme was adapted with ten further sub-categories defined in consultation with conservatoire professors giving thirteen rating categories which were marked on a 1–10 scale, mapping onto the percentage scales used in the conservatoire. This was adopted here, with the addition of Sense of Performance, for the prepared instrumental performance. For novice performance which being novice was outside conservatoire examination practice scales were created in collaboration with the Trinity music faculty. The scales are shown in Table 1. Further considerations included the assessment of vocal ability including scales such as Breathing with Music in Mind, Pitch, and Clarity of Diction (Technique), the avant garde nature of the vocal improvisation, and the fact that instrumental improvisation was unconventional (Creech et al., 2008). Musicians played before a small audience two contrasting pieces of their choice of up to 5-min duration from their current repertoire on their first study instrument. As before performances were filmed and randomised for pre–post-training order and group. There were two expert raters as for the first study. These were senior conservatoire academics with life-long experience in examining instrumental and vocal abilities in conservatoire students and beyond, and across the full range of instruments. The instrumentalist had a doctorate in Psychology and the vocalist had a distinguished recital career and had sung Stripsody (see musical assessments) on stage. As before the raters were blind to order and group.

In addition as an ancillary project the first 12 participants in the experimental groups, six in each (6 males and 6 females; mean = 23.5 years, s.d. = 3.66), were rated by a lay audience of three people. The audience was asked to rate the singing on a scale of 1–7 for three broad evaluation criteria: Physical Expressiveness, Stage Presence and Confidence. The lay raters were external to the college, did not know the students and were blind to group and order of performance.

2.2.2. Neurofeedback instrumentation

This was carried out with a Neurocybernetics (Encino, CA) EEG Biofeedback System www.eegspectrum.com and ProComp (Thought Technology Ltd.; Montreal, Quebec) www.thoughttechnology.com differential amplifier. Signal was acquire at 256 Hz sampling rate, low pass filtered and with a voltage

Table 1
Performance assessment ratings.

Rating	Instrumental		Vocal	
Domain	Prepared Overall	Improvised Overall	Folk song Overall	Improvised Overall
Technique	Overall Diction Pitch Breathing	Overall Diction Pitch Breathing Tonal Quality	Overall Rhythmic Accuracy Security Tonal Quality	Overall
Musicality	Overall Imagination At-One-with-Voice Stylistic Accuracy Rhythmic Accuracy	Overall Imagination At-One-with-Voice Timing	Overall Imagination Expressive Range	Overall Appropriate Fluency
Communication	Overall Depotment Commitment Confidence Sense Performance	Overall Depotment Commitment Confidence Enjoyment	Overall Depotment Commitment Confidence Sense Performance	Overall Depotment Commitment Confidence

threshold of 60 μ V to exclude muscle artefacts. The resulting low-pass signal was fed to a number of processing streams, which either triggered the provision of rewarding feedback, or inhibit rewards. In each stream, the lowpass signal was bandpass-filtered into various frequency bands using Infinite Impulse Response digital filters. The filter output was fed to an exponentially weighted 30-s moving average filter which produced a short-term average (peak-to-peak). The time constant of the averaging filter was 0.5 s. The peak-to-peak voltage was calculated as the voltage difference between the maximum and minimum points of a signal. The moving average from each stream was conveyed to the trainee, and used to determine whether reward should be provided (EEG Neurofeedback Software version 2005).

For SMR training amplitude measures in the filter-bands beta2 (22–30 Hz), SMR (12–15 Hz) and theta (4–7 Hz) were transformed online into graphical feedback representations together with reward points displayed on screen and gained whenever the trainee enhanced SMR without concurrent rises in theta and beta. They were instructed to let the feedback guide them. The active scalp electrode was placed at Cz, with the reference placed on the left and the ground electrode on the contralateral earlobe respectively. A 2-min eyes open baseline was used to assess the training criteria for feedback reward parameters and adjusted after each of five 170-s training periods with thresholds set at SMR 65%, beta2 15% and theta 20% referred to baseline.

For A/T training participants relaxed with their eyes closed and listened via headphones to auditory feedback representations of ongoing changes in theta (4–7 Hz) and alpha (8–12 Hz) power with respect to an eyes-closed relaxed 2-min baseline with the active electrode at Pz. Sounds of waves gently breaking on the shore were associated with theta and a babbling brook with alpha. When participants' alpha power was higher than theta power the brook sound was heard, and when theta was higher than alpha they heard the sound of waves. Each band also had an amplitude threshold, and supra-threshold bursts of alpha or theta were rewarded by a high- or low-pitched gong sound respectively. These thresholds were set automatically and updated such that alpha and theta amplitudes were over the threshold 55% and 25% respectively. In addition feedback was inhibited by delta (2–4 Hz; 20%) and beta2 (22–30 Hz; 15%). The basic principles of the protocol were explained to the participants and they were instructed to relax deeply, without falling asleep, letting the continuous feedback of the pleasant sounds guide them towards becoming more relaxed and thus hear more of the crashing wave and low-pitched gong sounds. There were 10 training sessions over one to two months.

2.2.3. Statistical analysis

Neurofeedback ratios were examined within sessions (five periods) and between sessions (ten sessions) with repeated measures analysis of variance (ANOVA) with Geisser and Greenhouse correction of degrees of freedom, coupled with regression analyses, hypothesised to take the form of a roughly linear trend as found previously. Music ratings for each of the four pieces were first examined with one way ANOVA and post hoc Tukey tests for any pre-training group differences and if evident led to ANCOVA with baseline as a covariate ($df=2.19$). Otherwise two-way Group (3) $\times$ Performance (2) repeated ANOVAs were applied. In addition planned paired t -tests within groups were conducted unless the data set distributions were not normal when the Wilcoxon test was applied. One-tailed levels of significance were adopted where there were a priori experimental and replication hypotheses as with A/T training, and with SMR training in the case of novice performance. Spearman correlations were used to examine individual differences in learning in relation to ratings; the number of sessions for across-session learning, and the five 3-min periods for within-session learning. Intra-class correlation coefficients were carried out on both the expert and lay raters. One A/T participant was an outlier with a 60% reduction in performance, possibly influenced by a repetitive rocking movement which disaffected the judges, and was excluded from the prepared instrumental performance ratings analyses.

3. Results

3.1. Alpha–theta ratios

Fig. 1 shows in 3D the theta/alpha amplitude ratio plotted for the five 3-min periods within sessions for each of the ten sessions. Within sessions there was a main effect of period ($F(1.39, 9.75)=4.41, p<0.05$), underpinned by an ascending linear trend ($F(1, 7)=5.07, p<0.059$). Across sessions theta/alpha amplitude ratios mostly followed a non-progressive course ($F(9, 63)=1.412, p<0.20$), and as can be seen in Fig. 1 only towards the end of training was there the progressive increase across sessions in ratio amplitude as customarily found and predicted: (sessions 7–10 linear regression, $F(1, 30)=4.07, p<0.05$; segmented regression analysis disclosed a break point between sessions 8 and 9 ($F(3, 396)=8.59, p<0.001$). Furthermore there was a significant correlation between ratio and session number ($r=0.70, p<0.05$).

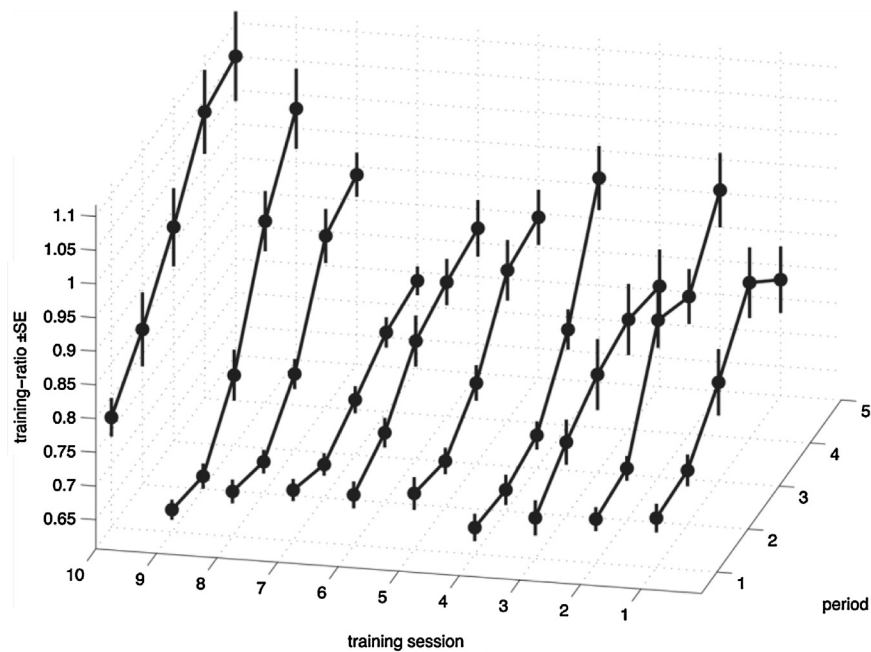


Fig. 1. A three dimensional theta/alpha ratio plot of the ten sessions against the five periods within sessions.

3.2. SMR ratios

In Fig. 2 the SMR amplitude ratio is shown plotted for the five 3-min periods within sessions for each of the ten sessions, as for Fig. 1. Whereas within sessions there was a general propensity for an increase in ratio amplitude this was not significant ($F(1.91, 13.43)=0.39$, ns). As a likely consequence there was no across-session learning ($F(9, 63)=1.28$, ns), and in keeping with the apparent decline shown in the figure there was a decline in the SMR/beta2 ratio ($F=2.86$, $p<0.04$; SMR/theta ratio $F=1.33$, ns) and the correlation between ratio and session number was negative, though nonsignificant ($r=-0.50$, $p<0.13$).

3.3. Music performance expert rater reliability

There was consistency among the judgements with the inter-rater reliabilities as follows: prepared performance ($r=0.76$, $p<0.05$); instrumental improvisation ($r=0.59$, $p<0.05$); folk songs ($r=0.63$, $p<0.05$); vocal improvisation ($r=0.94$, $p<0.05$).

3.4. Advanced instrumental prepared performance

A one-way ANOVA on the pre-assessments disclosed group effects ($df=2.19$) on up to half of the scales: Performance Overall ($F=4.30$, $p<0.03$); Overall Musicality ($F=3.67$, $p<0.05$);

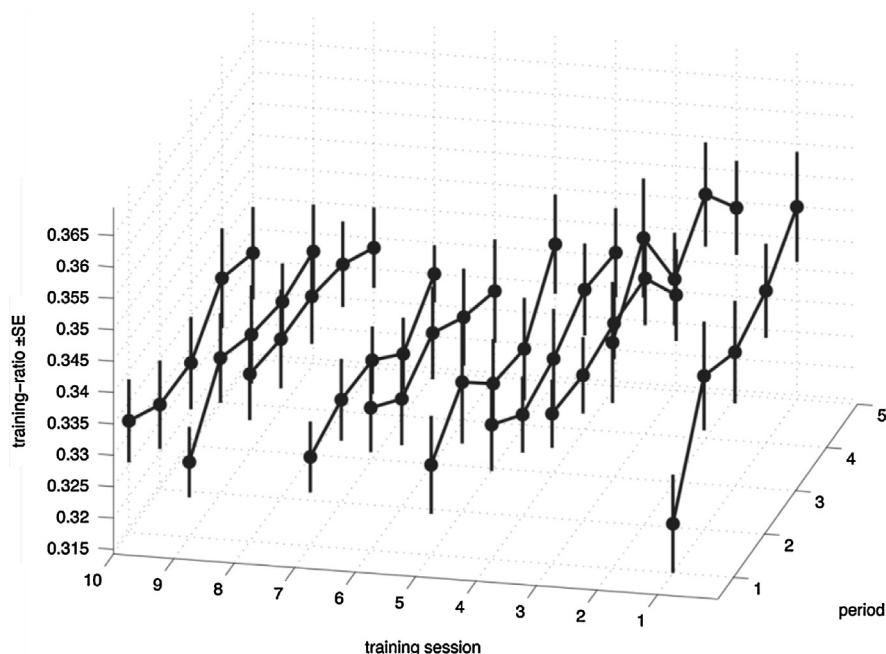


Fig. 2. A three dimensional SMR ratio plot of the ten sessions against the five periods within sessions.

Table 2

Alpha/theta group ($N=7$) t -statistics for prepared instrumental performance together with correlations between learning ratios within sessions and ratings.

Rating	t	p	r	p
Overall Quality	2.89	0.01	0.68	0.05
Technique Overall	1.99	0.05	0.70	0.05
Rhythmic Accuracy	3.23	0.01	0.43	0.09
Security	2.19	0.04	0.75	0.025
Tonal Quality	3.12	0.01	0.45	0.09
Musicality Overall	3.63	0.005	0.89	0.005
Stylistic Accuracy	2.56	0.02	0.89	0.005
Imagination	2.52	0.03	0.76	0.025
Expressive Range	2.79	0.02	0.67	0.05
Communication Overall	2.29	0.03	0.79	0.01
Department	1.88	0.055	0.45	0.09
Commitment	3.17	0.01	0.56	0.06
Confidence	4.87	0.002	0.81	0.025
Sense of Performance	3.14	0.01	0.72	0.03

Stylistic Accuracy ($F=3.78, p<0.04$); Imagination ($F=4.40, p<0.03$); Emotional Commitment ($F=4.39, p<0.03$); Confidence ($F=4.67, p<0.02$); Sense of Performance ($F=4.0, p<0.04$). That the interactions were due to lower ratings at baseline in the alpha/theta group was confirmed by post hoc Tukey tests ($p<0.02$ – 0.04).

Considering the effect of training with ANCOVA using the pre-intervention rating as the co-variate none of the scales disclosed group effects ($F=0.09$ – 2.21 , ns). However, in favour of the alpha/theta group the planned within-group t -tests (Table 2) showed all items were significant, see also Fig. 3 for group changes.

3.5. Correlations with alpha/theta learning

In support of the beneficial effects of training on performance, within-session theta/alpha ratio learning correlated positively with all the fourteen ratings (mean $r=0.683, p<0.05$) and therefore all three domains of music performance assessment, as shown in Table 2. In support of the strongest relation in the two prior

conservatoire studies the highest correlations ($p<0.005$) were with the Musicality domain ratings of Overall Musicality and Stylistic Accuracy. None the less all three domains were represented at the $p<0.025$ level including subcategories of Imagination, Communication Overall, Confidence and Security. At the $p<0.05$ level were Sense of Performance, Expressive Range and Technique Overall, while at the $p<0.10$ level were Emotional Commitment, Department, Rhythmic Accuracy and Tonal Quality.

Between-session learning, which had been slow, showed mostly weak positive correlations, though the rating of Confidence approached significance ($r=0.626, p<0.06$).

Correlations with SMR ratio learning were nonsignificant.

3.6. Novice vocal performance: folk songs

There was only one instance of a group pre-training difference where Overall Vocal Competence was inferior in the control group ($F(2, 20)=3.74, p=0.04$). While ANOVA disclosed no group differences in the effect of training, planned t -tests within groups disclosed the following improvements: A/T group – Emotional Commitment ($t=3.27, p<0.003$), Musicality Overall ($t=2.38, p<0.03$), Imagination ($t=2.39, p<0.03$), Expressive Range ($t=1.94, p<0.05$); SMR group – Pitch (Wilcoxon, $p, 0.02$).

There were no correlations between music performance and neurofeedback learning.

3.7. Novice vocal improvisation

The effects of training on novice vocal improvisation in the three groups are shown in Fig. 4. There were no pre-training differences and ANOVAs showed no group main effects. However, planned comparisons showed advantages in support of a priori hypotheses in the alpha/theta group on the primary creativity rating Imagination ($t=2.47, p<0.04$), and on Communication ratings including Department ($t=2.89, p<0.02$), Emotional Commitment ($t=3.07, p<0.02$), Confidence ($t=2.90, p<0.02$) and Overall Communication

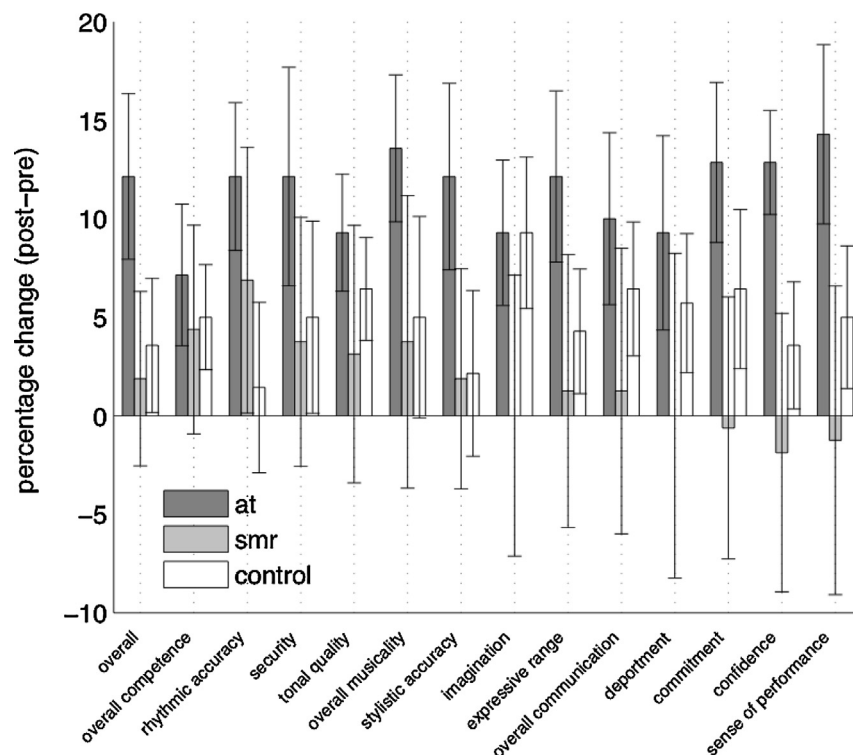


Fig. 3. Group ratings of prepared instrumental performance. * $p<0.05$ two-tailed unrounded.

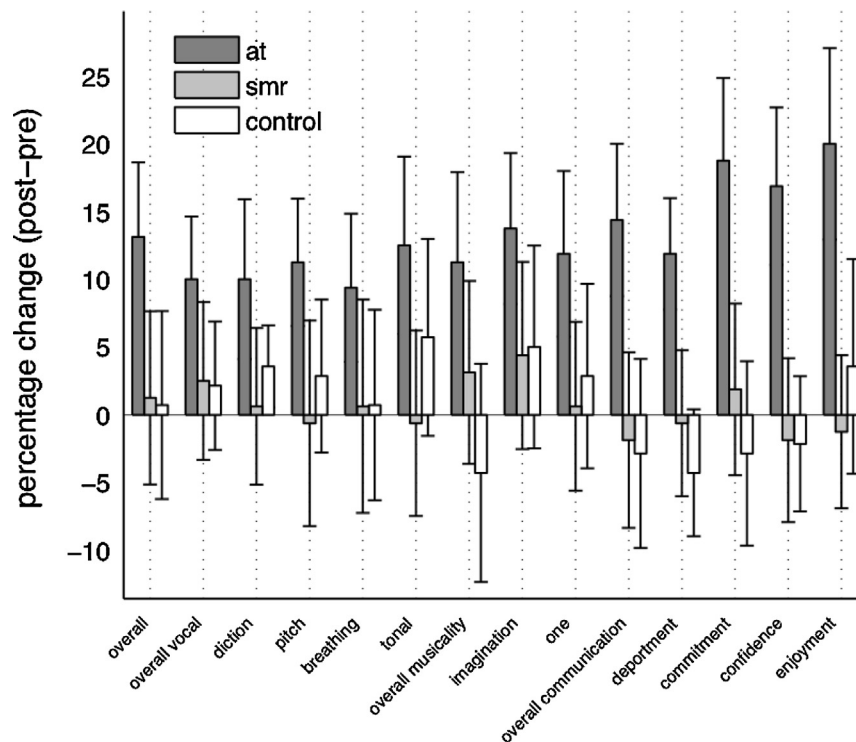


Fig. 4. Group differences in the effect of training on novice vocal improvisation. * $p < 0.05$ two-tailed unrounded.

($t = 2.56$, $p < 0.04$). Being At-One-with-Voice and Musicality Overall were significant at the one-tail level (1.94 , $p < 0.045$). In the Technical domain both Vocal Performance Overall ($t = 2.16$, $p < 0.035$) and Tonal Quality ($t = 1.91$, $p < 0.05$) improved following A/T training.

There were no correlations between music performance and neurofeedback learning.

3.8. Novice instrumental improvisation

On the whole compatible with a novice level performance was rated as low and there were no baseline differences and there was no effect of neurofeedback training. While the group as a whole did not display learning, when individual learning was considered the better the learned elevation of the SMR/theta ratio the higher was the Emotional Commitment ($r = 0.784$, $p < 0.05$), with further correlations at $< 10\%$ level with Performance Overall ($r = 0.672$, $p < 0.09$), Overall Communication ($r = 0.660$, $p < 0.09$), Confidence ($r = 0.684$, $p < 0.08$) and Temporal Sense ($r = 0.688$, $p < 0.08$).

3.9. Lay ratings of novice singing

There was consistency between the lay raters: inter-rater reliability $r = 0.81$; pre-training $r = 0.88$; post-training $r = 0.73$; change between performances $r = 0.77$.

In ANOVA comparing the groups for pre–post-training differences on each of the three ratings, as can be seen in Fig. 5 there were improvements following A/T training on all three ratings, whereas this was not seen following SMR training. This was reflected in significant interactions between Group and Session for Expressiveness ($F(1, 9) = 32.33$, $p < 0.001$), Confidence ($F(1, 9) = 10.32$, $p < 0.002$) and Stage Presence ($F(1, 9) = 16.38$, $p < 0.001$). t -Tests confirmed significant improvements following A/T training all ($p < 0.001$).

The improvement in Confidence correlated with the across session theta/alpha ratio ($r = 0.88$, $p < 0.02$).

4. Discussion

4.1. Methodological considerations

Our first attempts at measurement in the performing arts in order to capture changes in adult music performance as a result of neurofeedback was probably the pioneering controlled endeavour in the field (Egner & Gruzelier, 2003), and one we have extended to dancing and acting, as well as to musical performance with children (Gruzelier, 2012, 2013d). In terms of reliability and validity

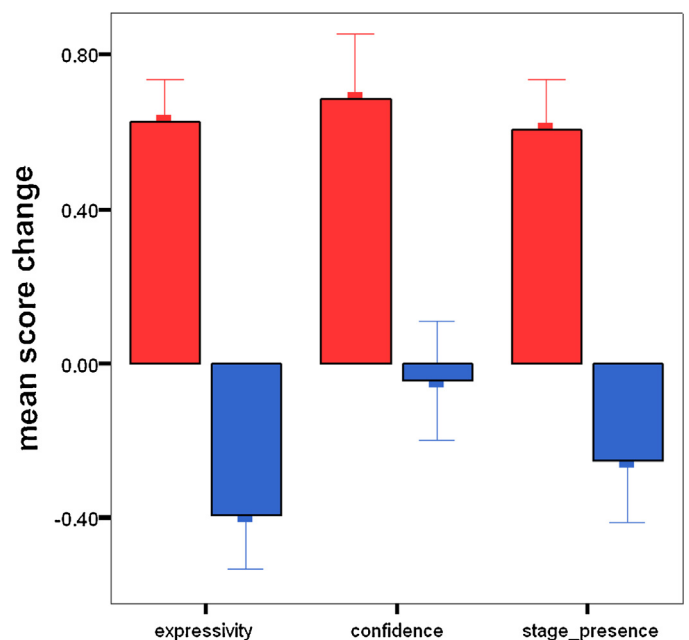


Fig. 5. Lay ratings of music performance showing improvement following A/T training.

the performing arts studies are at a very early stage, the assessment of performance in particular. In an ideal world one would have a large panel of assessors, a luxury that research in its infancy cannot command in terms of practical logistics and expense. The two assessors differed from the original panel of established virtuoso musicians (Egner & Gruzelier, 2003) in that here the two assessors, aside from a music performance history, had lifelong examination experience in music conservatoires. Experience as examiners may have underpinned the higher inter-rater reliabilities found here: prepared performance ($r=0.76$), instrumental improvisation ($r=0.59$), folk songs ($r=0.63$), vocal improvisation ($r=0.94$). These were higher than in the original studies where inter-rater reliability had been similar to previous reports on judging music performance (Campbell, 1970; Thompson, Diamond, & Balkwill, 1998; Wapnick & Ekholm, 1997). In fact on the whole reliabilities were at least as good if not better that has tended to be reported in the performing arts at large. Wapnick and Ekholm, 1997 are among the few to examine expert consensus in solo voice production comparing twenty-one experts who judged nineteen performances covering a wide range of ability. The average reliability was 0.49 with a range of 0.35 to 0.57 for individual judges-to-group reliabilities, and with a repeat reliability for six performances of 0.70. However, composites from four or more judges produced reliabilities <0.80 . Expert voice performance is not strictly relevant to novice voice performance evaluation because in elite performers a host of features such as intrinsic quality come into play (Wapnick & Ekholm, 1997). Earlier Campbell, 1970 had found for solo voice a range of 0.26–0.42 between judges while interestingly a computer simulation of adjudication produced correlations with average judge evaluations ranging between 0.47 and 0.63.

In the case of our lay raters, whereas the ability of the public to judge musical performance may have been questioned, their ratings on the other hand proved to have high consistency amongst themselves for pre-training performances ($r=0.88$), for post-training performances ($r=0.73$), as well as for the change in performance ($r=0.77$). In terms of validity there was both agreement with the expert judges as well as a positive correlation between the theta/alpha ratio learning and the Confidence rating. The strong impact on lay raters of the outcome of A/T training is worthy of further investigation.

In our larger six-group study (Egner & Gruzelier, 2003, study II) there were sufficient musicians to investigate co-linearity between the three judges (Thompson & Williamon, 2003). This had disclosed, despite the traditional conservatoire segmentation into three music domains, high co-linearity across the three domains. While this might have led to across the board advantages following A/T training, this was not the case for the advantages were restricted to the Musicality/Creativity domain. We are under no illusion that co-linearity operates too in the present study and underpins the correlations in Table 2, but we also note that the strongest correlation was with the Musicality/Creativity category, and that alpha/theta training has demonstrated a maximal influence on the more psychological aspects of performance as seen in both Musicality/Creativity and Communication/Presentation.

In our opinion it would be premature at this early stage of investigation and collaboration with experts in the Arts and Humanities to attempt statistical reductionism in exploring relations between brain oscillations and artistic performance. Once larger data sets are achieved this would be an interesting endeavour, mindful from the outset, in what is necessarily cross disciplinary research, not to disaffect our collaborators; the Humanities have little interest in the scientific reductionism where for example the richness of human personality has been condensed to extraversion and neuroticism. As discussed elsewhere (Gruzelier, 2013d) there is little agreement so far among music experts as to how to go about the issue of condensation or indeed whether to do so, provoking remarks

including: ‘such a rich diversity cannot be reduced to a single dimension’, ‘lost in a single mark’ and ‘the fudge of adding a category of overall only makes things worse’ (McPherson & Thompson, 1998).

Although the present ten-session study involved one hundred and sixty training sessions aside from pre- and post-training assessments, there were recruitment limitations compromising group sizes and leading to a modest sized sample. Neurofeedback performance enhancement investigations are labour intensive compared with single-session methodological studies (see Gruzelier, 2013a, 2013c for review).

There were also limitations in neurofeedback learning. Across-session A/T learning was slow, as has been found before, in that case when training was done in groups (Gruzelier, Thompson, Redding, Brandt, & Steffert, 2013). Here this was despite the ability to reach a state of hypnagogia in the short sessions in the midst of participants’ busy daily schedules as evinced by theta/alpha ratio learning within sessions. This facility was in keeping with our original studies (Egner & Gruzelier, 2003; Egner et al., 2002) and has been found in other contexts (Gruzelier, Thompson, et al., 2013), including school children scheduled to leave school classes one at a time for neurofeedback sessions (Gruzelier, Foks, et al., 2013). However, typically across-session learning curves have been found to be less regular, thought to be due to fluctuations in day-by-day levels of arousal (Gruzelier, 2013d). Another factor that may have contributed here was auto-thresholding. In other studies we have adopted a shaping approach which provides a closer monitoring of behaviour, facilitating learning (Egner & Gruzelier, 2003; Raymond, Sajid, et al., 2005; Raymond, Varney, & Gruzelier, 2005).

We were also unable to demonstrate SMR ratio learning at a group level in contrast to other investigations (Egner & Gruzelier, 2003; Hoedlmoser et al., 2008; Ros et al., 2009; Vernon et al., 2003). However, when individual differences were taken into account, learning ratios and improvements in novice musical performance were found to correlate positively, allowing for the inference that when considered in the absence of a group result both non-learners and learners were present. While non-learning had not impacted on our other reports, non-learning has been reported by others (Escolano, Aguilar, & Minguez, 2011; Hanslmayer, Sauseng, Doppelmayr, Schabus, & Klimesch, 2006); here small group sizes prevented an analysis of subgroup comparisons.

The investigation had a number of strengths.

- (i) It extended our previous research on music performance, supplementing prepared instrumental performance with three other music assessments providing four assessments in all.
- (ii) The impact of the two neurofeedback protocols was examined on novice as well as on advanced performance.
- (iii) The comparison between advanced and novice performance was done within the same musicians eliminating between subject confounds.
- (iv) Improvisation was included as a creative exercise in order to extend the implications of the impact of neurofeedback on creative performance (Sawyer, 2000).
- (v) By including lay raters in addition to expert raters the transparency of potential improvements was elucidated.

4.2. Training outcome

The main aim was to explore the differential impact of A/T and SMR neurofeedback on advanced versus novice musical performance. To reiterate, we had hypothesised that A/T training would benefit music performance as before, and that SMR training would benefit novice performance, achieving gains when more lower-order cognitive processes such as attention, working memory and psychomotor skills were required in performance when

performance was at a novice level. While there were advantages supportive of the hypothesised benefits of SMR training for novice music performance, as have been found in our complimentary studies (Gruzelier, Foks, et al., 2013; Gruzelier, Hirst, et al., 2013; and see also Gruzelier et al., 2010), here SMR ratio learning was less successful overall when compared with the A/T learning and SMR learning in the other studies. The evidence of a preferential effect on novice performance from SMR training will be considered, mindful of this reservation and the supportive evidence of the value of SMR training from the complimentary studies. But first will be outlined the stronger evidence base in favour of A/T training which benefited both advanced and novice music performance.

4.2.1. Replication of A/T training and music performance

4.2.1.1. *Advanced performance.* The findings of Egner and Gruzelier (2003) of the enhancement of elite music performance by alpha/theta training were replicated in musicians ranging more widely in ability. The experts rated gains in all three domains of evaluation – Musicality/Creativity, Communication and Technique, as was found in the first of the two original studies.

Positive correlations were found between within-session learning indices and music performance improvements in support of causation. These also applied to all the three music domains, attesting to the validity of the impact of neurofeedback on music performance, supporting the correlational evidence from the first of the two original studies of a role for the theta/alpha ratio in mediating the improvements in music performance. Furthermore the strongest correlations were with the Musicality domain in keeping with the overall finding from the original report. Between-session correlations were in the same positive direction though they were not significant.

4.2.1.2. *Novice performance.* A/T training facilitated the rating of Interpretative Imagination in vocal improvisation, the primary creativity rating and manifested here in a creative exercise – improvisation. Alpha/theta training also enhanced Communication and Technique, providing parallels with the gains for advanced performance. Furthermore in the singing of the folk songs alpha/theta training improved Emotional Commitment, and this rating by the experts was shared with the lay judges whose ratings of Confidence, Stage Presence and Expressiveness were highly in favour of the A/T intervention. There was no impact on instrumental improvisation; the fact that the latter was considered by the expert raters to be at such a low level may have contributed to this. With one exception there were no correlations between the performance of the novice-level pieces and A/T learning indices. The exception was the positive relation between Confidence in the singing of the popular folk songs as rated by the lay audience and the across session theta/alpha learning index.

4.2.1.3. *Theta and creative performance.* All in all there is clear evidence that A/T training improved prepared performance across all domains but especially with Musicality/Creativity. This extended to novice musical abilities in the domains of both Musicality/Creativity and Communication, as was found with the music teacher ratings of 11-year old children (Gruzelier, Foks, et al., 2013). Aside from its impact on creativity in music performance, learning to increase the theta/alpha ratio has enhanced dance performance in competitive university ballroom and Latin dancers (Raymond, Varney, et al., 2005), improving both artistry and technique as judged by expert raters who judge national competitions, and incidentally the dancers went on win the UK university dance championship. A/T training has also improved cognitive expressive creativity (Gruzelier, Thompson, et al., 2013). The correlational evidence between improvement in creative performance and learning ratios supports a causative role for neurofeedback.

The development of the A/T protocol arose from the anecdotal evidence of creative insights arising in the hypnagogic reverie. 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 when compared with faster rhythms the slower rhythms in the EEG spectrum carry information over long-distance, distributed connections (Varela, Lachaux, Rodriguez, & Martinerie, 2001; 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 making of the creative associations (Gruzelier, 2009).

While creativity tends to be thought of and measured in cognitive terms, outcome in the performing arts also includes affective and motivational variables which find expression in performance. This was seen in the rating categories of Communication which have included Commitment, Confidence, Emotional Expression and Enjoyment, which in turn had an impact on Deportment and Stage Presence. Artistic performance requires the integration and expression of past learning and expertise, the imbuing of this in performance, and communicating this to the audience with artistry. Theta activity has been associated with both cognitive and affective processes; theta is 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. Theta therefore is an ideal candidate for an integrative role and, coupled with theta's widely distributed neural connections, giving rise to neural and psychological integration (Gruzelier, 2009). In putting their life experience into their creative performance, performing artists must draw on whole brain connections. Even at a more fundamental level of novice psychomotor skills in instrumental performance, theta's role in sensory-motor integration (Kay, 2005) is apposite.

4.2.1.4. *SMR ratios and music performance.* There were three outcomes following SMR training in support of the experimental aims. Firstly, following SMR neurofeedback there was improvement in the domain of Technique as found with the rating of Pitch in novice vocal improvisation. This was in support of the *a priori* prediction that the basic features of performance reflected in Technique would be the most likely domain to disclose the greater benefits of SMR training. It was, however, the only significant improvement in ratings following SMR learning.

Secondly, there was correlational evidence with SMR/theta ratio learning in support of the hypotheses. While there had not been evidence of learning for the group as a whole, those participants with the better learning showed the greater impact on music performance. Positive correlations between the SMR/theta ratio across-session learning were found with instrumental improvisation. Relevant to the hypotheses were the low ratings that were assigned to instrumental improvisation by the experts, attesting to the students' difficulty in improvising with their chosen instrument, and a likely call on lower-order processes. The strongest association was in the Communication domain, in particular Emotional Commitment. Tendencies at the two-tail level of significance were found with Communication Overall, Confidence, Deportment, as well as with Temporal Sense, and by virtue of the impact on both the domains of Communication and Technique there was a correlation with Performance Overall. While these relations were slender they were in line with the experimental hypothesis that SMR training might benefit novice levels of performance.

Thirdly, improvements following SMR training were not seen with advanced music performance, and this was the case originally (Egner & Gruzelier, 2003). This gives some credence to the

differential protocol impact on novice versus elite performance, as do the a priori predictions of a differential influence hypothesised to arise because the novice level would present with the greater challenge, calling more on the basic cognitive processes shown to benefit from SMR training in healthy participants. There is a growing range of evidence for this in healthy participants (Barnea et al., 2005; Doppelmayr & Weber, 2011; Egner & Gruzelier, 2001; Egner, Zech, & Gruzelier, 2004; Gruzelier, 2013a; Gruzelier et al., 2010; Gruzelier, Foks, et al., 2013; Gruzelier, Hirst, et al., 2013; Ros et al., 2009; Vernon et al., 2003), combined with the clinical findings of gains in children and adults whose attention was compromised by ADHD (meta analysis Arns et al., 2009). As Sterman (2000) has reviewed, the impact of SMR ratio training is underpinned by ventrobasal thalamocortical afferent discharge to sensorimotor cortex with the consequence of decreased motor and muscle tone and inhibition of movement. As a likely consequence improved cognition would follow reduced motor interference in attention (Barnea et al., 2005; Doppelmayr & Weber, 2011; Egner & Gruzelier, 2004).

4.2.1.5. SMR and creativity. The present study has supported a role for benefits from SMR training for music performance in the domains of Technique and Communication and though the benefits did not extend to the Musicality/Creativity domain, there has been other evidence for an impact on creativity in music performance.

Firstly, in children the effects on improvised instrumental or vocal music performance (the children could choose either) were stronger than those here, and in fact the teachers' Creativity ratings of SMR training were on a par with the benefits from A/T training (Gruzelier, Foks, et al., 2013). This favourable impression extended to Communication ratings as they did here. Technique was not considered appropriate by the teacher assessors for the evaluation of improvisation in eleven year olds.

Secondly, in a subsequent university study with the same design and methodology (Gruzelier, Hirst, et al., 2013), and where SMR ratio learning was better established, the novice singing of the folk song disclosed significant main effects with ratings of Interpretative Imagination and Expressive Range in the Musicality/Creativity domain, and with a significant positive correlation between Vocal Competence and the SMR/theta ratio. A significant improvement was also found with Musicality in the stripsody vocal improvisation.

Thirdly, to date creative acting performance in sophomores has provided the strongest evidence for an impact of SMR ratio training on creativity (Gruzelier et al., 2010). With actors there were two methodological innovations especially devised for the training context which may have played a part in enhancing efficacy. To begin with we reasoned that the previous advantage for elite performance with A/T training over SMR training may have lain with the real-world connections made through imaginative visualisation in the eyes-closed A/T reverie (see phenomenological reports in Gruzelier, 2009). To facilitate this connection a theatrical performing space as seen from the stage, was rendered on the training screen for one group of actors, while for another the same image was seen through 3D glasses in the University College London's ReaCTor room, surrounding the actor with the auditorium image. Additionally, the learned control of brain rhythms was interfaced with the neurofeedback cues which were specifically chosen to signify the actors' control of aspects of the performing space with the ensuing mastery hypothesised to transfer to the control of the acting performance. Given that the sense of control theoretically contributes to the subjective experience of flow, actor self-ratings with a Flow scale were also obtained (Jackson & Eklund, 2004). SMR training did result in demonstrable benefits for acting performance, while the immersive 3D properties were superior to the 2D properties in both the speed of learning and in the ratings of the experts. This was especially true of Creative Imagination in acting.

Furthermore the experience of flow in performance was superior in the actors trained with neurofeedback than in untrained controls. Importantly enhancement in the actors' subjective flow state correlated comprehensively with the experts' ratings of all domains of acting performance. Here the ecological validity of the neurofeedback training context was successful in facilitating the transfer of the SMR learning process to the stage. A more immersive and ecologically relevant training context for SMR learning is worthy of further investigation.

4.2.2. Learning, validation and replication

Finally, returning to the consideration of validation with which we began, it is salutary that the preferential advantage for A/T training on music performance in this study had a counterpart in the positive correlations between within-session learning and music performance enhancement. Within-session learning can be seen to be a more robust indicator of learning dynamics as it pools data from across the multiple sessions providing a more reliable estimate of EEG changes due to its smoothing of sampling error variance; here pooled from ten sessions compared with the five 3-min periods within-sessions. The validation of A/T learning and its impact on playing music were affirmed by the positive correlations on all three music domains: Musicality/Creativity, Technique and Communication. These correlations attest to a causative role for neurofeedback in performance enhancement, as has been found in other optimal performance domains (Gruzelier, 2013a, 2013d). Though the clear emphasis with SMR ratio training has been on novice performance, as has been indicated an impact on elite performance should not be ruled out (Edge & Lancaster, 2004; Gruzelier, 2013b, 2010). Facilitating an immersion in the acting context during training may make all the difference for realising the impact of SMR training on elite performance; putatively achieved through the visualisation of empowerment with A/T training.

This millennium the evidence base for the promise of neurofeedback in the clinical, educational and optimal performance domains has been increasing exponentially, and now with extension to the methodologies of fMRI (Ruiz, Sitaram, & Birbaumer, 2013), near infrared tomography (NIRS, Kober et al., 2013), and transdoppler sonography (Duschek, Schuepbach, Doll, Werner, & Reyes del Paso, 2011) which hold exceptional promise. This promise is stimulating studies of underlying mechanisms (Ros, Munneke, Ruge, Gruzelier, & Rothwell, 2010, 2012). The ethos here is that a more comprehensive consideration of the nature of neurofeedback learning (see Gruzelier, 2013c), which has been spearheaded by controlled studies in the optimal performance field in the quest of validation, will provide further insights into the efficacy and practice of neurofeedback training for optimising function; it is noted that documentation of learning is virtually lacking in clinical studies. This approach focussing more on methodological concerns will lead to a more informed application of neurofeedback protocols and understanding of their outcome.

Acknowledgements

The research was supported by a grant from the National Endowment for Science, Technology and Arts (NESTA). We thank the participants and accompanists and support of EEG Spectrum and Thought Technology.

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