Immediate effects of Alpha/theta and Sensory-Motor Rhythm feedback on music performance

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John Gruzelier
Goldsmiths, University of London

AUTHOR QUERY FORM

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Highlights

International Journal of Psychophysiology xxx (2014) xxx – xxx

Immediate effects of alpha/theta and sensory-motor rhythm feedback on music performance

J.H. Gruzelier [a,*], L. Hirst [b], P. Holmes [b], J. Leach [a]

[a] Department of Psychology, Goldsmiths, University of London, Lewisham Way, New Cross, London SE14 6NW, UK
[b] Trinity/Laban Conservatoire of Music and Dance, London, UK

- A replication comparing A/T and SMR feedback with novice music performance
- Post-training performance was staged in the last session rather than later.
- Benefits followed SMR training in Creativity, Communication, Technique.
- A/T likely was compromised given proximity of stage1 sleep induction.

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J.H. Gruzelier [a,*], L. Hirst [b], P. Holmes [b], J. Leach [a]

[a] Department of Psychology, Goldsmiths, University of London, Lewisham Way, New Cross, London SE14 6NW, UK
[b] Trinity/Laban Conservatoire of Music and Dance, London, UK

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ABSTRACT

This is one of a series of investigations comparing two EEG-neurofeedback protocols – Alpha/theta (A/T) and Sensory-Motor Rhythm (SMR) – for performance enhancement in the Arts, here with the focus on music. The original report (Egner and Gruzelier, 2003) established a beneficial outcome for elite conservatoire musicians following A/T training in two investigations. Subsequently this A/T advantage was replicated for both advanced instrumental and novice singing abilities, including improvisation, while SMR training benefited novice performance only (Gruzelier, Holmes et al., 2014). Here we report a replication of the latter study in university instrumentalists who as before were novice singers with one design change — post-training performances were conducted within the tenth final session instead of on a subsequent occasion. As before expert judges rated the domains of Creativity/Musicality, Communication/Presentation and Technique. The proximity to training of the music performances within the last session likely compromised gains from A/T learning, but perhaps reinforced the impact of SMR training efficacy. In support of validation there was evidence of strong within- and across-session A/T learning and positive linear trends for across-session SMR/theta and SMR/beta-2 ratio learning. In support of mediation learning correlated with music performance. The A/T outcome was markedly discrepant from previous studies and should dispel any impression that the hypnogogic state itself is transferred to the performance context. The effects of SMR ratio training are consistent with an impact on lower-order abilities required in novice performance such as sustained attention and memory, and benefiting all three domains of music assessment.

1. Introduction

The present report is one in a series exploring the effect of EEG-neurofeedback in the performing arts (Gruzelier, 2012, 2013a) including creative music (Egner and Gruzelier, 2003; Gruzelier et al., 2014a, b), dance (Raymond et al., 2005a; Gruzelier et al., 2013 and this issue), and acting performances (Gruzelier et al., 2010). With neurofeedback, putatively through instrumental conditioning principles of reinforcement, an index of a physiological parameter is fed back to the participant in real time so that they may learn self-regulation. The ability dates back to the 1960s (Kamiya, 1969; Sterman et al., 1969). Through convention 'neurofeedback' is the term applied when the feedback involves the central nervous system via methods of EEG (Gruzelier, 2013a,b,c), fMRI (Ruiz et al., 2014), MEG (Florin et al., in press), NIRS (Kober et al., 2013) and transcranial Doppler sonography (Duschek et al., 2011), while an earlier term 'biofeedback' has become reserved for the feedback of peripheral nervous system measures.

1.1. Enhancing creativity in elite musicians

In the performing arts gains of pedagogic significance followed neurofeedback in music, dance and acting conservatoires (Gruzelier, 2013a). Here the focus is on novice musical abilities, in contrast to the earlier evidence of benefits for elite music performance (Egner and Gruzelier, 2003; Gruzelier and Egner, 2004). In two intervention studies at the Royal College of Music (RCM), London, we discovered that training slower rhythms in the EEG spectrum with the aim of raising theta (4–7 Hz) amplitude over alpha (8–12 Hz) amplitude in an eyes closed, quasi twilight or hypnogogic state, termed alpha/theta (A/T) training, was associated with professionally significant improvements in music performance as assessed by expert judges. Elevation of theta over alpha index stage 1 sleep (Niedermeyer, 1999), and hypnogogia has been associated with the production of creative insights in ubiquitous cultural spheres (Koestler, 1966). In the first of the studies benefits occurred across all the three domains of music performance that had been agreed on by the Associated Boards of the Royal Schools of Music (Harvey, 1994). The domains were Musicality/Creativity, Technical Competence and Communication/Presentation. Performance enhancement was found to be especially the case with the domain of Musicality/Creativity, which included the sub-category of Interpretative

* Corresponding author at: Goldsmiths, University of London, Lewisham Way, New Cross, London SE14 6NW, UK. Tel.: +44 20 7 9197635; fax: +44 20 7 919 7873.
E-mail address: j.gruzelier@gold.ac.uk (J.H. Gruzelier).

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Imagination. While the musicians experienced all three of the EEG protocols, so that conceivably benefits may have accrued from a cumulative effect, correlations between the various neurofeedback protocol learning indices and the various rating domains and domain subcategories disclosed significant correlations only with the Alpha/Theta protocol. All three were compared in separate groups in the second investigation with a new student cohort. This time benefits aside from improving Performance Overall enhanced the Musicality/Creativity domain only. In neither study were gains in music performance found with the faster wave Sensory Motor Rhythm (SMR 12–14 Hz) or Beta-1 (15–18 Hz) protocols, nor incidentally with other interventions such as mental skills training, aerobic fitness or the Alexander technique (Gruzelier et al., 2002).

1.2. A/T: beyond anxiety reduction

When psychological factors come to mind in the world of the performing arts the primary association is the reduction of anxiety in its various appearances, including stage fright. Importantly, whereas all the interventions reduced pre-performance anxiety, only alpha/theta (A/T) training advanced music performance. The preferential gains following A/T training supported associations between the hypnogogic or twilight state and creative production (Koestler, 1964; Green and Green, 1977; and see Gruzelier, 2009). Hence the benefits for performance went well beyond anxiety reduction, yet at the same time A/T training has been found helpful in elevating mood (e.g., Peniston and Kulkosky, 1991; Raymond et al., 2005b).

1.3. Novice musical abilities and protocols

Here the focus was on novice music abilities which was the aim of three investigations funded by the National Endowment for Science, Technology and Arts (NESTA, UK). This was the second of two adult investigations (see also Gruzelier et al., 2014a), and there was a further study of eleven year old school children (Gruzelier et al., 2014b). In all three studies two protocols were compared. The A/T protocol involves participants relaxing with their eyes closed listening via headphones to auditory feedback in the form of pleasant sounds that were contingent on changes in theta (5–8 Hz) and alpha (8–11 Hz) power, with the aim of raising the amplitude of theta above alpha indexing hypnogogia and stage1 sleep, and putatively a state that favours creativity (Gruzelier, 2009, and see the Discussion). This was contrasted with a faster-wave protocol which involved elevating the sensory-motor rhythm (SMR; 12–15 Hz) which aims to induce a relaxed and efficient sustained attention. Elevation of the SMR is rewarded via points on a computer screen without concurrent rises in theta (4–7 Hz) and high beta (22–30 Hz; beta2), termed inhibits, and involves, as does the A/T protocol, frequency band ratio training.

1.4. SMR ratio training and behavioural outcomes

While SMR training had not benefitted elite music performance (Egner and Gruzelier, 2003), it was hypothesised that it would assist novice performance for the following reasons. In novice performance there are greater demands on attention, memory and technical skill when compared with playing compositions once they have been rehearsed in advanced performance. Ancillary studies in the conservatoire musicians had disclosed that the faster-wave protocols had a favourable impact on sustained attention (Egner and Gruzelier, 2001, 2004), and in the case of SMR training this extended to Calmness self-ratings (Gruzelier, 2013d). Similarly in an interpretative phenomenological analysis of a subsample of the musicians (Edge and Lancaster, 2004) fast-wave training was described as relaxing; as one musician said it “lets my mind breathe”. But these advantages had not carried over to the elite music performance as assessed by the experts.

There is in fact growing evidence (see Gruzelier, 2013a,b,c for review) of benefits from SMR training in healthy participants with a range of higher-order processes beyond attention, including working memory (Vernon et al., 2003), recognition memory in children (Barnea et al., 2005), visuo-motor skills (Ros et al., 2009), mental rotation (Doppelmayr and Weber, 2011), and creative acting in sophomores (Gruzelier et al., 2010). This evidence supplements the clinical benefits of SMR training for sustained attention in ADHD (e.g., Lubar et al., 1995; Rossiter and LaVaque, 1995; Linden et al., 1996; Fuchs et al., 2003; Gevensleben et al., 2009).

1.5. Creative improvisation

As in the first novice singing study (Gruzelier et al., 2014a) we included creative music improvisation in addition to the singing of popular folk songs. This would provide a further source of evidence where A/T training may play a role in enhancing creativity, for by definition improvisation is a creative exercise (Sawyer, 2000). Improvisation, being unprepared, was additionally seen as another facet of novice-level performance upon which SMR training may also have an impact.

1.6. Replication and aims

We set out to replicate the gains found in the first adult novice singing study (Gruzelier et al., 2014a) where the beneficial effects of A/T training were found to extend in two ways. Firstly, in judging vocal improvisation there was an increase in Interpretative Imagination, the primary creativity rating. Secondly, in the singing of the folk song Emotional Commitment improved, and this was endorsed by lay ratings of Confidence, Stage Presence and Expressiveness. Accordingly improvement was seen in the domains of Musicality/Creativity and Communication/Presentation. With regard to SMR training, despite some limitations in feedback learning for the group as a whole, in support of the experimental aims there was improvement in the domain of Technique through higher ratings of Pitch accuracy in vocal improvisation. Stronger evidence in support of the value of both protocols was found in an ancillary music study with children (Gruzelier et al., 2014b).

Summarising the aims of the study, the effects of a slow versus a fast wave neurofeedback protocol were examined on the novice singing ability of instrumentalists drawn from a university Music department. As has been customary in the majority of our neurofeedback studies, in order to validate the occurrence of neurofeedback learning, 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. Evidence of mediation through correlational analysis was also sought between learning and performance. Singing was examined both with well known folk songs and a creative improvisation exercise. While it was hypothesised that as before A/T training would facilitate music performance, and that SMR training would also benefit musical performance at the novice level, compliance constraints due to university pressures led to the post-training music pieces being performed at the end of the last training session. It was therefore likely that, should A/T training have been successful, the effects of hypnogogia and stage I sleep would not have worn off, and would likely compromise rather than facilitate music performance. On the other hand the additional load on low-order processes such as sustained attention, working memory and technique might provide a more rigorous test of the hypothesised benefits from SMR ratio training on lower-level processes in performance.

2. Methods

2.1. Participants & design

19 undergraduate music students volunteered from the Music department at Goldsmiths, University of London who were instrumentalists

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with novice singing ability: 12 males and 7 females with a mean age of 24 ± 10.30, with no sex differences between the groups. The study met with the approval of the College Ethics committee; participants were paid £20 on completion. As the musicians were not drawn from a performance conservatoire there was a wider range of ability than in the RCM studies, from advanced amateur to postgraduate. Participants were randomly assigned to one of three experimental groups, A/T (n = 7), SMR (n = 6) and no-training controls (n = 6). Due to attrition in post-training assessments the numbers in each group were reduced by one.

2.2. Music performances

Singing assessments were as before: i) a choice of two popular Britten folk songs, with 15-min to prepare and sing for approximately 3-min with a piano accompaniment; ii) vocal improvisation with the aim of facilitating highly expressive and imaginative performance not requiring trained vocal ability. This piece was 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.' It was done without vocal preparation and was sung for 2-min with a different section on retest.

Instrumental performance was also examined as before involving both a prepared piece of their choice, which was regarded as at an advanced level, and improvised performance on their chosen instrument from a menu of options, regarded as at a novice level because improvisation is not typically part of music performance curriculum in the UK (Creech et al., 2008). However, due to the unavailability of one of the expert judges for instrumental performance the assessment of the instrumental results based on a single expert judge are presented for exploratory purposes only.

2.3. Assessors

The judges were the same two experts as in the previous study (Gruzelier et al., 2014a). Both were senior music conservatoire academics with life-long experience of examining in conservatoire students and beyond. One was an instrumentalist with a doctorate in Psychology, while the vocalist had a distinguished recital career and had sung Stripsody on stage. As before they were blind to order and group. Reliabilities for the novice song and the creative improvisation were respectively $r = 0.63$ ($p < 0.001$) and $r = 0.71$ ($p < 0.001$), compared with $r = 0.63$ ($p < 0.005$) and $r = 0.94$ ($p < 0.005$) previously.

2.4. Rating scales

Evaluation was based on the procedures of Egner and Gruzelier (2003) as before, and adapted to include vocal assessment. As mentioned above the assessment of music performance in the UK has been formalised with a mark scheme of the Associated Boards of the Royal Schools of Music (Harvey, 1994), consisting of an overall quality mark and three main categories: Technical Competence, Musicality/Creativity, and Communication/Presentation. 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. Additional considerations for the assessment of vocal ability included ratings of Breathing with Music in Mind, Pitch, and Clarity of Diction (Technique). In addition, as novice performance was outside conservatoire examination practice, scales were created in collaboration with the Trinity music faculty. These are tabulated in the report of the first novice study (Gruzelier et al., 2014a). As before performances were filmed and randomised for pre- post-training order and group.

2.5. Neurofeedback instrumentation

Recording involved a Neurocybernetics (Encino, CA) EEG Biofeedback System www.eegspectrum.com and ProComp (Thought Technology Ltd; Montreal, Quebec) www.thoughttechnology.com differential amplifier. Signal was acquired at a 256 Hz sampling rate and was low pass filtered. It had a voltage threshold of 60 µvolts to exclude muscle artefacts. The resulting lowpass 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 peak-to-peak average. The time constant of the averaging filter was 0.5 s. The peak-to-peak voltage was calculated as the 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 (EEGer Neurofeedback Software version 2005).

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 the sound of waves was heard. 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, as conventionally done (Penniston) so as to initiate the transition to stage 1 sleep which begins with the production of alpha before theta. In addition feedback was inhibited by delta (2–4 Hz; 20%) and beta-2 (22–30 Hz; 15%) to avoid movement artefacts and psychological correlates of sleep (delta) and over-arousal (beta-2). 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 so as to hear more of the crashing waves and low-pitched gong sounds.

For SMR training the amplitude measures in the filter-bands beta-2 (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 participant enhanced SMR without concurrent rises in theta and beta. 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%, beta-2 15% and theta 20% referred to baseline. Reward frequencies were chosen in both protocols so as not to satiate or conversely frustrate the participant. They were instructed to let the feedback guide them.

Participants understood that they were in a music performance enhancement programme and had been given an introductory lecture by JG. The control subjects were offered neurofeedback at the end of the study. There were 10 training sessions with on average eight days elapsing between sessions with the one experimenter, JL.

2.6. Statistical analysis

Neurofeedback ratios were examined both 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

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ANOVA; there were no pre-training differences. Two-way Group (3) × Performance (2) repeated ANOVAs were accompanied by planned paired *t*-tests within groups unless the data set distributions were not normal when the Wilcoxon test was applied. Correlations were used to examine individual differences in feedback learning in relation to ratings. Intra-class correlation coefficients were carried out with the two judges.

3. Results

3.1. Neurofeedback

3.1.1. Alpha/theta training

Within sessions. Changes in the five 3-minute periods in the theta/alpha ratio and respective band values are shown in Fig. 1A,B. Evidence of effective learning was provided which was corroborated by the statistical analyses with Geisser and Greenhouse corrections. In a repeated measures one-way ANOVA there was a significant effect of period ($F(1.206, 7.24) = 7.08$, $p < 0.001$, underpinned by a significant ascending linear trend ($F(1,6) = 9.65$, $p < 0.02$).

The increase in the ratio was underpinned by descending trends depicting the conventional initial reduction in power with neurofeedback training in general (Gruzelier, 2013c), particularly apparent when participants close their eyes with the aim of entering a hypnogogic state. Corresponding effects were seen with both theta amplitudes ($F(1, 8) = 6.38$, $p < 0.03$; descending linear trend ($F(1,6) = 7.72$, $p < 0.03$), and alpha amplitudes ($F(1, 8 = 6.72$, $p < 0.03$; descending linear trend ($F(1,7) = 7.69$, $p < 0.03$). As shown in Fig. 1B, training was highly effective, with the cross-over of theta above alpha amplitude occurring midway through the session.

Across-sessions. Theta/alpha ratios are shown in Fig. 2. Repeated measures one-way ANOVA confirmed significant differences between sessions ($F(9, 54) = 2.30$, $p < 0.03$), with an ascending linear trend in the across-sessions t/a ratio at a marginal level of significance ($F(1, 6) = 4.33$, $p < 0.08$). This was elucidated by a subsequent ANOVA on session × period relationships which disclosed that the within-session differences in the elevation of t/a ratio became more marked as sessions progressed ($F(36,216) = 1.52$, $p < 0.04$) (see Fig. 3).

In summary, when compared with the literature on A/T learning functions (Gruzelier, 2013a,c) there was strong evidence of both within- and across-session enhancement of the theta/alpha ratio.

3.1.2. SMR ratio training

Within sessions. The within-session dynamics of the individual band amplitudes are shown in Fig. 4. With both the SMR and theta amplitudes, following an initial increase from period one to two, there was

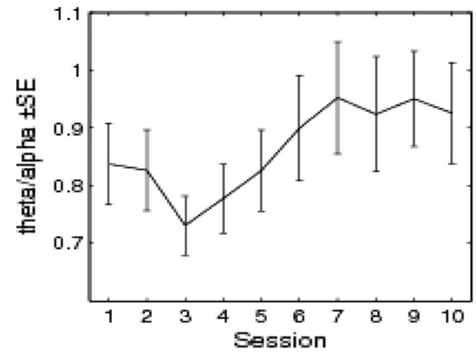

Fig. 2. Across-session theta/alpha ratios.

a progressive reduction. However, the reduction in power was greater for the theta than the SMR band leading to a significant effect for the SMR/theta ratio period ($F(4, 20) = 4.09$, $p < 0.01$) with an ascending linear trend in the ratio ($F(1, 5) = 7.51$, $p < 0.04$). In contrast beta-2 power continued to increase across periods declining only in the last period, with the consequence that beta power was not progressively inhibited, and there was no learned reduction in the SMR/beta-2 ratio for sessions as a whole ($F = 0.121$, ns).

Across sessions. The results are shown in Fig. 5A,B. Learning developed with the SMR/theta ratio over the first five sessions, followed by a falloff, with learning regained in sessions nine and ten (Fig. 5A). Similar irregularity was seen with the SMR/beta-2 ratio (Fig. 5B). In line with such irregularity a repeated measures ANOVA disclosed no significant session effect for the SMR/theta ratio ($F(9, 45) = 0.57$, ns) or SMR/beta-2 ratio ($F(9, 45) = 1.83$, ns). Nevertheless there was a significant rising linear trend in the SMR/theta ratio ($F(1, 7) = 7.66$, $p < 0.03$), and a significant cubic polynomial trend in the SMR/beta-2 ratio ($F(1, 5) = 4.12$, $p < 0.04$). In looking at individual band amplitudes with repeated measures one-way ANOVAs there were significant linear trends for SMR amplitude ($F(1, 5) = 8.63$), $p < 0.03$), and theta amplitude ($F(1, 5) = 14.20$, $p < 0.01$), and cubic, 4th and 6th order trends for beta-2.

In summary, within-session learning disclosed evidence of increments in the SMR amplitude relative to inhibiting an increase in theta, while inhibition of beta-2 was not successful. There was a rising linear trend in the SMR/theta ratio set against irregular shifts in the power spectrum across sessions. There was evidence of initial learning for the SMR/beta2 ratio, with a substantive increase with session two which was sustained despite shifts in power.

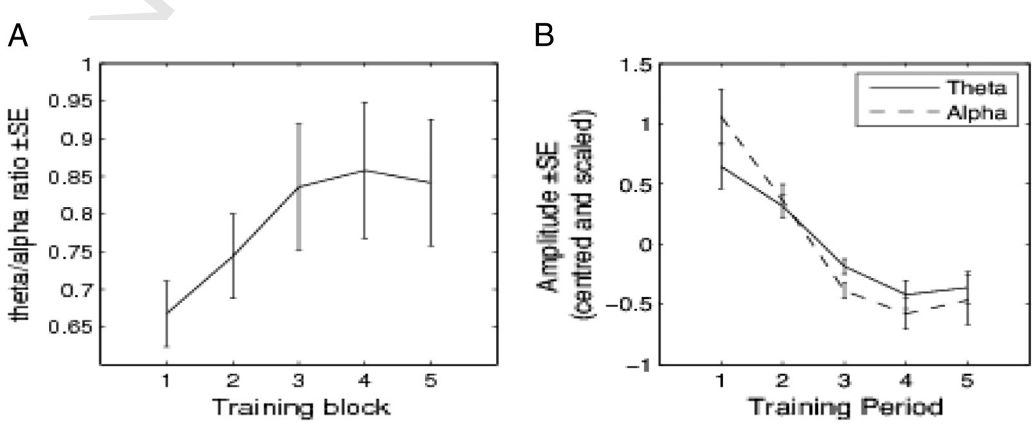

Fig. 1. Within-session theta/alpha training parameters. (A) Theta/alpha ratios, (B) theta and alpha amplitudes.

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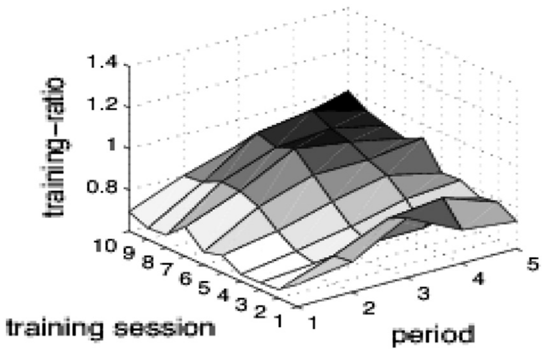

Fig. 3. Theta/alpha ratios depicted as a session × period interaction.

3.2. Novice vocal performance

3.2.1. Folk song

The inter-rater reliability was r = 0.63 (p < 0.001). In a one-way ANOVA there were no group differences at baseline. Pre-post changes are shown in Fig. 6. As can be seen the SMR group showed mostly improvements, as exemplified by the mean increase in the Overall Performance rating. Group comparisons disclosed a significant effect for Expressive Range (F(2,15) 3.98, p < 0.04), which planned paired *t*-tests confirmed was due to a significant improvements in the SMR group (t (5) 2.74, p < 0.04). This was along with an improvement in Interpretative Imagination (t(6) 3.64, p < 0.01). Both effects were in the Musicality domain. In contrast there was mostly a decline in performance for the A/T and control groups, reaching significance for Overall Vocal Competence t(6) 3.24, (p < 0.02) and Stylistic Accuracy (t(5) 2.70, p < 0.04) for the two groups respectively.

Correlations between the changes in the music ratings and within-session neurofeedback learning disclosed a positive relation between the SMR/theta ratio average within-session elevation and Vocal Competence (r = 0.97, p < 0.01), including the last session immediately before the music performance (r = 0.97, p < 0.01). In contrast the greater the increase in the theta/alpha ratio in the last session before performance, and hence the successful learned attainment of the training goal of hypnogogia, the worse was both Communication (r = −0.97, p < 0.01) and Musicality (r = −0.88, p < 0.04).

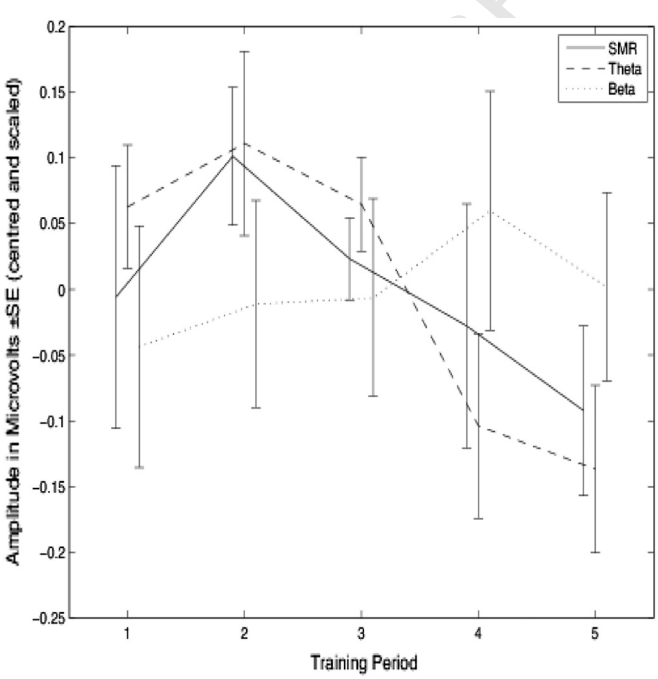

Fig. 4. Within session changes in SMR, theta and beta-2 ampliitudes.

3.2.2. Vocal improvisation

The inter-rater reliability was r = 0.71 (p < 0.001). A one-way ANOVA on the pre-training ratings disclosed no differences between groups at baseline. Pre-post changes are shown in Fig. 7. As can be seen from the figure, changes in the A/T group were all negative except for Pitch, whereas changes for the SMR and control group were mostly positive, though all groups were similarly poor for Vocal Competence Overall. Within group planned comparisons with paired *t*-tests showed that following SMR training there was an improvement in Musicality Overall (t(5) 3.16, p < 0.03), and following A/T training a suggestive decline in Confidence (t(6) 1.92, p < 0.10).

Turning to correlations, there was a suggestive positive correlation between the SMR/theta ratio across sessions (r = 0.81, p < 0.10), whereas within-session SMR/beta-2 learning correlated negatively with Interpretative Imagination (r = −0.91, p < 0.04). Notwithstanding the decline in performance following A/T training, there was a positive correlation between mean within-session A/T learning and Oneness with Voice (r = 0.91, p < 0.02).

3.2.3. Instrumental performance

Analyses were carried out on an exploratory basis given the single assessor. Instrumental performance disclosed no differences between the groups at baseline, nor with ANOVA were there any changes on repeat performance between or within groups. However, through paired *t*-test comparisons instrumental improvisation disclosed that following A/T training there were lower ratings of Deportment (t(6) 2.52, p < 0.05), Emotional Commitment (t(6) 2.50, p < 0.05), and Confidence (t(6) 2.52, p < 0.05), with mean changes of −0.86, −0.71 and −0.90 respectively, in line with a deleterious effect on performance.

Regarding correlations with neurofeedback learning there was only one in the form of a suggestive positive relation between the SMR/beta-2 ratio across sessions and Deportment (r = 0.81, p < 0.10).

4. Discussion

4.1. Validation of feedback learning

Concerning the essential question of validity, beginning with within-session learning, set against reductions in SMR and theta power the SMR/theta ratio increased whereas the beta-2 amplitude was not inhibited (Fig. 4). The later was a likely reflection of increased arousal accompanying the exertion of effort in learning, an interpretation which would benefit from administering subjective mood scales within sessions (see Gruzelier, 2013d). However, learning carried over from one session to another for both SMR/theta and SMT/beta-2 ratios which increased across sessions despite irregular shifts in power (Fig. 5A,B). It has not been uncommon for across-session learning to occur in the absence of within-session learning, and vice versa (Gruzelier, 2013c).

On the other hand evidence of A/T learning was strong. Not only was the theta over alpha amplitude cross-over achieved within sessions quickly, between the sixth and ninth minutes on average (Fig. 1B), but across sessions there was a positively accelerated curve from the third session, reaching an asymptote by the seventh session (Fig. 2). In comparison with previous studies these A/T results combined to represent successful training (Fig. 3), more swiftly achieved within sessions than is customary, and once training had got underway, evidence of cumulative learning across sessions following a smoother course than is customary (Gruzelier, 2013c). These advantages may reflect the greater susceptibility of the students to hypnogogia and stage I sleep as the university term and workload with impending exams impacted on them;

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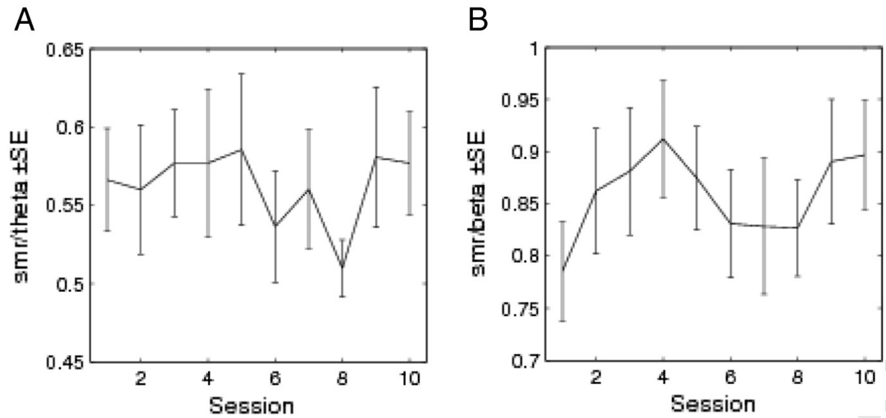

Fig. 5. Across-session training ratios and amplitudes for SMR/theta (A) and SMR/beta-2 (B) ratios.

the previous novice ability study had been largely conducted following exams and in the summer vacation. This inference finds support in a falloff in the nonintervention control group in folk song singing (Fig. 6), which was significant in the case of their Stylistic Accuracy ratings.

4.2. Reliability of music assessments

Considering the reliability of the rating assessment, the same raters participated who were used in the previous study (Gruzelier et al., 2014a), and the same novice vocal performances were involved. Reliabilities for novice song and improvisation were respectively $r = 0.63$ ($p < 0.001$) and $r = 0.71$ ($p < 0.001$), compared with $r = 0.63$ ($p \le 0.005$) and $r = 0.94$ ($p \le 0.005$) previously. Only one of the assessors was available to rate the instrumental performances. The reliabilities for the previous assessments of instrumental performance were for prepared performance ($r = 0.76$, $p < 0.005$) and for instrumental improvisation ($r = 0.59$, $p < .005$). The two judges had lifelong examination experience in music conservatoires and in the case of the vocalist a distinguished music performance history. Their experience in examining may have underpinned the higher inter-rater reliabilities found both here and in the previous novice ability study (Gruzelier et al., 2014a) than was found in the original RCM studies. There the assessors had been virtuoso musicians; notwithstanding inter-rater reliability had been as good or better than previous reports on judging music performance (Campbell, 1970; Thompson et al., 1998; Wapnick and Ekholm, 1997). The higher coefficients found here and in the previous novice study attests to the reliability of the judgements in these constructive replication studies.

4.3. Serendipity informs

Academic pressures played a part in the unplanned- at-the-outset scheduling of the post-training music performances immediately following and within the tenth training session. While this compromised the experimental aim of replicating the advantages of A/T training on creative performance, it did have an important serendipitous outcome. A misconception has sometimes been voiced about the positive outcome of A/T in the original two RCM studies (Egner and Gruzelier, 2003) and the other two novice studies (Gruzelier et al.,

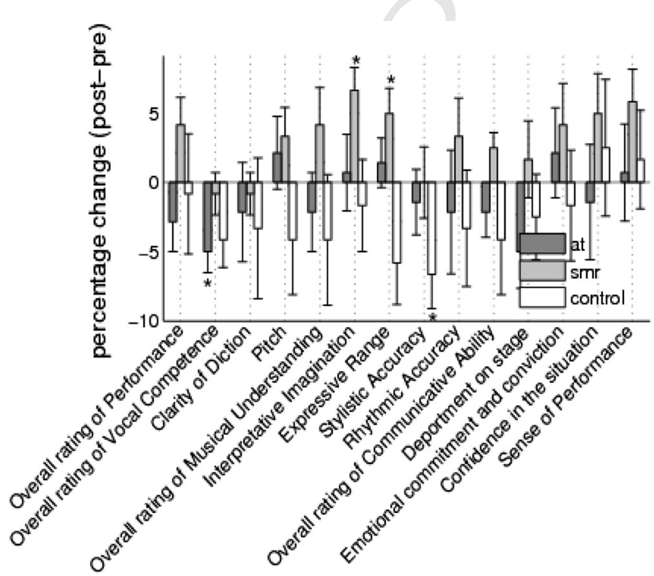

Fig. 6. Pre-post changes in folk song ratings; error bars show ± se. *p < 0.05.

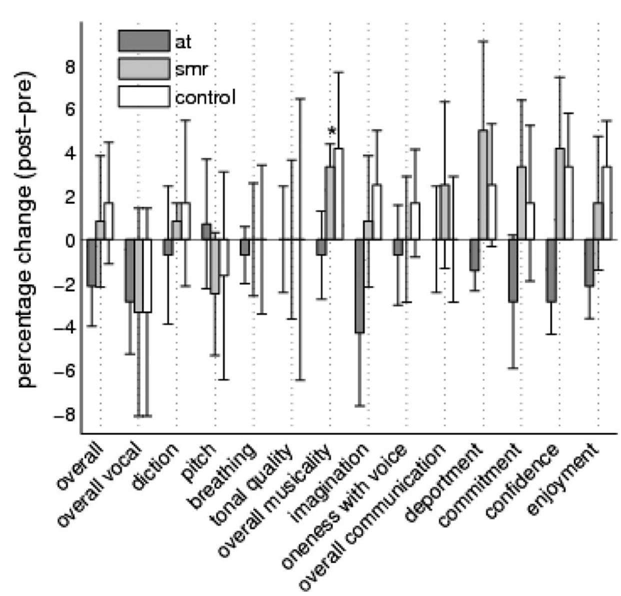

Fig. 7. Pre-post changes in improvisation ratings; error bars show ± se. *p < 0.05.

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2014a, 2014b), namely that somehow music performance following training is conducted in an alpha/theta state? This of course is impossible as hypnogogia represents stage I sleep (Niedermeyer, 1999). Here the results show that even half an hour or so afterwards, music performance is deleteriously affected. This was the case both with the singing of the well known folk songs and with the more challenging-for-novices, avant-garde Stripsody improvisation.

4.4. A/T training and the music performance

Following A/T training the Overall Vocal Competence ratings with the folk song were significantly impaired, while correlations showed that the greater the achievement of stage I sleep, as indexed by the higher the theta/alpha ratio in the final session and before performing the folk song, the worse were their Communication and their Musicality. In combination all three domains – Vocal Technical Competence, Communication and Musicality – were deleteriously affected in the singing of the popular folk song. Regarding vocal improvisation, with one exception ratings declined, approaching a suggestive effect with Confidence. Finally, keeping in mind vis a vis reliability that there was only a single assessor, the instrumental performance of prepared pieces with a chosen instrument, which was at a relatively more advanced level though not on par with the conservatoire studies, disclosed a falloff in the Communication/Presentation domain as shown with Deportment, Emotional Commitment and Confidence, which was consistent with their singing performance.

Notwithstanding, there was one result that bucked the trend, namely the combined assessors' rating of Oneness with Voice. This withstood the compromise of reduced arousal for the change in Oneness with Voice with improvisation, which on average showed a slight decline (Fig. 7), was positively correlated with within-session theta/alpha ratio learning. It is noteworthy that this was only found when learning was averaged across all ten sessions, and as this was not found in the last session, it is suggestive of the more enduring outcome of A/T learning. As such it was in support of A/T training enhancing music performance despite the contextual vissitude.

4.5. SMR ratio training and the music performance

Importantly, given that the SMR ratio training group faced the same contingencies of having to perform shortly after their last training session, it is noteworthy that SMR ratio training had positive effects on performance with the folk song, with vocal improvisation, and to some extent with prepared instrumental performance. This outcome is in support of hypothesised benefits for the lower-level processes required for novice performance, such as sustained attention, working memory and psychomotor skills (for review see Gruzelier, 2013a,b). It is also in keeping with the outcome of the complimentary novice ability studies in this series (Gruzelier et al., 2014a, b) where the post-training sessions were arranged on another occasion. However fortuitously, the fact that the performing requirements were more taxing – for neurofeedback sessions including SMR ratio training have been shown to elicit higher Tiredness ratings (Gruzelier, 2013d) – the performance context serendipitously provided a more robust test of the putatively affirmative gains for sustained attention following SMR ratio training. Benefits for sustained attention have been found in musicians (Egner and Gruzelier, 2001, 2004), trainee eye-surgeons (Ros et al., 2009) and other healthy participants (Vernon et al., 2003), as well as their underpinning the efficacy of the SMR ratio protocol with ADHD (for a meta analysis see Arns et al., 2009). Therefore SMR benefits for optimising performance were both immediate and longer term in contrast to A/T training which were predominantly longer term.

Here the gains following SMR ratio training were as follows: 1) Within group improvements with the folk song were found in the Musicality/Creativity domain with the subcategories of Interpretative Imagination and Expressive Range. 2) Importantly in terms of reliability this gain in Musicality/Creativity was also found with the creative improvisation exercise where the Musicality/Creativity total rating score improved. 3) Correlations were affirmative supporting a mediational relation with feedback learning as found between the SMR/theta ratio mean within-session learning and Vocal Competence, and to include learning in the last session. 4) The across-session SMR/beta-2 ratio showed a suggestive relation with Deportment in instrumental playing. Therefore all the three domains of music assessment were facilitated, with the stronger impact found on Musicality/Creativity.

4.6. Companion novice studies

How do the two protocol results compare with the companion novice studies in adults and children, and with the original RCM music studies? Due to compromise in the timing of the music performances the only valid comparison can be made with SMR ratio learning. As already mentioned there was no impact of either SMR or beta-1 ratio training on elite music performance in the two original studies (Egner and Gruzelier, 2003), and this was a consistent result which was replicated in the comparative novice/advanced study (Gruzelier et al., 2014a). Nor was an impact found on the prepared performances of children (Gruzelier et al., 2014b). In terms of the novice abilities of adult musicians in the earlier study, Vocal Technique gained through an improvement in Pitch ratings, while the SMR/theta ratio across-session learning correlated with Temporal Sense, an aspect of technique. However, the stronger correlational evidence was with ratio learning across sessions, and to include instrumental improvisation, notably through Emotional Commitment and also Communication Overall, Confidence and Deportment. The impact on both communication and technical domains contributed to a correlation with the total Performance Overall rating. In children, while the SMR/beta-2 ratio was unchanged there was effective SMR/theta ratio learning. This benefitted Communication and Creativity in either vocal or instrumental improvisation, chosen according to the children's preference.

While the benefits of A/T training on music performance were compromised here, they have been found to be more extensive and powerful statistically than those found with SMR learning. These have been reviewed elsewhere (Gruzelier, 2013a). In brief, with regard to novice musical ability in adults (Gruzelier et al., 2014a) they have included:

i) Vocal improvisation improvements in the primary creativity rating Interpretative Imagination as well as in Musicality Overall, while a more general impact was found on Communication/Presentation including Deportment, Emotional Commitment, Confidence and At-One with Voice scales. In the Technical domain both Vocal Performance Overall and Tonal Quality improved.
ii) The novice singing of folk songs also disclosed stronger benefits in the Musicality/Creativity category, and an impact on Emotional Commitment.
iii) An evaluation of the folk songs on scales of Confidence, Stage Presence and Expressiveness by a panel of three lay people, demonstrated highly significant advantages following A/T compared with SMR learning, along with an affirmative correlation between A/T learning across sessions and Confidence.
iv) In children there was an impact on Technique and Communication in prepared performance, and Communication and Creativity in improvised performance (Gruzelier et al., 2014b).
v) In elite rehearsed performance (Egner and Gruzelier, 2003), as outlined in the Introduction there were replicable improvements in the Musicality/Creativity domain, and correlations with A/T learning across all domains in the first study, a broad influence that was replicated in our subsequent investigations.
vi) Finally a positive impact has also been found with competitive ballroom dancing (Raymond et al., 2005a).

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4.7. A/T and creative performance in general

To reiterate, the impact of A/T training on enhancing creativity in performance is not achieved by transferring hypnogogia to the performance space as shown by the compromise when music performance is required immediately after emerging from stage1 sleep. Referring then to performances that follow a course of training with a gap between training and performance, it has been theorised that during training, through instructions of empowerment, and in the case of the performing arts studies through specific or unspecific instructions of gains in artistic performance, associations are made between performance and the theta rhythm which acts as a carrier throughout the brain (Gruzelier, 2009). It has been shown in animals and man that the slower rhythms traverse the brain in widely distributed networks in contrast to the more focal reach of the faster rhythms (von Stein and Sarntheim, 2000; Varela et al., 2001). Consistent with this, a study of creative thinking confirmed anatomically an increase of widely distributed coherence of EEG oscillations, especially amongst the low end of the spectrum (Petsche, 1996). Theta power and low alpha power have been shown to dominate the EEG spectrum in the state of meditative bliss in experienced meditators, along with increased theta coherence between distal electrodes in the topographical EEG, leading to a more connected brain (Aftanas and Golocheikine, 2001). The type of creativity traditionally associated with hypnogogia involves making new cognitive associations between items already stored in long-term memory, which are likely facilitated by the integration of distributed neural networks allowing for creative associations to be made. 'Accordingly, …. it is hypothesised that creative cognitive associations arise from integration through the co-activation by slow wave activity of distributed neural networks, for which the relaxed hypnagogic state is especially conducive.' (Gruzelier, 2009).

The performing artist must instil in performance their expertise based on life-long learning in emotional, technical and cognitive spheres, as seen in the performance ratings here. Artistic performance requires the integration and expression of past learning and expertise, imbuing this in performance, and communicating this to the audience with artistry. The breadth of impact of A/T training on performance comes as no surprise in view of the extensive theta correlates in animal and human studies. These include theta as a carrier of mnemonic processes which have pervasive influences on attention, effort and sensory-motor regulation, and with a role in the mediation of emotion, motivation, effort and arousal circuits in limbic and cortico-reticular systems. Theta circuitry allows for the underpinning of the cognitive, emotional, and in the case of instrumental playing psychomotor skills and sensory-motor integration (Kay, 2005), and then their coordination in performance.

4.8. SMR and creative novice performance in general

Finally, turning to SMR ratio training, in the novice performer this was found to have an impact on Creativity and Communication ratings. This had not been seen in the elite performer. This benefit for novice performance was also found in children (Gruzelier et al., 2014a,b), and in the previous adult conservatoire cohort (Gruzelier et al., 2014a). Perhaps the strongest evidence for an impact of SMR ratio training on creative performance was demonstrated in American sophomore acting students who were on semester placement in London (Gruzelier et al., 2010). That study incorporated two methodological innovations. Firstly, to facilitate transfer of learning to acting performance a theatrical space as seen by the actor from the stage was rendered on the training screen, and this was compared with training in a virtual environment where the same image surrounded the actor as seen through 3D glasses. Secondly, the learned control of EEG frequency bands was contingent on the control of aspects of the performing space including moderating the lighting and reducing intrusive audience noise. It was hypothesised that this would not only facilitate transfer to the real world of performing, but the mastery in controlling the performing context would facilitate control in acting, accompanied by the subjective experience of flow. SMR training did in fact 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 those trained with neurofeedback than in untrained controls, while the subjective flow state correlated comprehensively with the experts' ratings in all domains of acting performance. In sum the transfer of the SMR learning process to the stage was facilitated by the ecological validity of the neurofeedback training context.

4.9. Study limitations

The study had limitations, foremost the small sample size. Recruitment proved more difficult within a university Music department than in a music performance conservatoire, possibly because in the latter there is a greater allocation of performance practice time, allowing more opportunities for participation with neurofeedback training. The intersession interval with a mean of eight days was greater than desirable in our experience, for in the trainee ophthalmic surgeon study superior surgical skill outcome was found in those with a four day interval between training than in those where the interval was greater than a week in the second half of the eight-session course of training (Ros et al., 2009). Then the unavailability of the second assessor for the instrumental performances was unfortunate, but did not compromise the main thrust of the study which involved novice singing. It did prevent our using dissociation methodology to contrast novice with advanced playing within individuals as we had done in the previous study (Gruzelier et al., 2014a). Here the gains were not as extensive as in the ancillary studies, and their importance is best appreciated in the context of our performing arts series as a whole (Gruzelier, 2013a).

4.10. Conclusion

In conclusion, controlled optimal performance neurofeedback programmes, particularly in the performing arts, are a character building exercise requiring commitment ideally by the collaborating arts institution and essentially by the participants to undertake the course of training and the pre- and post-assessment sessions, as well as the performances; we have had several studies fall by the wayside despite an especially enthusiastic reception at outset. Then there are the considerable logistics for the experimenter in coordinating lab sessions, expert raters, accompanists, and so on.

Though there is a new generation of over fifty controlled studies that attest to the validity of EEG-neurofeedback for optimising performance in healthy subjects, including the elderly (for review see Gruzelier, 2013a,b), as many questions as answers have emerged from these pioneering endeavours (Gruzelier, 2013c). Setting aside from their promise for performing arts education, there are clear clinical advantages accruing slowly from controlled trials (e.g., Arns et al., 2014). There is potential for self-reliance in the elderly and resilience in soldiers, to mention some other obvious applications. Such endeavours when coupled with methodological advances and the promise of perfecting protocols through multimodal brain imaging methods, are all factors that should encourage substantive future investment in the potential of neurofeedback.

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