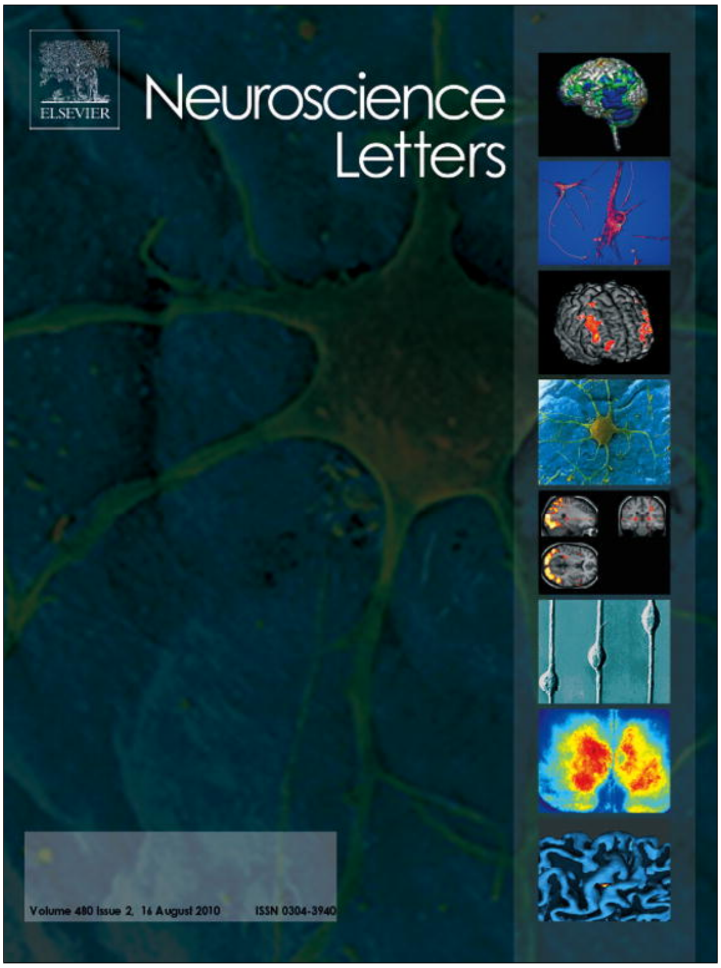
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Acting performance and flow state enhanced with sensory-motor rhythm neurofeedback comparing ecologically valid immersive VR and training screen scenarios

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ABSTRACT

Actors were trained in sensory-motor rhythm (SMR) neurofeedback interfaced with a computer rendition of a theatre auditorium. Enhancement of SMR led to changes in the lighting while inhibition of theta and high beta led to a reduction in intrusive audience noise. Participants were randomised to a virtual reality (VR) representation in a ReaCTor, with surrounding image projection seen through glasses, or to a 2D computer screen, which is the conventional neurofeedback medium. In addition there was a no-training comparison group. Acting performance was evaluated by three experts from both filmed, studio monologues and Hamlet excerpts on the stage of Shakespeare's Globe Theatre. Neurofeedback learning reached an asymptote earlier as did identification of the required mental state following training in the ReaCTor training compared with the computer screen, though groups reached the same asymptote. These advantages were paralleled by higher ratings of acting performance overall, well-rounded performance, and especially the creativity subscale including imaginative expression, conviction and characterisation. On the Flow State scales both neurofeedback groups scored higher than the no-training controls on self-ratings of sense of control, confidence and feeling at-one. This is the first demonstration of enhancement of artistic performance with eyes-open neurofeedback training, previously demonstrated only with eyes-closed slow-wave training. Efficacy is attributed to psychological engagement through the ecologically relevant learning context of the acting-space, putatively allowing transfer to the real world otherwise achieved with slow-wave training through imaginative visualisation. The immersive VR technology was more successful than a 2D rendition.

Neurofeedback training has enhanced attention, memory, microsurgical skills, intelligence and well-being in healthy participants [6,8,24,12,21,14,18], and has benefited patients with epilepsy [20], attention deficit hyperactivity disorder [1], autism [17], and insomnia [2]. Musical creativity has been enhanced in elite performers [7], results extended to competitive ballroom dancing [19]. Here we extend the performing arts application to actors with virtual reality (VR) technology.

In two music studies we had compared three neurofeedback paradigms, along side mental-skills training, aerobics and the Alexander technique [7]. Of the three neurofeedback paradigms the successful one involved slow-wave training rewarding theta and alpha activity with pleasant sounds presented while relaxed with eyes closed aiming to induce hypnogogia. Hypnogogia is a state which historically has been regarded as productive of creative ideas [15,9]. Slow-wave training produced professionally significant improvements, including creativity, interpretative imagination, musicality and stylistic accuracy, according to ratings of pre- and post-training videos by music experts who were blind to order and training group. Comparable benefits were not found following training in mental skills, aerobic fitness, the Alexander technique, SMR or beta1 neurofeedback, nor in one study with a standby control group.

The latter two neurofeedback paradigms required the participant to view a computer screen with the aim of elevating either the sensory-motor rhythm (SMR, 12–14 Hz) or low beta activity (beta15–21 Hz), without increases in higher and lower activity than the targeted band; amplitudes were represented schematically together with a reward count. The fast-wave procedures, especially SMR training, though not of musical benefit were beneficial in assisting sustained attention through inducing a relaxed attentional style in the same participants [6,8], and in subsequent studies improved verbal working-memory [24], and produced an efficient and modulated performance in the perceptual-motor skills

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of trainee eye surgeons engaged in a simulated cataract operation [21]. Furthermore an interpretative phenomenological analysis of interviews supported the value of fast-wave training [5]. “It lets my mind breathe” reported one musician, however, this impression did not carry over to ratings of music performance.

Here in an exploratory study we re-examined the impact of SMR training on creative acting performance, drawing on theory from VR presence research [22], which studies the illusion of being in a place, facilitated by surrounding immersive displays such as CAVE-like [3] and head-mounted displays. Actors interacted with a computerised rendering of a theatre through neurofeedback. Given SMR neurofeedback benefits for sustained attention, mental relaxation, working-memory and skilled psychomotor performance [10], we proposed that SMR training should hold promise for advancing artistic performance. Conceivably the proven advantage of slow-wave training in musicians had lain with the greater artistic engagement during training through their imagination in their eyes-closed hypnogogic state [9, p. 105].

Engagement in the acting during training was enabled by a computer rendition of a theatre auditorium as seen by the performer from the stage. Changes in the auditorium were contingent on learning to control brain oscillations: elevating SMR activity was contingent on changes in the lighting level in the auditorium, while learning to decrease the activity that was slower and faster than SMR was contingent on a reduction in intrusive audience noise. Two levels of immersion were examined. In one the auditorium was rendered on a computer screen—the conventional medium for faster wave training. This was compared with a more immersive medium, a CAVE™-like system [3] called the ReaCTor, where the seated participant was surrounded by the same theatre auditorium projected seamlessly on the surrounding walls. We hypothesised that neurofeedback learning in the technically more immersive virtual environment would be the more beneficial of the two media for artistic performance.

Notwithstanding, because both conditions provided ecological validity for the training context, both media were hypothesised to facilitate the transfer of learned performance to the actors' real world performance; but more so with the 3D ReaCTor context than the 2D computer screen. Efficacy was measured in four ways: superior across session EEG learning curves, faster learning of the required mental state according to subjective rating, superior creative performance according to expert ratings of performance, and higher subjective ratings of Flow in performance. Flow is a psychological construct [4] describing that optimal experience when the performer is totally absorbed in performing and for them everything comes together. It arose out of consideration of the creative process, subsequently extended to the work domain, where the individual is fully absorbed in the present moment, which is itself intrinsically motivating and does not rely on any product or extrinsic reward. This requires an optimal balance between skill, mastery and challenge with immediate feedback about accomplishment. Subjectively the flow state involves intense concentration without self-consciousness and a feeling of satisfaction and the experience of a ‘high’.

In summary, whereas previous attempts to demonstrate advantages for creativity in the performing arts were successful with slow-wave training, we had been unable to show benefits from SMR training, despite evidence that in other contexts SMR training improved psychological processes germane to creative performance. By providing a training context with relevance to performance, we hypothesised that ecological relevance would enhance the learning process and its transfer to creative performance. We further hypothesised that the more technically immersive ReaCTor training environment, offering potential for greater presence [22], would prove to be superior in transfer than the conventional computer screen approach to SMR training. Nevertheless both media would be effective in enhancing creative performance to some extent. In this study, we examined sophomore actors whose performances were examined in acting studios and the stage of Shakespeare's Globe Theatre, London. Aside from objective ratings of performance obtained from three experts, we examined the actors' subjective experiences with the Flow State Scales of Jackson and Eklund [13].

Participants were the total class ($N = 15$) of second year drama students from Illinois on semester placement in London (7 male, 8 female, mean age 20, range 20–23 years). The study was conducted in accordance with the Declaration of Helsinki. Following approval by the College Ethics Committee, written informed consent was obtained from volunteers who did not receive any monetary reward. They were randomised to one of two training groups: a ReaCTor group, $N = 5$, or a Screen group, $N = 6$. An additional four students were unable to participate due to other commitments such as an internship with a theatre company, and formed a control comparison group for acting performance and self-assessment of the Flow State. The training groups did not differ in age, sex or years in college, whereas 2/3 students who were >20 years at study onset belonged to the control group.

Training groups underwent between seven and ten half-hour sessions of training within 6 weeks with no more than one session per day. Before and after training the actors performed monologues of their choice before a studio audience and excerpts from Hamlet on the Globe Theatre stage. The dark lighting conditions on stage did not provide satisfactory filming at pretraining assessment so that evaluation of the filmed performances was based on the studio performances. These were filmed and were rated by three experts who taught in acting academies. The raters were blind to order of performance and training group. Neurofeedback training took place in the ReaCTor, Department of Computer Science, University College London.

The ReaCTor is a CAVE™-like system using multi-projection based stereo and head-tracking. The participant is surrounded by four screens: three back-projected, 2.2 m by 3 m walls, and a front projected 3 m by 3 m floor. Stereo imagery is produced in an active stereo mode at 45 Hz using CrystalEye™ glasses. The images on the walls were seamlessly joined, so that participants did not see physical corners, rather a continuous virtual world projected with active stereo. Using the XVR software from VRMedia we created a representation of the Vanburgh Theatre, RADA, which has a contemporary proscenium-arch auditorium.

EEG signals were acquired using a Nexus 4, wireless portable system (Mind Media BV, The Netherlands) with BioTrace+ software. EEG was measured at 256 samples per second, then digitally filtered with a IIR Butterworth Bandpass 3rd order filter, and root mean squared in 1/8 s epochs in three frequency bands: SMR (12–15 Hz), Beta (15–21 Hz) and Theta (4–8 Hz).

Training began with a 3-min baseline period when EEG-band amplitudes were recorded at rest with eyes open, in the absence of feedback. This baseline was used as the initial criterion for the contingent feedback that followed. This consisted of five 170 s feedback periods, with approximately 10 s breaks. Band amplitude values were transformed online. A composite value of SMR/Theta + Beta was calculated. When over a threshold value a “GO” signal was send to the VR computer where the lighting level of the auditorium was slowly increased or decreased on separate trials. Simultaneous reductions in theta and beta, termed inhibits, were conveyed by reductions in intrusive audience noise. XVR on the ReaCTor and Biotrace software were connected over the network using a custom TCP/IP protocol. Operant contingencies included rewards (‘points’) which were gained whenever the subject increased SMR-band activity without concurrent increases in theta and high beta band activity. They were instructed to simply let the feedback process guide learning how to maximize their point score. The thresholds from the baseline remained fixed for the 5 training epochs to maintain a constant level of reinforcement. The reward band threshold was set at 0.8 times its baseline average, while the high beta and theta inhibit thresholds were set at 1.2 times their baseline average. All neurofeedback EEG was recorded from the motor cortex (Cz), with a left mastoid reference and a right mastoid ground, and with impedance below 10 kΩ. The subjects were seated in a comfortable chair either about 1.5 m from the computer monitor or 1.5 m inside the ReaCTor.

The Acting Performance Scale was devised in collaboration with faculty at RADA. It consisted of ten-point scales covering overall performance, voice, movement, creativity, communication. The 11 scales were as follows: Overall Performance, Vocal Transformation, Vocal Expression, Movement Fluency, Movement Inhabitation, Imaginative Expression, Imaginative Conviction, Imaginative Characterisation, Seamlessly Engaged, At-One with Performance and Well-Rounded Performance.

The Flow State Scale (FSS) [13] contains 35 items measuring nine dimensions of flow [4]: Merging of Action & Awareness, Clear Goals, Unambiguous Feedback, Concentration on the Task at Hand, Sense of Control, Loss of Self-Consciousness, Transformation of Time, Autotelic Experience and Challenge-Skill Balance. In view of the relative brevity of the performances it was not anticipated that there would be evidence for Unambiguous Feedback or for Transformation of Time, the two scales which require a deep experience [23].

In addition the participants completed a four-item, ten-point rating scale on Presence-in-Performance used elsewhere to examine construct reliability with the FSS: How much "present in the moment" did you feel during your performance? How much did you feel you were able to express yourself? How distracted were you by thoughts or surroundings unrelated to your performance? How well were you able to focus on your performance?

The first question was whether neurofeedback learning occurred while interacting with the theatrical space? EEG analysis (general linear model) confirmed that learning to raise the SMR to theta/beta ratio was successful across sessions (F (5,6) = 3.70, $p < 0.05$) with a significant linear trend (F (1,10) = 9.30, $p < 0.05$). There was also a significant quadratic trend differentiating the groups (F (1,10) = 7.12, $p < 0.05$). As can be seen in Fig. 1, the ReaCTor group reached an asymptote in session 4, one session earlier than the Computer Screen group. Examining SMR amplitude alone, there was a Group × Session quadratic interaction (F (1,10) = 8.84, $p < 0.05$) with the ReaCTor group reaching an asymptote on session 3, a session earlier than their control of the SMR to theta/beta ratio, whereas the Screen group peaked at session 5, and had lower SMR amplitudes overall ($p < 0.05$), though the groups did not differ at baseline.

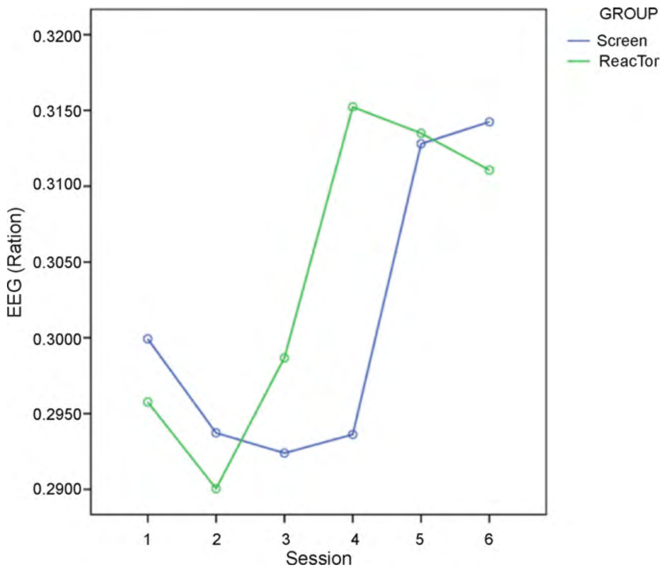

Fig. 1. SMR/theta–beta amplitude ratio for training with the ReaCTor and Screen.

The advantage for the ReaCTor group in the EEG learning curves was in keeping with their subjective impression disclosed by the Neurofeedback questionnaire. In response to the item "At what stage did you recognise the mental state we were seeking in you?", recognition was significantly earlier in the ReaCTor than the Computer Screen group (F (1,10) = 7.36, $p < 0.027$). This occurred on average during the 3rd week for the ReaCTor group and 4th week for the Computer Screen group; in line with their control of the SMR band. All of the participants reported recognising the state and felt they gained control, while all reported their acting performing had improved.

Given that there was evidence of learned control of the EEG through interaction with the computer rendered theatrical space, the primary hypothesis was considered: did the greater immersion, conferring more presence, result in a superior impact on acting from neurofeedback training with the ReaCTor than with the Computer Screen, and with a particular interest in imagination in performance? Results in support of the hypothesis are shown in Fig. 2, expressed as the percent improvement between pre- and post-training monologue performances averaged across the three judges. In an ANOVA there was a significant interaction between Group (2) and Rating (11) (F (1,10) = 2.79, $p < 0.035$), and post hoc t-tests confirmed for the ReaCTor group significant advantages ($p < 0.05$, one-tailed) for Imaginative Expression, Imaginative Conviction, Imaginative Characterisation, and the Imagination subscale ($p < 0.04$), and for Performance Overall and Well-Rounded Perfor-

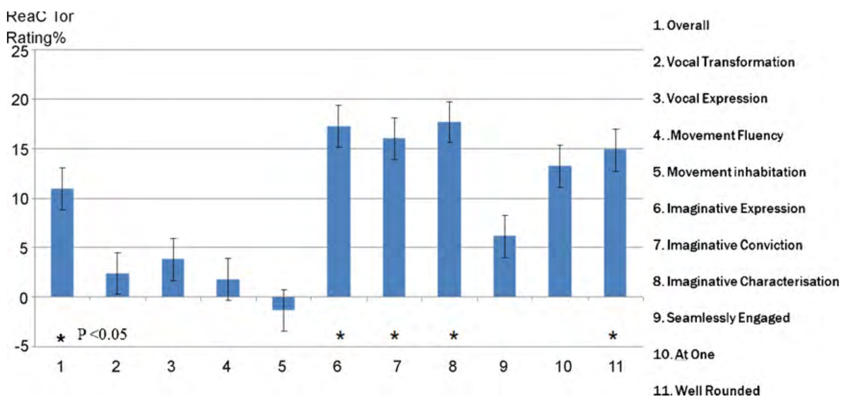

Fig. 2. Percent improvement in acting advantage for ReaCTor over Computer Screen group.

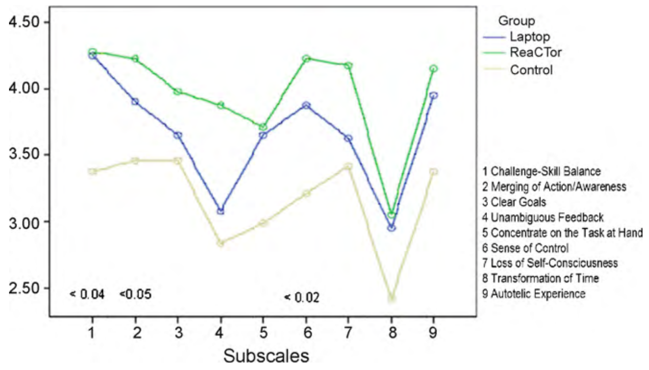

Fig. 3. Flow State self-ratings averaged for Hamlet excerpts and monologues indicating superior flow with neurofeedback training.

mance. There were no ReaCTor group advantages for the voice or movement ratings.

On average the ReaCTor group experienced the highest Flow followed by the Computer Screen group, with the Control group experiencing the least flow. These results are shown in Fig. 3. Averaging the Hamlet and monologue scales the combined training groups had higher Flow overall than the controls (Chi-Square 3.80, $p < 0.05$), and the subscales of Sense of Control (Chi-Square 4.33, $p < 0.04$), Challenge-Skill Balance (Chi-Square 3.2, $p < 0.05$), and with a tendency with Merging of Action and Awareness (Chi-Square 2.65, $p < 0.10$). Statistically there were no differences between the neurofeedback groups.

There were numerous positive correlations (Pearson) between the experience of Flow and expert ratings of improvement in acting performance and/or level of performance at the study end. Correlations were found with five of the Flow scales: Sense of Control, Loss of Self-Consciousness, Merging of Action/Awareness, Challenge/Skill Balance, and Autotelic Experience. These are summarised for the five Flow subscales showing correlations with acting:

Flow, Sense of Control: Being-at-One with performance, $r = 0.616$, $p < 0.03$; Vocal expression, $r = 0.52$, $p < 0.07$; Well-rounded performance, $r = 0.53$, $p < 0.07$; % improvement, $r = 0.58$, $p < 0.048$.
Flow, Loss of Self-Consciousness: Creativity Scales Factor, $r = 0.685$, $p < 0.029$; Conviction, $r = 0.655$, $p < 0.04$; Movement fluency/inhabitation, $r = 635$, $p < 0.049$; Mean of acting rating, $r = 0.616$, $p < 0.058$.
Flow, Merging Action & Awareness: Being-at-One, $r = 0.56$, $p < 0.056$; Vocal Scales % improvement, $r = 0.596$, $p < 0.041$; Vocal expression, $r = 0.55$, $p < 0.06$; Imaginative expression, $r = 0.53$, $p < 0.08$.
Flow, Challenge/Skill Balance: Being-at-One, $r = 0.56$, $p < 0.06$; Well-rounded, $r = 0.52$, $p < 0.08$; Vocal Scales, $r = 0.534$, $p < 0.07$.
Flow, Autotelic Experience/Enjoyment: Vocal Scales, $r = 0.567$, $p < 0.05$.

Pearson correlations were also examined with the Presence laboratory scale [11]. Those at less than $p = 0.01$ were with Challenge/Skill Balance ($r = 0.787$, $p < 0.004$) and Merging of Action & Awareness ($r = 0.814$, $p < 0.002$).

This is the first study to demonstrate advantages for creative performance following fast-wave SMR training. Previous attempts were unsuccessful, showing advantages only for slow-wave training; see two experiments reported by Egner and Gruzelier [7] with creative music performance. Raising the theta–alpha ratio was highly successful, but no benefits resulted from SMR or low beta training aside from the subjective experience of mental relaxation which did not transfer to music performance [5]. In line with our hypotheses the ecologically valid representation of the theatrical performing space allowed associations in memory to be forged between the simulated laboratory theatre context and the real theatrical performing space, allowing the laboratory-trained brain state to carry over to acting performance. This was not achieved previously by computer training screens irrelevant to creative stage performance [7]. Slow-wave training, where the aim was to increase the theta–alpha ratio to facilitate hypnogogic imagery, apparently enabled this connection to be made with acting through an imaginative involvement with performance in the hypnogogic state [9, p. 105].

The hypothesis was supported that the presence enhancing properties of the more immersive ReaCTor context would have greater benefits. Creative acting performance was facilitated by NF training in the immersive ReaCTor rendition of the theatrical space versus the computer screen. Importantly this was found with the Imagination subscale and its three constituent ratings of Expression, Conviction and Characterisation, as well as with creative acting performance as a whole as seen in ratings of Performance Overall and Well-Rounded Performance. The ReaCTor training advantages did not extend to vocal and movement scales.

The advantages of the Presence inducing ReaCTor rendering of the performing space was also reflected in the EEG self-regulation learning curves. Regarding the SMR/theta–beta ratio, the ReaCTor group reached an asymptote in session 3, one session earlier than the Screen group. Regarding enhancement of the SMR amplitude by itself, the chief training goal, the ReaCTor group reached their asymptote on week 3 whereas the Screen group peaked a week later. This advantage to the ReaCTor group was in keeping with their subjective impression in identifying the required brain state over which they were to achieve self-control recorded with the self-rating questionnaire, with exact correspondence for the ReaCTor group.

Neurofeedback training produced subjective benefits evinced by the actors' experience of Flow which was higher in the training groups. This was seen in Challenge-Skill Balance representing confidence and mastery, Merging of Action and Awareness or Being-at-One with Performance, and Sense of Control. Importantly increasing the Sense of Control was directly in line with the device of making the self-control of brain rhythms contingent on controlling aspects of the theatrical performing space.

The many relations disclosed between the actors' experience of Flow State on the one hand and the observed ratings by the experts, further validated the effects of neurofeedback training. This relation between objective and subjective ratings was shown in five attributes of Flow: Sense of Control, Loss of Self-Consciousness, Feeling At-One with Performance, Confidence & Mastery, and Autotelic Experience/Enjoyment. While all acting domains were implicated: Vocal, Movement, Imagination, Communication, and Performance overall, even though in the case of Voice and Movement the improvements were not reflected in the judges' observations.

In conclusion, in this exploratory study ($N = 15$), demonstrable benefits for acting performance were disclosed as the result of fast-wave SMR training in an ecologically valid training context hypothesised to facilitate transfer to performance. This warrants replication with a larger sample. Furthermore the immersive VR properties were superior to 2D properties, even though the same auditorium was depicted [16]. This was especially true of the expert ratings of the imaginative aspects of acting which found a counterpart in the actors' experience of the Flow State. This is the first demonstration of enhancement of artistic performance with eyes-open neurofeedback training, previously demonstrated only by eyes-closed slow-wave training. Efficacy is attributed to psychological engagement through the ecologically relevant learning context of the acting space, putatively allowing transfer to the real world otherwise achieved with slow-wave training through imaginative visualisation.

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