noise-free oscillations, pink noise, and white noise to elucidate their contributions.

Methods: EEG data were recorded during eyes-closed resting and meditation conditions in 36 healthy young adults ($M_{age} = 21.08$; 23 females) in two testing sessions six-weeks apart. Following the first session, participants were assigned randomly to daily mindfulness training or classical music listening. Global power in four traditional bands were used to assess factors of session (pre-, post-training), state (rest, meditation) and training group (music, mindfulness). Analyses were run on the raw oscillations in the traditional bands (i.e., non-noise-corrected), and repeated in the exploratory analysis of pink noise and white noise, and the noise-free oscillations.

Results: Participants completed on average 5.7 ($SD = 0.8$) exercises per week in the mindfulness group ($n = 18$) cf. 5.4 ($SD = 1.3$) exercises per week in the music group ($n = 18$). In the raw oscillations, no significant effects were found in delta, while theta increased (across groups) post-training. Across the groups, alpha and beta were each lower during meditation compared with rest, and a group by training interaction indicated an increase post-training in the mindfulness group but decrease in the music group. Pink noise showed a near significant increase post-training ($p = .055$) while white noise showed no effects. In the noise-free oscillations, delta power was lower in the mindfulness than music group, and as in the raw oscillations a post-training increase was found in theta, and a reduction was seen in alpha and beta during meditation compared with rest. The mindfulness group had greater noise-free alpha than the music group during rest; differing from the group by training interaction seen in the noise-free alpha and beta bands.

Conclusions: Changes in pink noise appear to contribute to, and perhaps underly, the mindfulness training-related interactions in the traditional alpha and beta bands. Further, group differences evidenced in the noise-free delta oscillations reflect the finer resolution of this analysis compared with the traditional approach. These novel findings highlight the importance of disentangling pink noise and white noise from the periodic oscillations, and their utility as insightful independent measures.

doi:10.1016/j.ijpsycho.2023.05.102

Extending applications of PaWNextra: Frequency PCA of resting EEG magnitude spectra

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Introduction: Pink Noise (PN) and White Noise (WN) are formally defined by the functions linking their power to EEG frequency (PN: power inversely proportional to frequency; WN: constant power across frequency). Our recent brain dynamics studies linking ERP components to EEG activity have found that EEG magnitude provides better conceptual clarity than power. This study explored the impact of noise in resting EEG magnitude spectra, and examined their constituent oscillations.

Methods: Eyes-open and eyes-closed resting EEG was recorded (30 scalp electrodes) at 1000 Hz from a group of university students ($N = 50$) aged between 18 and 27 years. After standard pre-processing, Discrete Fourier Analysis was used to obtain EEG magnitude spectra from artefact-free 2 s epochs in each condition. We estimated PN and WN from the magnitude spectra using an option in *PaWNextra* that maintains their definitional integrity. We then used separate frequency-PCAs with Promax rotation for each condition (EC and EO) to estimate data-driven frequency components in the raw EEG spectra, and after removal of PN and WN.

Results: Frequency PCA extracted 9 components from the EC data (carrying 91.3 % of the variance), and 8 components from the EO data (carrying 92.2 % of the variance). Removal of noise significantly reduced all component peak amplitudes except 3 of 4 alpha components in EC, thus impacting the ratio of slow/fast frequencies.

Conclusions: The present data suggest that using the magnitude option in *PaWNextra* to obtain magnitude estimates of PN and WN may extend its applications into brain dynamics and other areas where EEG magnitude data are preferred. The use of frequency-PCA to extract noise-free estimates of data driven oscillation components from EEG spectra extends potential applications further. The differential impact of PN and WN in low-frequency (delta and theta) components cf. high frequency (alpha and beta) components suggests that this approach could help clarify EEG band imbalances reported in some patient groups, such as in ADHD.

doi:10.1016/j.ijpsycho.2023.05.103

Symposium

Connecting mind and body with biofeedback: innovative and rigorous approaches to cognitive enhancement

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Biofeedback is a training technique based on the self-regulation of physiological parameters provided by real-time feedback. This technique has seen a resurgence of interest in recent years as a method of cognitive enhancement, therapy and as a tool to study the relationship between mental and physiological activity. In this context, we will demonstrate novel psychophysiological findings derived from innovative methods and the use of biofeedback applications (i.e., neurofeedback, heart rate variability [HRV] biofeedback). Out of five presentations of this symposium, two will focus on clinical populations (patients with depression or attention-deficit hyperactivity disorder [ADHD]) and three on healthy participants. 1) Bögge and colleagues will present two pioneering studies conducted with healthy participants investigating the impact of HRV biofeedback on cognitive control and memory and its ties with HRV. In study 1, they demonstrate persistent effects of HRV modulation on cognitive performance using a newly developed virtual reality-based biofeedback device. In study 2, HRV biofeedback was coupled with a false memory paradigm to explore the effect of HRV stimulation during subsequent cognitive processing on cognitive control over memory. 2) Schumann and colleagues will present fMRI data from depressed patients to study the impact of HRV biofeedback on brain functional connectivity with a particular focus on rumination. 3) Chikhi and colleagues will present a study investigating the effect of a single neurofeedback training session of theta or high alpha frequency on working memory compared to an active control condition using random frequency amplitudes. They also investigated psychological, cognitive, and electrophysiological factors that can predict neuromodulation. Despite that no specific behavioral gains were observed, they found that the resting amplitude of trained frequencies predicted the amplitude increase during training. 4) Blanchet and colleagues trained theta or both theta and gamma frequencies in young and healthy adult during five weeks. They showed that targeting both theta and gamma frequencies enhances recollection of temporal contextual information and attention during an ecological episodic memory task implemented in virtual reality. These innovative and original results contribute to the development of a rigorous investigation of the modulation of neurophysiological activity by biofeedback. Finally, 5) Ros and colleagues will present the application of a new analytical framework to identify the neural correlates of ADHD called EEG microstates. The authors show the feasibility of converting these novel EEG biomarkers into neurofeedback regulated signals to provide more spatiotemporally specialized training, impacting behavioral measures of impulsivity and inattention among patients with ADHD.

doi:10.1016/j.ijpsycho.2023.05.104

Investigation of the link between heart rate variability and cognition using biofeedback

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Cognitive performance has repeatedly been linked to heart rate variability (HRV) and may be persistently improved by stimulating HRV during biofeedback. The main focus was given to the study of cognitive control which supports goal-directed behavior and higher-level cognitive functions such as memory. Preliminary findings in healthy young adults showed that HRV biofeedback improves inhibitory control acutely and attention as well as short-term memory even beyond training. However, the empirical evidence on cognitive effects and their underlying physiological underpinning remains sparse. Researchers hypothesized that increases in vagal activity, which can be characterized by HRV, are the driving force for cognitive improvements. Yet, the direct relationship between HRV and cognitive control remains unclarified. We demonstrate here our attempt to uncover the potential of HRV biofeedback to improve cognitive control and memory functions and to clarify the mediating role of HRV stimulation in healthy young adults. Firstly, we present a newly developed biofeedback system coupled with virtual reality to increase training efficacy and experimental control. In a randomized placebo-controlled experiment including six training sessions, we explored one-week persistent effects on cognitive domains including cognitive control and flexibility, long-term episodic memory, and the self-reference encoding effect. Furthermore, we investigated for the first time the link between respiration driven HRV during autonomic self-regulation and cognitive changes. In a second experiment, we tested the feasible use of HRV biofeedback to stimulate HRV during subsequent cognitive processing. Moreover, it was hypothesized that these changes in HRV would predict improvements in cognitive control over memory. Self-regulation training was integrated into a classical false memory paradigm, where participants exercised either HRV biofeedback or controlled breathing at a natural rhythm before word list memorization and memory retrieval. True to false memory discrimination performance assessed and conditions compared within and between 70 subjects. The findings of the first study suggest that HRV biofeedback can persistently strengthen specific facets of cognitive control as well as memory and that these improvements are linked to the degree of HRV stimulation during training. The second study demonstrates that a short HRV biofeedback induction evokes no immediate effects on cognitive control over memory and does not affect HRV during subsequent cognitive processing. Moreover, we found that HRV reactivity during memory recall, but not resting state HRV, predicts cognitive control over memory within and between subjects. HRV biofeedback appears to be an appropriate technique for examining and improving cognition only when applied repeatedly.

doi:10.1016/j.ijpsycho.2023.05.105

The effect of biofeedback on depressive rumination and its functional correlates in the brain

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Recent studies suggest that lower resting heart rate variability (HRV) is associated with an increased vulnerability to depressive rumination. In this study, we investigated how HRV changes during rumination induction and the effect of HRV-biofeedback on functional correlates of rumination in the brain. Fourteen patients suffering from depression completed a biofeedback intervention for 6 weeks. Before and after the training, we employed a well-established rumination induction task to provoke a state of pervasive rumination. We acquired functional magnetic resonance images of the brain while recording psychophysiological signals simultaneously. Changes in functional connectivity and HRV induced during the rumination task were compared before and after the intervention. After biofeedback, resting vagal HRV increased and self-ratings of rumination and general depressive symptoms decreased. Before the intervention, rumination induction led primarily to deactivation of the default mode network and an activation of occipital and motor areas that were accompanied by sympathetic arousal as indicated by heart rate acceleration and skin conductance increase. After the intervention, functional connectivity in cognitive control networks were less deactivated during the rumination condition. Our results indicate that an HRV-biofeedback intervention can be applied to reduce severity of depressive symptoms including rumination. The interplay of functional brain networks that are involved in depressive rumination seems to be affected by biofeedback.

doi:10.1016/j.ijpsycho.2023.05.106

Effect of neurofeedback training of theta and high alpha frequency on working memory: a single-blind controlled study

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Neural oscillations measured by electroencephalogram are involved in cognitive processes. Theta frequency (4-8 Hz), for instance, has been associated with cognitive control, while High alpha frequency (10-12 Hz) has been associated with working memory. Thus, the modulation of these brain signals could have an impact on the associated cognitive processes. Neurofeedback is a particular technique that aims to teach individuals to modulate a signal of their brain activity by providing them with real-time feedback on this activity. In addition to being non-invasive, this technique could allow individuals to self-regulate their brain activity outside the laboratory or clinic. However, the mechanisms involved in this technique are still poorly understood and critics point to the lack of control groups, insufficient consideration of non-specific factors and a non-negligible proportion of "non-learners". This study aimed to investigate the effect of a single neurofeedback training session on brain frequency amplitude and working memory. We compared the performance of a group trained to increase the amplitude of theta frequency (in Fz, $N = 28$) with a group trained to increase high alpha frequency (in Pz, $N = 39$) during a single session (10 training blocks of 3min using Thought Technology neurofeedback system). To better distinguish specific and non-specific effects of the neurofeedback training, we also included a control group trained to modulate randomly selected frequencies (between 1 and 30 Hz) in each training block (in Cz, $N = 34$). Brain frequency amplitude, performance on working memory tasks (numerical span, *n*-Back, Corsi blocks), and self-reported mental state (emotional and attentional state) were measured before and after training. We also aimed to identify factors (electrophysiological, cognitive or psychological) that could predict success in the neurofeedback task. While our analyses did show electrophysiological