

Individual Tailoring of Stress Coping Training via a VR-Based Process-Neurofeedback

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Introduction

Stress regulation involves shifting between approach (fight) and avoidance (flight/freeze) coping strategies. The amygdala, a core region of the negative brain system, and the ventral striatum (VS), a core region of the positive brain system, were found to be involved in adaptive coping.^{1–3} Neurofeedback (NF) targeting the amygdala or VS could enhance specific processes related to relevant coping strategies in adults and youth.⁴

Neurofeedback (NF) is a neuromodulation approach that has been widely studied for training stress resilience. The development of real-time functional magnetic resonance imaging (rt-fMRI) has renewed the translational potential of NF, particularly by enabling modulation of deeply located limbic regions involved in stress processing. However, the high cost, limited accessibility, and immobility of fMRI pose major barriers to scalability and clinical implementation. Moreover, most NF protocols to date are conducted in neutral or low-arousal environments that do not reflect real-world stress demands, thereby creating a significant translational gap.

Acute stress, while aversive, is also a major driver of learning and neural plasticity.⁵ We therefore assume that NF under stress would enhance real-life transfer of adaptive coping strategies related to the modulation of the amygdala and VS.

Goal: To identify the neural mechanisms associated with active coping of approach versus avoidance under stress.

Assumption: The context of the stress coping strategy during NF will affect the neuromodulation, specifically:
Avoidance coping → amygdala downregulation
Approach coping → VS upregulation

Methods

To overcome the limited applicability of rt-fMRI, our lab developed an electroencephalography (EEG)-based model with improved spatial specificity, derived from simultaneous EEG–fMRI recordings, enabling the targeting of deep limbic activity. This approach yields Electrical FingerPrints (EFPs) of specific brain regions, including the amygdala (Amyg-EFP) and ventral striatum (VS-EFP). The EFP framework has been validated across multiple studies and is currently used for clinical applications.^{1,2,3}

The current study is an ongoing pilot study using a between-subjects design. To address the translational gap, we developed an immersive, gamified virtual reality (VR) stress environment for closed-loop self-neuromodulation. Participants undergo five neurofeedback (NF) training sessions, with six training cycles per session. Each cycle lasts four minutes. The protocol trains both downregulation of amygdala-related activity and upregulation of VS-related activity, as both play a crucial role in stress coping and controllability.⁴

The current sample includes N=5 healthy pilot participants. Participants are randomly assigned to one of two feedback conditions, each designed to instantiate a different coping strategy during stress exposure: a protective-oriented modality, in which participants generate a defensive shield against a threatening agent, and an approach-oriented modality, in which participants actively engage the threat by shooting an arrow toward it. These contingencies allow us to examine whether different coping contexts drive distinct neural regulation patterns.

The primary outcome measure is change in Amyg-EFP and VS-EFP during NF training. Secondary outcomes include self-report questionnaires, behavioral assessments (Approach-Avoidance Task; AAT), and physiological measures. EEG is continuously recorded during the NF training, with real-time feedback generated based on the EFP framework. Behavioral and self-report measures are assessed before and after the intervention (first and final sessions).

Preliminary Results

These preliminary feasibility data include the first three sessions of two participants (one per feedback condition); therefore, no group-level conclusions can be drawn.

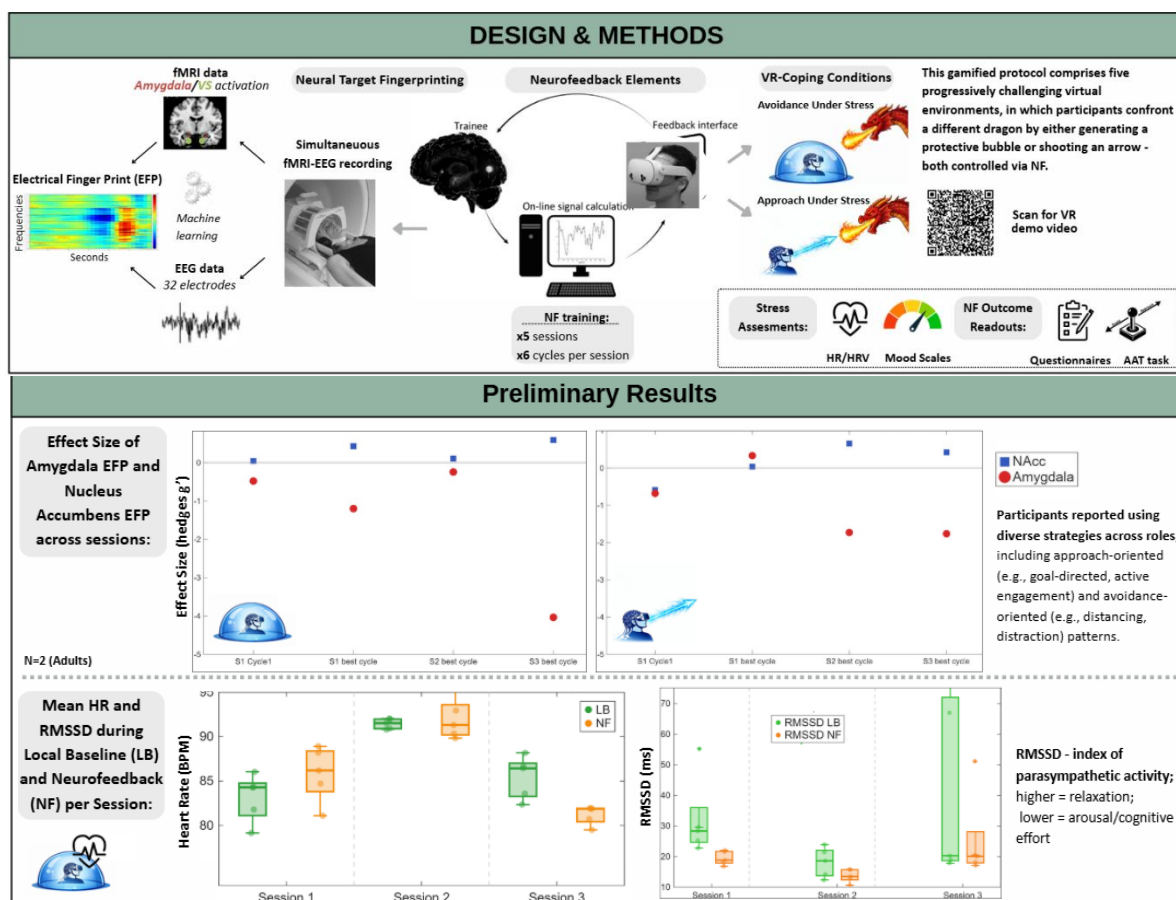
Preliminary neural findings suggest learning under both feedback conditions, with improvements in both amygdala downregulation and VS upregulation. However, the participant in the protective-oriented (shield) condition showed stronger amygdala downregulation than the participant in the approach-oriented (arrow) condition.

Preliminary physiological findings were consistent with the degree of successful neural regulation. In Session 1 (protective-oriented), HR was higher during the regulation phase than during baseline, potentially reflecting increased stress as participants began regulating while the dragon initiated its attack. In Session 2, when neurofeedback performance was less successful, HR remained elevated during both baseline and regulation. In contrast, in Session 3, which showed the strongest amygdala downregulation, HR decreased markedly during regulation relative to baseline, suggesting successful autonomic regulation through the participant's mental strategy. HRV measures showed a similar pattern, supporting these findings.

Conclusions

The protocol demonstrated high acceptability and feasibility, with no adverse events reported. Participants reported a highly immersive experience, providing preliminary support for the paradigm's ecological validity in simulating stress dynamics. Preliminary results demonstrate the feasibility of NF-learning under immersive stress, characterized by the downregulation of the amygdala and/or upregulation of the ventral striatum (VS) as expected by the coping context. These findings support the feasibility of immersive process-based neurofeedback as a promising approach for stress-coping training with potential for improved real-world transfer.

Figures



References (link)