

Representational similarity-based real-time fMRI neurofeedback for emotional state regulation: from semantic maps to digital avatars

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Introduction

Most real-time fMRI neurofeedback (rt-fMRI-NF) studies provide feedback based on activation within predefined brain regions. While effective for regulating single neural targets, such approaches may be insufficient for differentiating and guiding multiple emotional states represented by distributed and overlapping neural systems. Representational similarity analysis (RSA) offers a multivariate framework for characterizing neural representations and has recently been adapted for real-time neurofeedback. The present work investigates the feasibility of representational neurofeedback for emotional state regulation using two feedback modalities: an abstract circular semantic map (CSM) interface and a naturalistic avatar-based interface.

Methods

Two real-time fMRI neurofeedback studies were conducted using emotion imagery tasks involving four affective states: joyful relaxation, sadness, enthusiasm, and anger. Individual emotion-specific neural patterns were first identified using functional localizer runs. During neurofeedback training, ongoing multivoxel activity patterns were compared with these target patterns using real-time representational similarity analysis. In the CSM study, feedback was presented through a combined interface including thermometer levels and a moving red dot on a circular semantic map. The thermometer levels conveyed the intensity of similarity to each target emotion, whereas the red dot represented the participant's current position within the emotion similarity space. In the avatar study, feedback was delivered through a dynamic avatar whose appearance changed according to the similarity between the current neural pattern and the target emotional representations. Neurofeedback performance was evaluated using changes in representational similarity within and across training runs, together with behavioral ratings and subjective evaluations of the feedback experience.

Results

The CSM study demonstrated distinguishable multivariate representations of emotional states and significant within-run improvements in similarity to target representations during neurofeedback training. Participants were able to navigate among multiple target emotions using the representational feedback framework. Preliminary analyses of the avatar study indicate that participants can similarly modulate neural similarity to target emotional states using naturalistic feedback. Behavioral and subjective measures suggest good feasibility and user engagement for

both feedback modalities. Ongoing analyses are examining the specificity of regulation effects and the relative contributions of valence and arousal dimensions.

Conclusions

Together, these studies demonstrate the feasibility of representational neurofeedback for regulating multiple emotional states using distributed neural representations rather than single-region activation levels. The findings further suggest that feedback presentation may influence user experience and potentially regulation strategies, with naturalistic avatar-based feedback representing a promising extension of abstract representational interfaces. Future work will directly compare feedback modalities and investigate their impact on neurofeedback learning and emotional regulation outcomes.