

Navigating Emotional Space: A Pilot 7T real-time fMRI Study using Semantic Neurofeedback for Emotion Regulation

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Introduction

Neurofeedback (NF) using real-time functional magnetic resonance imaging (rt-fMRI) has demonstrated promising results for emotion regulation training across a range of psychiatric conditions [1]. However, conventional approaches rely on thermometer-style displays mostly reflecting univariate activation in a single target region, limiting feedback to one dimension [2]. Semantic neurofeedback (sNF) offers a fundamentally different approach: by applying representational similarity analysis (RSA) and multidimensional scaling (MDS) to multivariate brain activation patterns, it constructs a two-dimensional semantic map that captures the similarity structure among multiple target brain states [2, 5]. Participants navigate this map in real time by modulating their current neural representation toward a target state, with their position on the map updated every few seconds. While sNF has been validated for mental imagery paradigms [3], its application to emotional states had not yet been empirically tested. Translating the measure to emotions brings additional difficulties since emotions are encoded in largely overlapping patterns throughout the brain that show strong individual heterogeneity [4]. This study aimed to establish the feasibility of sNF for navigating emotional space between four different emotions and subsequently to validate the feedback signal and optimize key parameters through systematic offline analyses.

Methods

In this pilot study five participants completed a behavioral pre-session and two fMRI sessions at 7 Tesla. During the behavioral session, four personalized target emotions were selected based on each participant's comfort, engagement, and valence/arousal ratings. Emotions were selected to maximize spread across the valence/arousal space. Before and after each session behavioral assessments were completed to investigate participants mood and investigate the stability of valence/arousal ratings. Functional images were acquired using a 2D gradient-echo echo-planar imaging sequence (resolution = 1.8 mm isotropic, TR = 1.5 s, TE = 22 ms) and analysed in real-time using Turbo-BrainVoyager. In the localizer session, three localizer runs were acquired during which participants engaged in autobiographical memories associated with each of their four emotions. Localizer runs consisted of a block design with 15 seconds of emotion engagement followed by baseline with six repetitions for each emotion. Subsequently, the NF target network was selected within a mask comprising cortical and subcortical regions involved in emotional processing using voxel ranking from univariate analysis of the localizer runs [4]. The dissimilarity of the activation patterns in the target regions were computed using correlation distance (CD) [5] and MDS was used to construct a two-dimensional map representing the emotional space of each individual (see figure 1). In the subsequent sNF session, participants completed three sNF runs, each one including four repetitions of each target emotion (24 s each) in randomized order. During the NF runs, the current mental state was displayed as a moving dot on the semantic map, updated every 6 s, with the target emotion highlighted by a white circle. The size of the moving dot changed relative to the target-related pattern strength value (projection on target) representing the strength of the activation related to the target emotion pattern [2]. Participants were instructed to try to reduce distance between the current mental state to the target mental state and additionally increase the size of the moving dot hence increasing the engagement with the target emotion. Performance was assessed using both CD in the representational dissimilarity matrix and Euclidean distance (ED) on the semantic map. Systematic offline analyses were performed to investigate different methods to identify the target brain network and stability of the emotion patterns between sessions.

Results

Regions were successfully selected within the emotional network for all participants. Emotional maps based on the patterns within these regions are displayed in figure 1. Participants achieved above-chance accuracy in navigating toward target emotions, reaching the target as the closest state in

41.5% of trials in ED and 42.1% in CD ($p < .001$, chance = 25%, see figure 2 for CD). Accuracy was significantly above chance at all trial timepoints (except the first) increasing as the hemodynamic response stabilized and peaking at 18 s and 24 s. The correct valence category was reached in 66.7% of cases and the correct arousal level in approximately 61% of cases. Individual accuracy ranged from 26% to 50%, reflecting meaningful inter-individual variability. Projection on target also increased throughout the task block for all participants consistently (see figure 2). Offline comparative analysis between different region selection approaches showed that support vector machine-based region selection and offline preprocessing yielded improved region selection compared to the original approach.

Conclusions

This pilot study provides initial empirical evidence for the feasibility of sNF for navigating between different emotions using rt-fMRI. Participants successfully modulated their brain representations toward multiple distinct target emotions, with a robust and well-validated feedback signal. Preliminary offline analysis results suggest optimising region selection and translation between CD and ED to improve the feedback signal. Additional refinement to improve the participant experience can also be implemented in future studies, such as shorter runs and sessions. Future studies with larger samples, and multiple training sessions will be needed to assess emotion regulation learning and to explore sNF as a therapeutic tool for populations with emotion dysregulation.

Figures

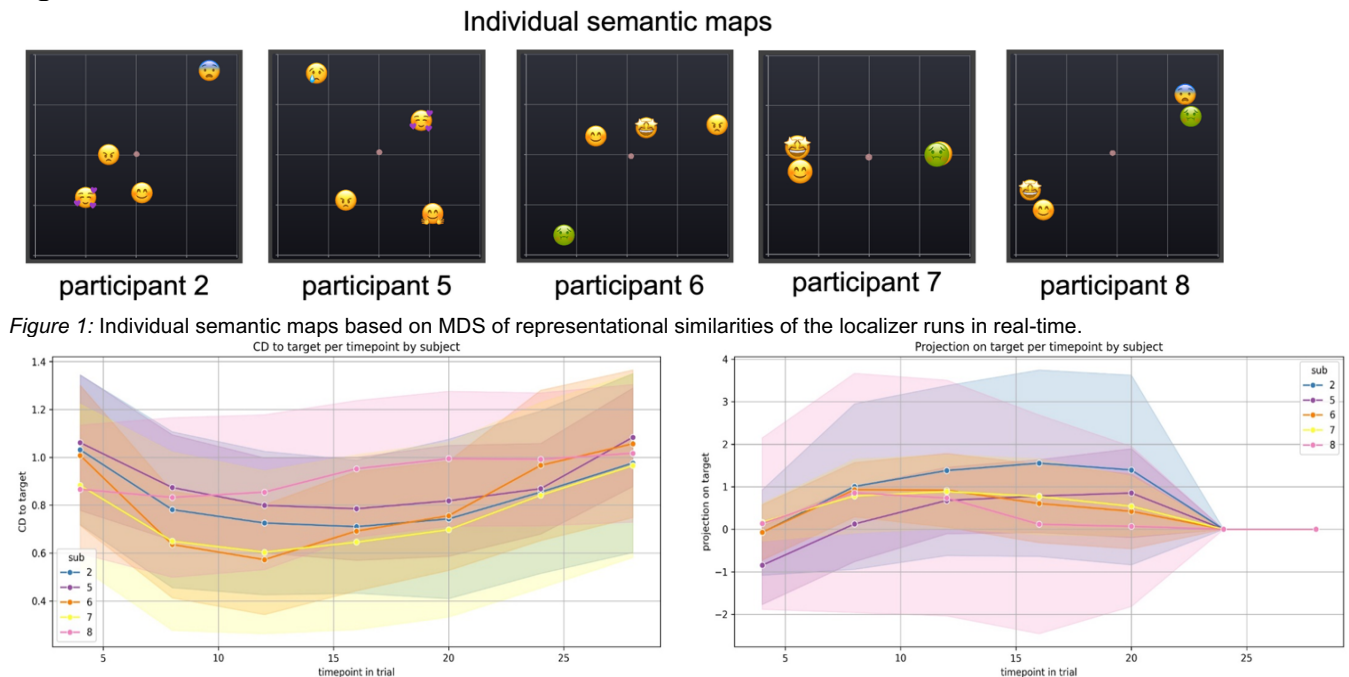


Figure 2: Average trial time course of CD to target (left) and projection on target (right). Lines indicate individual participants and shaded areas indicate standard deviations.

References

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