

# Training the brain to resist:

## fMRI-based Neurofeedback for Food-Salience Network Activity Modulation in Chocolate Lovers

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### Introduction

The modern food environment is characterised by persistent exposure to highly palatable, energy-dense foods, with robust evidence indicating that those contribute to habitual overeating and weight gain. Although food cues reliably elicit activation in reward-related and visual cortices (Hill *et al.*, 2005), evidence that these responses are consistently enhanced is inconsistent (Vartanian *et al.*, 2025), suggesting limited diagnostic specificity and a more general role in motivational processing. In contrast, converging evidence indicates that attentional focus — the evaluative framing of food stimuli — systematically modulates neural responses during food cue processing (de Almeida Ivo *et al.*, 2025; Kochs *et al.*, 2023; Pimpini *et al.*, 2022), engaging a distributed frontoparietal network associated with salience attribution. In our previous work, this food-salience network was identified as comprising the left inferior, middle, and superior frontal gyri together with the right inferior parietal lobe (de Almeida Ivo *et al.*, 2025). The present study tests whether real-time fMRI neurofeedback can downregulate activation in this food-salience network during exposure to chocolate cues and whether such modulation is associated with changes in subjective craving and consumption. We hypothesise that, relative to a yoked-feedback control condition, neurofeedback will reduce food-salience network activation, decrease chocolate craving, and reduce chocolate intake, and that the magnitude of neural downregulation would translate to these behavioural changes.

### Methods

This study employed a randomized controlled single-session design comparing a real-time fMRI neurofeedback group with a yoked-feedback control group. A total of 30 healthy adults (BMI 18.5–25; high chocolate liking  $\geq 75/100$ ; no history of eating disorders) were recruited from Maastricht University. The intervention consisted of motivational real-time fMRI neurofeedback in which participants viewed chocolate images and were instructed to downregulate activity in the food-salience network. Neurofeedback information was embedded directly in the stimulus, with vertical image movement reflecting moment-to-moment changes in fMRI-activation level. The primary outcome was the fMRI-activation level within the food-salience network, measured during regulation. This neurofeedback-target network was individually defined using an individual functional localizer, within a predefined group-level mask (de Almeida Ivo *et al.*, 2025). The top 10% most responsive voxels (based on hedonic vs. neutral attentional focus contrasts) were selected to define participant-specific regions of interest (ROIs). Secondary outcomes included self-reported chocolate craving and hunger (0–100 visual analogue scales), and behavioral chocolate intake, assessed using an *ad libitum* bogus taste test (grams consumed converted to kilocalories). Assessments were collected within a single session at three points: pre-intervention (baseline craving and hunger ratings), during the experiment (fMRI localizer and neurofeedback regulation), and post-intervention (craving, hunger, and chocolate intake).

### Results

Participants in the neurofeedback group demonstrated significantly lower activity in the food-salience network compared with the control group ( $t(28) = -2.57$ ,  $p = 0.006$ ,  $d = -1.09$ ; mixed-effects  $\beta = -0.334$ ,  $p = 0.004$ ), indicating successful neural self-regulation in the desired direction. Baseline activation within the target network did not differ between groups ( $p = 0.91$ ). A small decline in modulation was observed across runs (\*Run 4 vs. Run 1:  $p = 0.013$ ), with no Run  $\times$  Group interactions.

Contrary to hypotheses, the neurofeedback group exhibited a greater increase in self-reported craving from pre- to post-session compared with the control group (Time  $\times$  Group:  $F(1,28) = 6.13$ ,  $p = 0.02$ ; increase in NF,  $p < 0.001$ ; no change in controls,  $p = 0.29$ ). No significant group differences were observed for chocolate intake ( $p = 0.32$ ). Furthermore, the decrease in activity was not significantly associated with changes in craving or intake (*all*  $p > 0.5$ ), indicating a dissociation between neural and behavioral effects.

## Conclusions

These findings indicate that rt-fMRI neurofeedback can enable voluntary modulation of a distributed food-salience network under tightly controlled conditions. Real-time fMRI neurofeedback targeting the food-salience network may therefore provide a non-invasive approach to modulate attentional and motivational processing in response to food cues. However, the absence of behavioural transfer highlights the need for further investigations, possibly using repeated longer-term interventions by, e.g., more ecologically valid and cost-effective approaches, such as portable neuroimaging (e.g. fNIRS), to characterise the time-dependent relationship between neural modulation and behavioural change in naturalistic settings. The present findings support a shift from static reward-reactivity models towards dynamic and trainable accounts of attentional salience, in which hedonic value is flexibly constructed rather than fixed. This offers a more optimistic view of food-related motivation, in which individuals may exert measurable influence over the neural processes that shape their responses to food cues.

## Figures (optional, only if needed)

## References (optional, maximum 6)

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