Intermittent Compared to Continuous Real-time fMRI Neurofeedback Boosts Control of Amygdala Activity

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Introduction

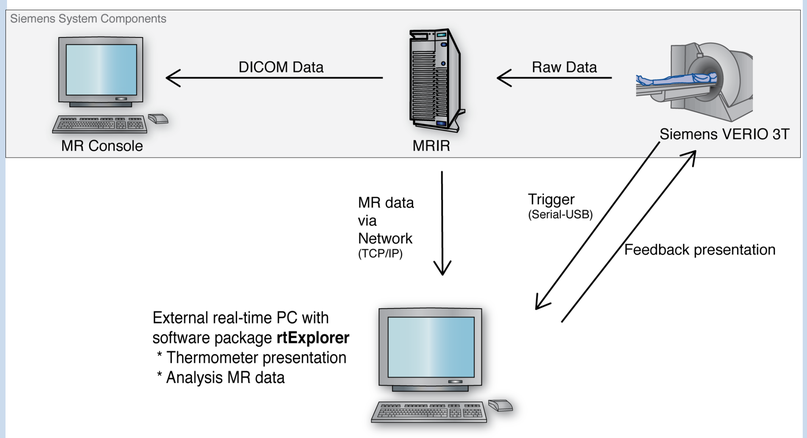
Real-time fMRI (rt-fMRI) neurofeedback (NF) allows participants to dynamically self-regulate activation in several brain regions through the evaluation and adaptation of mental strategies [e.g., 1, 2, 3]. However, there are several technical challenges in the field of rt-fMRI [4]. One outstanding issue is the timing of NF presentation to guarantee optimal performance.

In many studies NF was presented continuously [e.g., 1, 2, 5]. Although this kind of NF provides participants with a maximum of information, it might distract from the experimental task. Alternatively to continuous NF delivery some studies averaged the BOLD signal over longer intervals and presented NF intermittently [6, 7, 8]. Intermittent NF seems to improve learning to self-regulate brain activity at least under some conditions [9].

Here, we compared self-regulation performance of amygdala activity via positive mood between participants receiving continuous or intermittent NF. In addition, we explored whether amygdala regulation could be trained without any NF. Our results showed that intermittent neurofeedback boosts learning to control amygdala activity

Methods

1 Rt-fMRI and NF setup



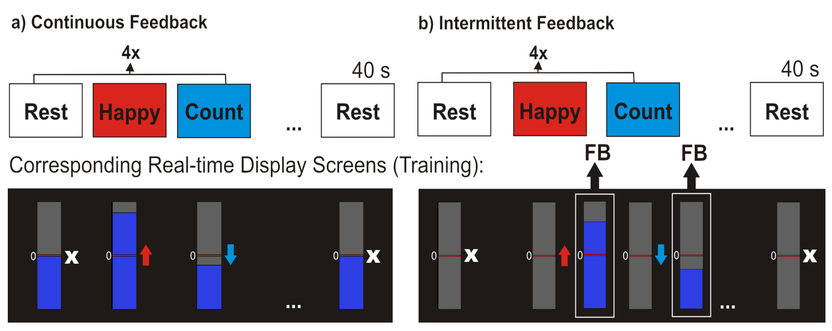
MR data acquisition:

- EPI-sequence on Siemens 3T VERIO: TR = 2 s, TE = 25 ms, matrix size=64 x 64 voxel, bandwidth = 1953 Hz, flip angle = 90˚, voxel size: 3 x 3 x 2.6 mm^3, AC/ PC aligned

Online data analysis rtExplorer:

- Feedback signal: averaged BOLD signal of ROI (CON: mean of last 3 volumes, INT: mean of preceding block)

2 Training Sessions

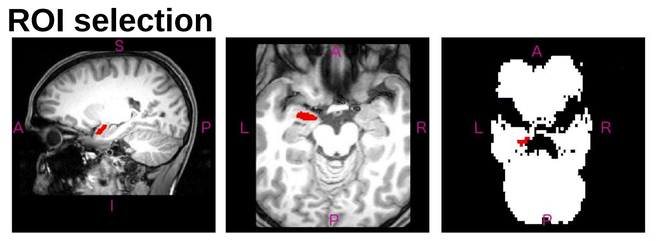


Experimental paradigm:

- **Task:** generate a positive mood by positive memories or creation of general positive feelings [10]
- **Sessions**: Practice, 3 x Training, Transfer (same task, no NF)

- **Continuous NF (CON, n=16):** Feedback update after each TR
- **Intermittent NF (INT, n=18):** Feedback update after each block (Happy, Count)
- **No Feedback group (NOF, n=8):** NF thermometer visible, but inactive → no feedback presentation

3 ROI selection



Region of interest (ROI):

- left amygdala (following [10])
- manual individual mask creation with FSL
- presented NF based on BOLD signal of this region

Offline data analysis:

- SPM 8: GLM regressors for training and transfer runs
- SPSS: ROI-based group analysis for mean signal change
- Linear trend analysis: to assess success of training within every group; separate repeated measures ANOVAs were performed (within-subject factor: run)
- 4x2 repeated measures ANOVA (restricted to NF groups): to assess potential main effects or interactions of run (within-subject factor, 4 levels) and group (between-subjects factor, 2 levels) on learning performance

Results

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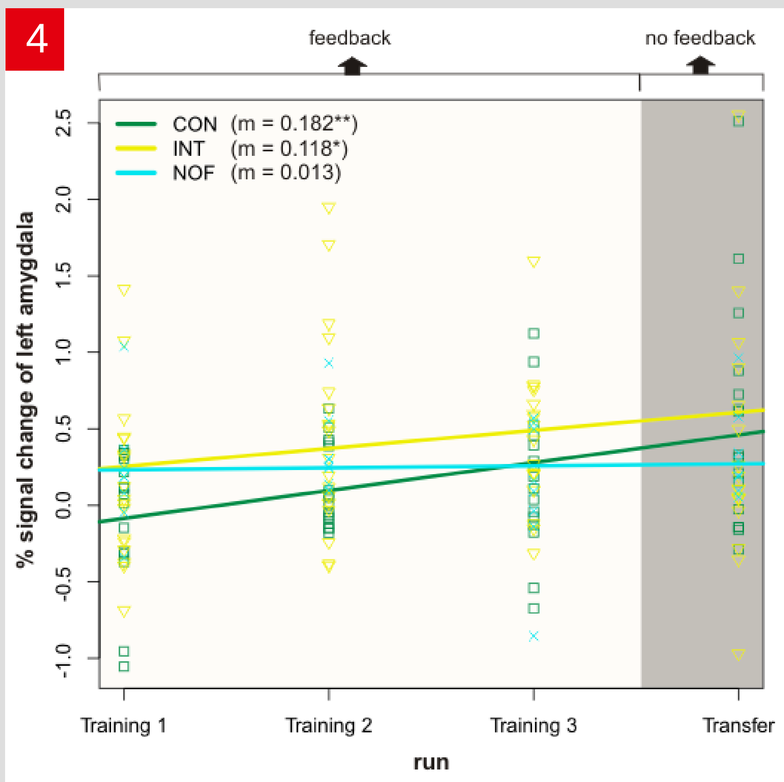

Fig. 4: Linear trend analysis of the 4 experimental runs. Depicted are the individual values of the 3 training runs as well as the transfer run of each group (CON: continuous feedback, INT: intermittent feedback, NOF: no NF).

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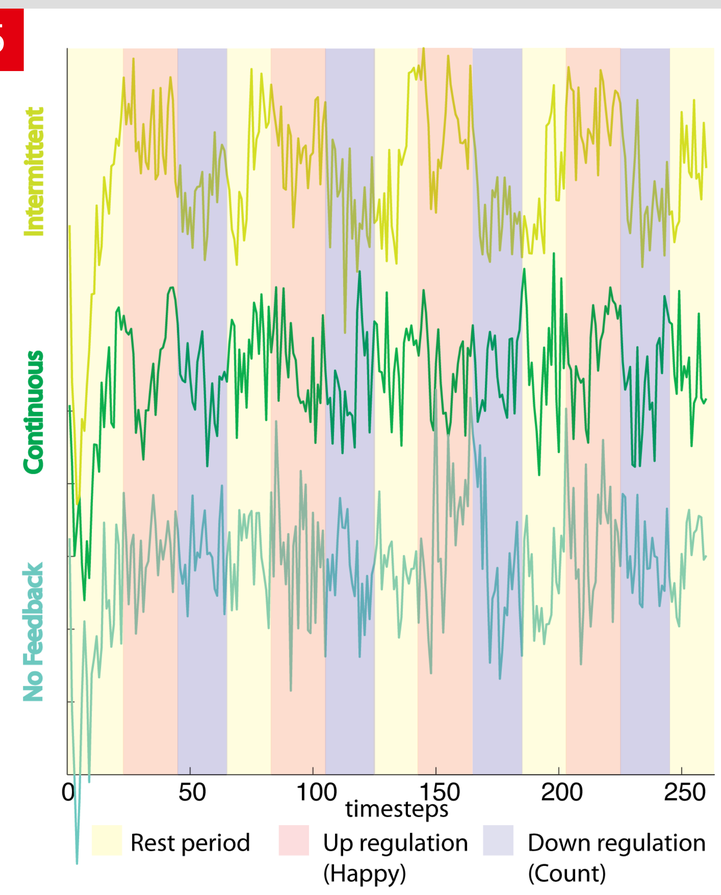

Fig. 5: Averaged timecourses for groups. Depicted are the averaged timecourses for the groups in the 3rd training run.

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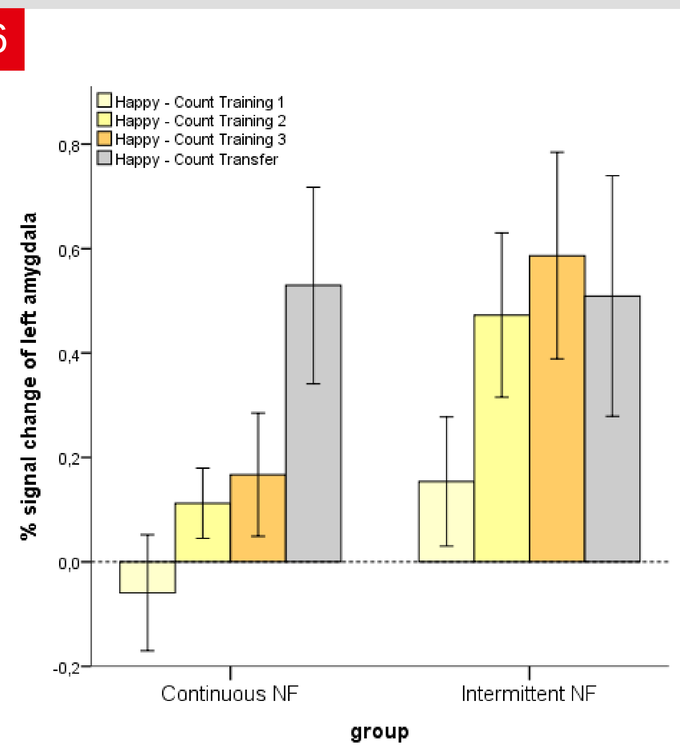

Fig. 6: % fMRI BOLD signal change (Happy vs. Count) of the left amygdala (mean ±s.e.). Depicted are the 3 training runs as well as the transfer run of the two NF groups (CON: continuous feedback, INT: intermittent feedback).

Success of training:
Self-regulated **amygdala activation progressively increased across the experiment in the feedback groups** (linear trend: CON: F(1,14)=9.326, p=0.009; INT: F(1,16)=4.714, p=0.045), **but not the control group**. Therefore, we considered the group without NF presentation (NOF) not to learn self-regulation of the amygdala. Due to the linear trend, both NF groups, on the other hand, are assumed to learn amygdala regulation by the help of NF.

Comparison of timecourses:
The averaged timecourses over all subjects from the different groups show that **participants who received intermittent feedback could follow the feedback instructions most precise** (Correlation coefficients for INT: r = 0.45, p < 0.001; CON: r = 0.13, p < 0.03; NOF: r = 0.21, p < 0.12)

Comparison of different kinds of neurofeedback (CON vs. INT):
Repeated measures ANOVA revealed a significant **main effect of run** (F(3,29)=10.427, p=0.003) and **group** (F(1,29)=5.202, p=0.013). Due to the group effect, we assume the NF groups to differ regarding their performance over the course of the whole experiment. More specifically, **participants receiving intermittent NF outperformed those receiving continuous NF**.

Discussion

This study showed that **NF** was **necessary to learn self-regulation of amygdala activity**. Moreover, although both NF groups learned to regulate amygdala activation, the group receiving **intermittent NF outperformed the continuous NF** group.

As continuous feedback is updated after each acquired volume, it provides participants with a maximum of information. Johnson et al. (2012) also mentioned that continuous feedback may induces greater interest or engagement in the task and ensures high attention. Nevertheless, there might be some constraints inhibiting participants' learning.

Participants have to associate feedback to mental events that occurred several seconds prior (temporal delay ~6s, due to the character of the hemodynamic response) while simultaneously evaluating the feedback and still engaging in the experimental paradigm. In the end this **might distract from the task**.
Although in **intermittent** paradigms the NF signal is averaged over longer periods, a **reduction of** the afore mentioned **distracting factors** probably outweighs this disadvantage.
That's why we **recommend usage of intermittent NF** over continuous NF for paradigms where subjects know about the strategy to be used. As rt-fMRI experiments are per se rather exhausting, less distracting NF probably helps to improve performance in future NF tasks.

References

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