

Individualized Gamma Neurofeedback: Associations Between Individual Gamma Frequency Modulation and Auditory Working Memory in Healthy Elderly Adults

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Background: Gamma-band (>30 Hz) neural oscillations are implicated in sensory and cognitive functions and exhibit alterations in various neuropsychiatric conditions. Gamma-based neurofeedback (NFB) represents a promising noninvasive neuromodulation approach. We developed an individualized EEG-NFB system based on gamma auditory steady-state responses (ASSR), targeting individual gamma frequency (IGF). The present study was aimed at testing the system in healthy older adults, assessing its potential effect on auditory working-memory performance.

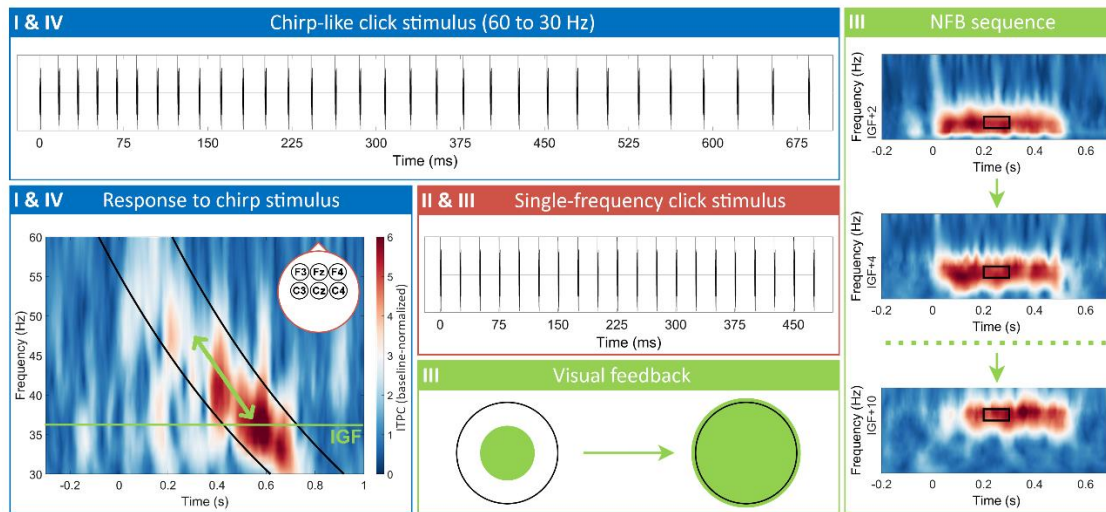


Figure 1. Single session full NFB procedure consisted of: I. IGF extraction using chirp-like click stimulation and time-frequency analysis. II. Reference response at IGF estimation using single-frequency click stimulus. III. NFB with auditory click stimulation above IGF using online visual feedback with the aim of reaching reference response at IGF.

Methods: 26 healthy elderly subjects (aged 69.5 ± 5.5 , all F) participated in 4 NFB sessions on separate days. Participants were randomly assigned to experimental ($N = 16$) and sham-NFB control ($N = 10$) groups. During NFB training, participants underwent multiple runs of periodic stimulation at a frequency above IGF (estimated using 30-60 Hz chirp stimulus) while observing real-time visual feedback representing online changes in ASSR. Each time a pre-defined response goal was successfully reached, stimulation frequency increased in a 2-Hz step; if participants failed to reach the goal, stimulation with the same frequency was repeated. Auditory 2-back performance was assessed at baseline, after session 2, and session 4. Mixed-effects linear models were used to examine changes in EEG and behavioral measures across sessions and measurements. Within the experimental group, NFB success rate over repeated NFB runs was used as a measure of NFB responsiveness.

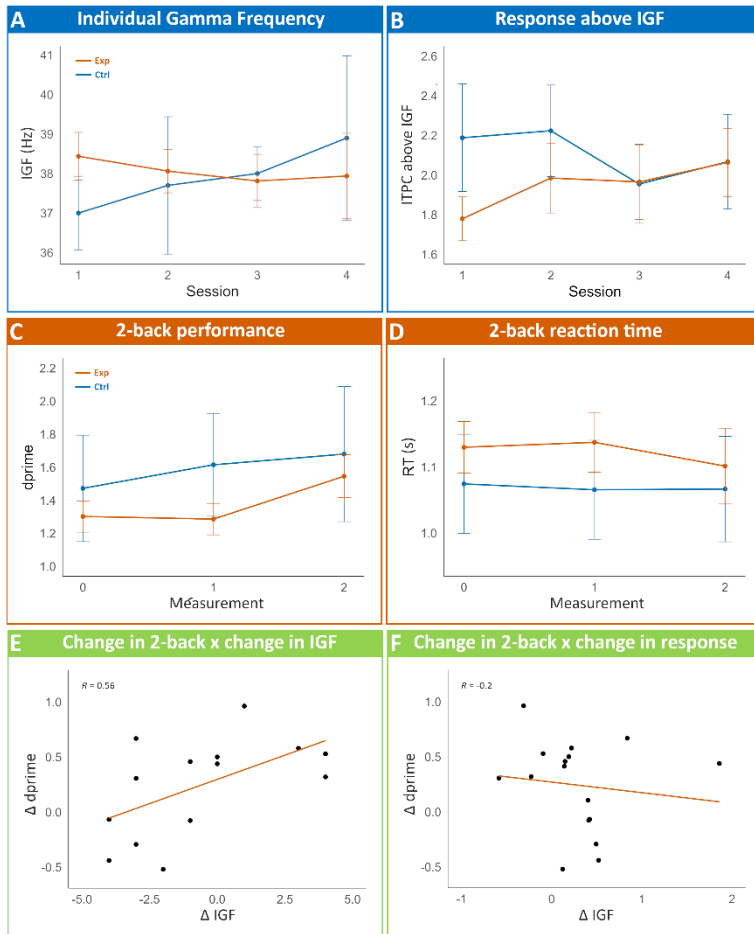


Figure 2. Top panel – IGF (A) and response above IGF (B) change across sessions. Middle panel – 2-back performance expressed as dprime (C) and reaction time (D) across measurements. Bottom panel – correlation between IGF change (E) and response above IGF change (F) and 2-back dprime. Correlations are presented for visualization, statistical evaluation was performed using mixed effects linear models

Results: NFB success rate tended to increase across sessions within the experimental group, although statistical significance was not reached ($\beta = 0.04, p = 0.075$). No significant group, session, or group $\times$ session effects were observed for baseline IGF ($p > 0.18$). However, within the experimental group, NFB success rate predicted subsequent increases in baseline IGF, as indicated by a significant session $\times$ success rate interaction ($\beta = 4.44, p = 0.01$). For responses above IGF, a significant group $\times$ session interaction ($\beta = 0.14, p = 0.03$) was observed. Auditory 2-back performance (dprime) showed no significant group, session, or group $\times$ session effects ($p > 0.15$). Nevertheless, the relationship between changes in baseline IGF and auditory 2-back performance differed significantly between groups (Group $\times$ Δ IGF interaction: $\beta = 0.08, p = 0.03$). Specifically, participants in the experimental group exhibiting larger increases in IGF from the first to the final session demonstrated greater improvements in auditory 2-back dprime. In contrast, neither changes in responses above IGF nor their interaction with group significantly predicted changes in auditory 2-back performance ($p > 0.28$).

Conclusions: Repeated individualized IGF-targeted neurofeedback was associated with enhancement in auditory responses above IGF. Although group-level changes in IGF and working memory performance were not observed, successful neurofeedback training predicted subsequent increases in IGF, and greater IGF increases were associated with improvements in auditory working memory. These findings suggest that individualized gamma-frequency neurofeedback may facilitate neurophysiological changes linked to cognitive benefits in healthy older adults. However, substantial inter-individual variability was observed, highlighting the importance of identifying individual factors associated with NFB responsiveness.