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Beta Neurofeedback Training Improves Attentional Control in the Elderly

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Abstract

One of the well-documented behavioral changes that occur with advancing age is a decline in executive functioning, for example, attentional control. Age-related executive deficits are said to be associated with a deterioration of the frontal lobes. Neurofeedback is a training method which aims at acquiring self-control over certain brain activity patterns. It is considered as an effective approach to help improve attentional and self-management capabilities. However, studies evaluating the efficacy of neurofeedback training to boost executive functioning in an elderly population are still relatively rare and controversial. The aim of our study was to contribute to the assessment of the efficacy of neurofeedback as a method for enhancing executive functioning in the elderly. We provided a group of seniors with beta up-training (12–22 Hz), consisting of 20 sessions (30 minutes each), on the Cz site and tested its possible beneficiary influence on attentional control assessed by means of the Stroop and Simon tasks. The analysis of the subjects' mean reaction times during consecutive tasks in the test and the retest, after implementation of neurofeedback training, showed a significant improvement. In contrast, the difference in reaction times between the test and the retest in the control group who had not been submitted to neurofeedback training was not significant.

Keywords

Aging, attentional control, neurofeedback, EEG rhythms

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Introduction

The considerable increase in life expectancy which has been observed in modern societies is also associated with a burden of age-related conditions like decline in cognitive performance (Reis et al., 2016). Age-related cognitive impairments entail high personal, social, and financial costs (Lustig, Shah, Seidler, & Reuter-Lorentz, 2009). This is why the research on cognitive aging is growing in importance and calls for the pursuit and development of effective and widely available intervention approaches that can minimize or, ideally, reverse these effects of aging.

Age-related cognitive changes are often thought to be fundamentally caused, or at least mediated, by variables which are defined in terms of a distinct theoretical construct of executive functions or executive functioning (Braver & West, 2011). Despite the controversy and confusion as to which cognitive and behavioral processes fall under the purview of executive functioning, and as to whether they are independent of one another or rather represent different aspects of a single construct, the concept has been broadly defined as the control processes responsible for planning, assembling, coordinating, sequencing, and monitoring other cognitive operations. Executive functioning is therefore believed to have the potential to affect performance in a wide variety of cognitive variables, although the processes which they represent may essentially remain intact (Salthouse, Atkinson, & Berish, 2003). This makes research on the age-related decline of executive functioning and the need for methods to treat it even more relevant.

Regardless of the theoretical outlook on the construct of executive functioning, the concept encompasses attentional control. There is also a consensus that it refers to selection (Liu, Banich, Jacobson, & Tanabe, 2004) which can occur at the perceptual stage of processing (with regard to a specific attribute of the object) or at the response stage (involving a certain bodily reaction). Commonly used paradigms to examine attentional control are the Stroop and Simon tasks. The Stroop effect refers to the interference people experience when two attributes of the same stimulus conflict with each other. The Simon effect refers to the interference people experience when there is a stimulus–response conflict.

In the classic version of the Stroop (MacLeod, 1992; Stroop, 1935), subjects are required to name the color of the ink in which a word is written while ignoring the meaning of the word. Reaction times (RTs) to naming the ink color are typically slower when the name of the word is incongruent (e.g., the word red in blue ink) relative to when it is congruent with the color name word (e.g., the word red in red ink). This interference effect from the meaning of the word on naming its color is supposed to reveal our problems in attending selectively to one component of a multidimensional stimulus while ignoring an automatized, that is, an over learned, response to another.

The Simon task serves to study competition at the stimulus–response level (Simon & Small, 1969). It assesses the extent to which the dominant association to irrelevant spatial information affects subjects' response to task-relevant non-spatial information. Their performance of the incongruent trials on which one must give a response that is spatially incompatible with the stimulus (e.g., responding with the right hand to the color of a stimulus presented on the left side of visual field) is compared to that of the congruent trials (e.g., responding with the right hand to the color of the stimulus presented on the right side). Typically, responses are longer for the incongruent as compared to congruent stimuli (for a review, see Proctor & Reeve, 1990).

Neuroimaging studies show that these two measures of attentional control activate the same brain regions, namely, the dorsolateral prefrontal cortex and the dorsal anterior cingulate cortex. However, each of them appears to activate unique brain regions as well. The regions significantly more activated by the Stroop task are the inferior and posterior parietal cortex, which are involved in biasing the processing toward the task-relevant attribute. In contrast, the Simon effect usually also activates supplementary motor areas, precuneus, and visuo-spatial–motor association areas, which are involved in the detection of response conflict, response selection, and planning (Liu et al., 2004).

The Stroop task and the Simon task have also played a prominent role in theories of cognitive aging. For example, it has been found that in the Stroop task, older adults demonstrate a greater color-word interference effect than the younger ones (Verhaeghen & De Meersman, 1998; West, 1999). This interference has also been found to accelerate especially at a later age (Uttl & Graf, 1997; van Boxtel, ten Tusscher, Metsemakers, Willems, & Jolles, 2001). van der Lubbe and Verleger (2002) found a larger Simon effect in a group of older adults than in a comparable group of young ones, even after correcting for the general slowing associated with aging.

The progressive decline in cognition that occurs with nonpathological aging, particularly in general processing speed, encoding new memories of episodes or facts, and such aspects of executive functioning as working memory or attentional control, is associated with well-documented underlying neurobiological factors (Hedden & Gabrieli, 2004). Age-related changes in neural structure and function have mostly been found in the prefrontal, parietal, and medial temporal regions. These changes are related to the lower volume of gray matter in older brains which is a consequence of smaller synaptic density rather than cell death. The changes are involved in decreases in the level of neurotransmitters like dopamine, noradrenaline, and serotonin. The loss of integrity has also been documented in the frontal white matter tracks, which affects the interaction between the prefrontal cortex and structures such as the hippocampus and stratum (Hedden & Gabrieli, 2004; Raz & Rodrigue, 2006).

Decreases in neuronal connectivity that are paired with age-related poorer cognitive performance manifest themselves in oscillatory activity which is thought to play a key role in the process of brain network integration. The electroencephalography (EEG) recordings show generally slower EEG activity at advanced ages (Giaquinto & Nolfe, 1986; Prichep, 2007) such as, for example, in the enhanced parietal and temporal delta band (1–4 Hz) oscillation (Breslau, Starr, Sicotte, Higa, & Buchsbaum, 1989). Theta coherence and alpha coherence between frontal and fronto-parietal regions, as well as the alpha peak frequency in those regions in the left hemisphere, have also been shown to decrease with age (Dias et al., 2015). Theta (4–8 Hz) and alpha (8–12 Hz) oscillations have been linked to tasks involving working memory and attentional control (see, e.g., Klimesch et al., 1996, 1999). Also, a decrease of beta band oscillation (12–30 Hz) is considered as a marker of unhealthy aging and a predictor of the progression from mild cognitive impairment to dementia (see Rossini et al., 2013).

The relationship between cognitive performance and EEG signals suggests that EEG features in specific cortical sites may be used as targets of neuromodulation approaches. One of the methods that may serve this purpose is neurofeedback (NF). It aims at acquiring self-control over certain brain activity patterns, deriving self-regulation strategies, and implementing them in daily life (Gevensleben et al., 2010). NF functions by giving feedback to the subjects about their electrophysiological state and directing it to the desired activity via a brain–computer interface. It has been used in such clinical conditions as autism spectrum disorder (Coben, Linden, & Myers, 2010), depression (Hammond, 2005), and epilepsy (Egner & Sterman, 2006).

NF is also considered as a potentially effective treatment approach to improving the attentional and self-management capabilities in patients with attention-deficit hyperactivity disorder (ADHD) (Gevensleben et al., 2010, 2014) who show a neuropsychological profile (for review, see Barkley, 1997; Monastra et al., 1999) which bears some resemblance with the one outlined earlier for the elderly. For example, Mullane, Corkum, Klein, and McLaughlin (2009) showed that children with ADHD exhibited a longer RT and higher percentage of errors on incongruent relative to congruent trials in the Simon task than in a control group. Bush et al. (1999) also demonstrated the lower activity of the anterior cingulate cortex while performing the Stroop task by ADHD subjects, supposedly resulting in their poorer scores. Since deficits in the executive functioning of the ADHD patients have been linked to the reduced activity of their frontal lobes, one of the standard NF protocols used in this case is theta/beta training which aims at reducing the amplitude of activity at slower EEG frequencies (4–8 Hz) and increasing activity at faster frequencies (13–20 Hz) in the frontal regions of the brain (Gevensleben et al., 2014; Monastra et al., 2005) or variants of it (Arns, Heinrich, & Strehl, 2014; Rossiter & LaVaque, 1995).

To our knowledge, studies evaluating the efficacy of NF training to boost executive functioning in an elderly population are still rare and controversial and focus rather on a limited number of training protocols. For example, the relevant research lack information regarding the ability of NF to alter beta band amplitude in order to improve attentional performance in the elderly, although this is the oscillatory frequency which has already been recognized as an attention carrier (Fan et al., 2007; Wróbel, 2000, 2014;). Wróbel (2000), for example, reports several studies linking enhanced beta activity with increased visual attention in animals and humans. He also highlights research results suggesting that attention-related bursts of beta activity correlate in time with flanking alpha (e.g., Mundy-Castle, 1951) and gamma (Bekisz & Wróbel, 1999) bands which are supposed to serve as mechanisms for the idle arousal of the visual network and for feature integration, respectively. The author then develops a hypothesis assuming that the beta band is to be a key component of the dynamic perceptual system. The system would consist of the alpha oscillation characterizing its idle arousal and the beta band which shifts it into an attention mode that allows for gamma synchronization as the neural substrate of perception (Wróbel, 2000). The beta band has been reported to decline with age (Huang et al., 2000) which is supposed to result in attentional deficits in an elderly population. The question then arises concerning the efficacy of NF training as a method to up train the power of beta activity in the elderly as one which could rebuild their attentional resources. The existing limited number of studies on NF training aimed at increasing beta band activity in a healthy population have so far either been applied to improve other cognitive functions in the elderly (Staufenbiel et al., 2013) or attentional skills but in younger adults (Jurewicz, Paluch, Kublik, Mikicin, & Wróbel, 2018). There are also studies evaluating the ability of NF trainings to alter theta and alpha bands to boost executive functioning in an elderly population (Becerra et al., 2012; Reis et al., 2016). They are not, however, aimed at improving attentional skills either. Given the conceptual framework provided by Wróbel (2000, 2014) and the lack of research on the efficacy of NF to enhance the beta power as an attention carrier in the elderly our study may be considered as helping to fill this gap.

Following those theoretical and empirical premises, we decided to study the behavioral effects of beta (12–22 Hz) NF training in attentional control of the elderly as measured by the Stroop and Simon tasks. If NF improves this aspect of executive functioning, then the subjects' performance on these behavioral tasks should increase in the posttest as compared to the pretest but only in the NF training group. Such an improvement should not occur in a control group in which the subjects completed behavioral tasks twice (in the test and the retest) but have not been submitted to the NF training in between.

Methods

Participants

Fifteen students (4 males and 11 females) of the University of the Third Age took part in this study and were aged from 66 to 75 years (mean = 73 years, standard deviation (SD) = 5.7). All of them had at least completed tertiary education. Only subjects without any diagnosed neuropsychiatric and/or neurodegenerative disorder were recruited according to a standard survey. They were randomly divided into two groups: NFs (1) were meant to undertake NF training ($N = 7$; two males, five females; mean = 72 years, SD = 7.02) and (2) were meant to be assessed in test and retests as a control group who would not undertake NF training ($N = 8$; two males, six females; mean = 74 years, SD = 4.56). The study was approved by the Research Ethics Committee at the Jesuit University Ignatianum in Krakow and carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). All the participants signed up voluntarily and were informed that they would be provided with clear and specific goals as well as the results of the experiment once it was completed.

Stimuli

Stroop task. There were four words displayed on the center of the screen. The RGB breakdowns for the stimuli were as follows: blue= 0, 39, 194; green = 0, 255, 38; red = 255, 0, 0; and yellow = 255, 215, 0. The words were written in courier new font, 40 point, bold. All stimuli were presented in the white background (RGB: 252, 252, 252).

Simon task. There were two targets (blue and red squares subtending 2° of arc) displayed 4° to the left or the right of the fixation point ($1^\circ \times 1^\circ$ gray cross) on the center of the screen. The RGB breakdowns for the stimuli were as follows: blue = 0, 39, 194 and red = 255, 0, 0. The stimuli were presented in the white background (RGB: 252, 252, 252).

Apparatus and procedure

Participants were seated 60 cm away from a 18-inch LED monitor (85-Hz refresh rate). Stimulus presentation and data collection were controlled by a Pentium PC. Behavioral tasks were run using DMDX software, while the BioGraph Infiniti 5.1.2 software for the ProComp 5 Infiniti hardware (Thought Technology Ltd.) were used for NF training. The design of the study is illustrated in Figure 1. It consisted of three parts: a test and a retest for both groups and NF training for the experimental group or an interval lasting two weeks for the control group, in between.

Measures of attentional control. During test and retests, all participants were submitted to the Stroop task and the Simon task. The order of tasks was balanced across subjects.

In the Stroop task, the participants were asked to identify the color (blue, green, red, and yellow) of color words displayed on the center of the screen in

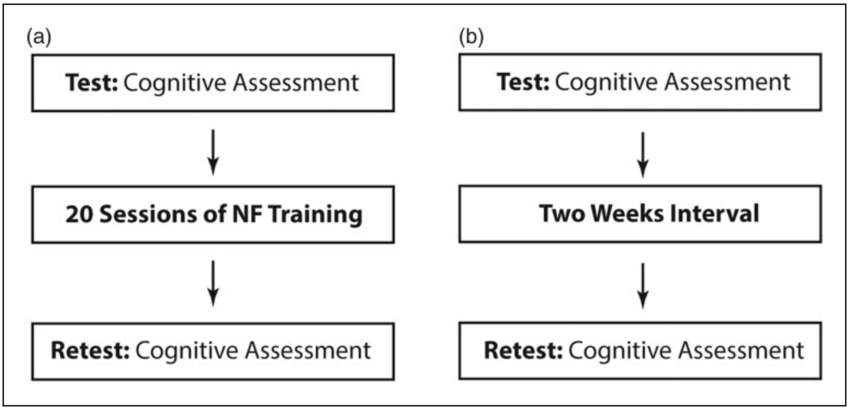

Figure 1. Schematic illustration of the design of the study which shows its phases in (a) experimental and (b) control groups. NF: neurofeedback.

neutral (congruent) and interference (incongruent) conditions by pressing matching keys on a keypad. The tasks were counterbalanced across the group. For the half of the group, the experiment started with the neutral condition, while for the other half, the interference condition started first.

The task was divided into two parts: practice and experimental. The practice consisted of 80 congruent and 80 incongruent trials. After each trial, the participant was provided with feedback written on the screen: *correct*, *incorrect*, or *try to be faster*. The experimental part consisted of 120 neutral and 120 interference trials in five blocks of 24 trials with mandatory 1-minute breaks between the blocks. In each condition (congruent and incongruent), the trials were presented in the randomized order. In this session, there was no feedback. Each time the word was presented until a response was elicited or for 5000 milliseconds. The time interval between trials was 200 milliseconds. The Stroop task conditions (mean RT in congruent and mean RT in incongruent trials) was a dependent measure.

In the Simon task, participants were seated in front of a monitor with their eyes fixed at a central fixation cross, hands stretched comfortably in front, the right index finger on a red key (the left shift), and the left index finger on the blue one of a keyboard (the right shift). They were instructed to press one of the keys matching the color of the square appearing in either the right (red in congruent and blue in incongruent trials) or in the left (blue in congruent and red in incongruent trials) half of a computer screen. The task was divided into two parts: practice and experimental. The practice consisted of 32 trials. After each trial, the participant was provided with feedback written on a screen: *correct*, *incorrect*, or *try to be faster*. The experimental part consisted of 120 congruent and 120 incongruent trials in two blocks of 120 trials with mandatory 2-minute breaks between the blocks. Each time the stimulus was presented for 200 milliseconds. The trial lasted until the response was executed or for 1000 milliseconds. The time interval between them was 1000 milliseconds. The Simon task conditions (mean RT in congruent and incongruent trials) was a dependent measure.

NF training. The training aimed at increasing the amplitude of beta rhythm (beta 1). Its frequency was defined as 12 to 22 Hz. EEG biofeedback continued through 20 sessions over a period of five to seven weeks. The subjects were seen three to four times a week for 45-minute meetings that included 30 minutes of NF training. The active electrode was placed at Cz, using the 10 to 20 International System, with a reference electrode on the left ear and a ground electrode on the right ear. Skin preparation was conducted according to recommendations by the equipment manufacturer. Electrodes were attached with a conductive paste. Impedance was maintained below 10 kΩ, and the signal was sampled at 256 Hz. The artifact rejection thresholds were set to suspend feedback in case of significant EEG variations. The ongoing EEG at the site Cz was fast Fourier transformed. The bandpass filtered between 0.1 to 60 Hz with a notch filter at 50 Hz in order to eliminate electrical interference and continuously measure the amplitude value for the beta band (12–22 Hz). Feedback information was provided visually in the form of animated graphics shown on a computer screen and put in motion as a reward controlled by the value of the band amplitude. The subjects were told that particular brainwaves would start the animation and that they had to find out themselves how to generate these brainwaves. The trainer's display on another screen contained a bar with the threshold defining the required value of the amplitude. The same threshold was set to be achieved by each participant to provide a relatively constant rate of reward across subjects. However, it could be adjusted manually by the trainers during the session if a participant consequently failed to receive any rewards. Initially, it referred to 50% of the maximum amplitude. When the amplitude reached this value, the reward was provided by moving the animation on.

Data analysis

The preparation of data for analysis concerning both tasks (the Stroop and the Simon) was conducted in an identical fashion. The data were first submitted to a descriptive analysis, and all error trials were excluded from further process (21% for the Stroop task and 15% for the Simon task). The responses were then submitted to a trimming procedure with a cutoff criterion of 2.5 SD using the "prepdat" R Package (Allon & Luria, 2016). For the remaining RTs, we calculated mean RTs and performed two separated analyses of variance (ANOVAs) for the training and the control group.

Results

Stroop task

In the training group, ANOVA for mean RTs showed a statistical significance for the main effect of Stroop task and Repetition of measurement. Both factors also interacted with one another. In the control group, ANOVA only showed a statistical significance for the main effect of Stroop task. Any other effects were not observed. We additionally performed a three-way ANOVA (Group × Stroop task × Repetition of measurement). Only the main effect of Stroop and the interaction of Stroop and Repetition were significant. The difference was not large enough for the three-way interaction to be statistically significant. The effects of individual factors are detailed later.

The data for the training group are shown in Figure 2(a). Stroop task (congruent and incongruent condition) and Repetition of measurement (test and retest) were the within-subject factors. There was a main effect of Stroop task with slower RTs in incongruent (1392 milliseconds; SD = 82) than in congruent (1042 milliseconds; SD = 52) condition ($F(1, 6) = 41.52$; $p < 0.001$, $\eta^2_p = 0.87$). The main effect of Repetition of measurement was also significant ($F(1, 6) = 13$, $p < 0.01$, $\eta^2_p = 0.68$). Furthermore, the experiment revealed a significant interaction between these two factors ($F(1, 6)=10$, $p < 0.05$, $\eta^2_p = 0.62$) which was caused by an incongruent condition: the RTs were 239 milliseconds (Cohen's *d* for differences

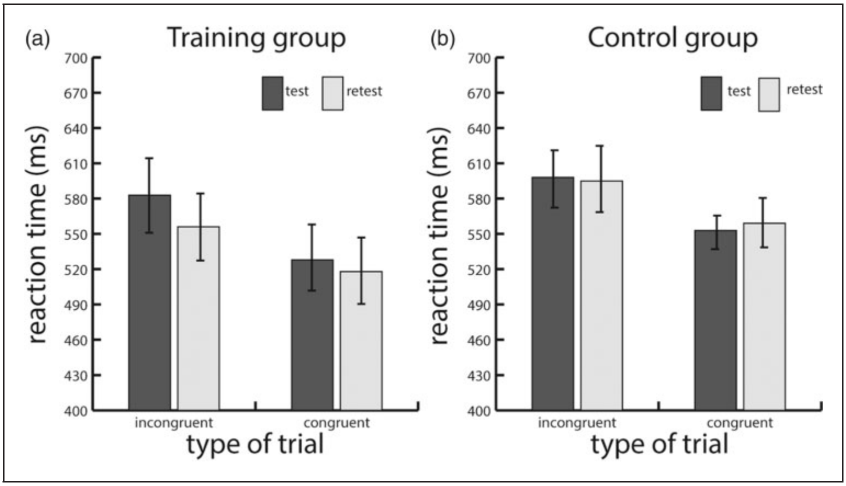

Figure 2. Mean reaction times in the Stroop task, for the neurofeedback training group (a) and the control group (b) as a function of the task condition and repetition of measurement (black bars as a test and gray bars as a retest). Only in an interference condition and for the training group was the test/retest difference statistically significant. Error bars show ± standard error of the mean.

(*d*diff) = 1.37) shorter in the retest (1272 milliseconds; SD = 55) than in the test (1511 milliseconds; SD = 74).

The data for the control group are shown in Figure 2(b). Stroop task (congruent and incongruent condition) and Repetition of measurement (test and retest) were the within-subject factors. There was a main effect of Stroop task with slower RTs in incongruent (1333 milliseconds; SD = 97) than in congruent (1070 milliseconds; SD = 47) condition ($F(1, 7) = 24.58$; $p < 0.01$; $\eta_p^2 = 0.77$). The main effect of Repetition of measurement (test and retest) was not significant ($F < 1$). The interaction between these two factors was also not significant ($F(1, 7) = 1.43$; $p = 0.27$).

We also ran an additional ANOVA in which we included Group (Training, Control) as a between-subject factor along with within-subject factors: Stroop task and Repetition of measurement. The main effect of Group was not significant ($F(1, 13) = 0.39$; $p = 0.54$). The interaction between Group and Stroop task was not significant ($F(1, 13) = 0.20$; $p = 0.65$) either. We also compared the subjects' performance of the task in both groups in the first measure of Stroop task which was not significant ($F < 1$). There was no significant main effect of Repetition of measurement ($F(1, 13) = 3.87$; $p = 0.07$), but the main effect of Stroop ($F(1,13) = 38.01$; $p < 0.001$; $\eta_p^2 = 0.77$) and the interaction between Stroop and Repetition ($F(1, 13) = 5.33$; $p < 0.05$; $\eta_p^2 = 0.32$) were significant. The difference was not large enough for the three-way interaction of Stroop × Repetition × Group to be statistically significant ($F(1, 13) = 0.11$; $p = 0.73$).

Simon task

In both training and control groups, the ANOVAs for mean RTs showed statistical significance for the main effect of Simon task but not for Repetition of measurement. However, only in the training group, there was a significant interaction between these two factors. This interaction was not observed in the control group. We also conducted an additional ANOVA analysis with Group as a within-subject factor and Simon task and Repetition of measurement as between-subject factors. Only the main effect of Simon and the interaction of Simon and Repetition were significant. The difference was not large enough for the three-way interaction to be statistically significant. The effects of individual factors are detailed later.

The data for the training group are shown in Figure 3(a). Simon task (congruent and incongruent condition) and Repetition of measurement (test and retest) were the within-subject factors. There was a main effect of Simon task with slower RTs in incongruent (569 milliseconds; SD = 40) than in congruent (523 milliseconds; SD = 41) trials ($F(1, 6) = 21.39$; $p < 0.01$; $\eta_p^2 = 0.78$). The main effect of Repetition of measurement (test and retest) was not significant ($F(1, 6) = 3.29$; $p = 0.1$; $\eta_p^2 = 0.35$). However, the experiment revealed a significant interaction between Simon task and Repetition of measurement ($F(1, 6) = 7.39$, $p < 0.05$, $\eta_p^2 = 0.55$) which was caused by an interference condition: the RTs were

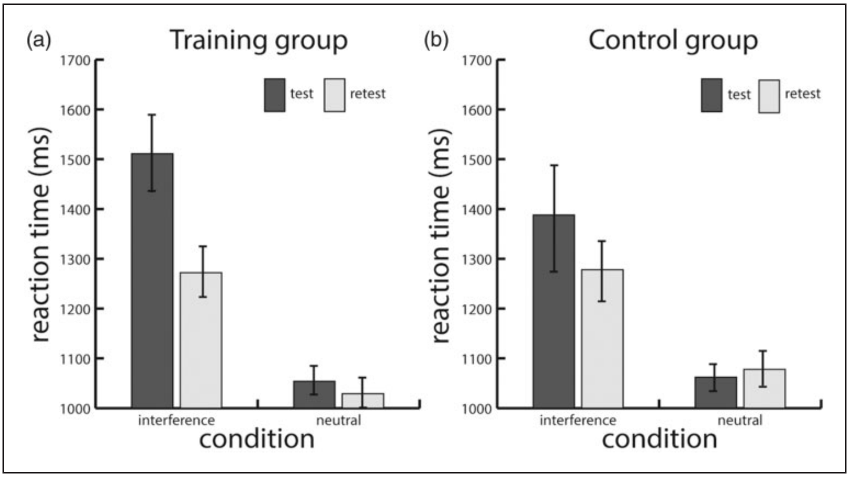

Figure 3. Mean reaction times (RTs) in the Simon task, for the NF training group (a) and the control group (b) as a function of type of trial (incongruent/congruent) and repetition of measurement (black bars as a test and gray bars as a retest). The Simon effect (incongruent RT *minus* congruent RT) was reduced only in the training group. Error bars show ± standard error of the mean.

27 milliseconds (*d*diff = 0.35) shorter in the retest (556 milliseconds; SD = 28) than in the test (583 milliseconds; SD = 30).

The data for the control group are shown in Figure 3(b). Simon task (both congruent and incongruent conditions) and Repetition of measurement (test and retest) were the within-subject factors. The Simon effect also occurred in this group ($F(1, 7) = 27.66$; $p < 0.001$; $\eta_p^2 = 0.80$) with slower RTs in incongruent (596 milliseconds; SD = 31) than congruent (556 milliseconds; SD = 30) trials. However, the interval between the first and the second measure (Repetition of measurement) turned out to be a factor which did not affect the results ($F < 1$). The interaction between these two factors was also not significant ($F(1, 7) = 1.96$; $p = 0.20$).

We conducted an additional ANOVA in which we included Group (Training, Control) as a between-subject factor along with within-subject factors: Simon task and Repetition of measurement. The main effect of Group was not significant ($F(1, 13) = 0.31$; $p = 0.58$) and the interaction between Group and Simon task was not significant ($F(1, 13) = 0.40$;$p = 0.53$) either. We also compared the performance of the task in both groups (the training and the control) in the first measure of the Simon task, and it was not significant ($F < 1$). There was no significant main effect of Repetition of measurement ($F(1, 13) = 0.27$; $p = 0.61$), but the main effect of Simon ($F(1, 13) = 45.93$; $p < 0.001$; $\eta_p^2 = 0.80$) and the interaction between Simon and Repetition ($F(1, 13) = 7.94$; $p < 0.01$; $\eta_p^2 = 0.42$) were significant. The difference was not large enough for the three-way interaction of Simon × Repetition of measurement × Group to be statistically significant ($F(1, 13) = 0.20$; $p = 0.65$).

Discussion

One of the well-documented behavioral changes that occur with nonpathological aging is a decline in executive functioning, for example, attentional control. Age-related executive deficits have mostly been associated with deterioration and a decrease of activity, mainly in the frontal regions of the brain. Widely available approaches which could minimize or even reverse these effects of aging without the risk of negative side effects are in high demand. NF is considered such a method (Egner & Gruzelier, 2001; Reis et al., 2016; Staufenbiel, Brouwer, Keizer, & van Wouwe, 2013). In our exploratory study, we aimed at assessing NF efficacy to improve attentional control in the elderly to be used as a relatively straightforward intervention. Given the interpretation of beta oscillation as an attention carrier (Fan et al., 2007; Wróbel, 2000, 2014), we conducted an experiment using a beta 1 (12–22 Hz) upregulation protocol to improve attentional control measured in the Stroop and the Simon tasks.

Our findings suggest that NF training improves attentional control in the elderly. The analysis of the subjects' RTs during consecutive tasks in the test and the retest after the implementation of the NF training showed a significant improvement in both tasks. The difference in RTs of the subjects in the control group during both tasks in the test and the retest was not significant. Since the scores obtained by the subjects in both groups in the test were comparable, these findings indicate that the NF training may be accounted for as the specific factor of the improvement in attentional control in the experimental group rather than a practice effect. Additionally, the improvement of performance on both tasks after NF training, even though the Stroop and the Simon tasks are supposed to reflect some different processes (Liu et al., 2004), suggests that they can still be seen as part of the same mechanism of executive functioning. Yet, the difference in the effect size between the interaction in the Stroop and the Simon may also suggest that both tasks involve the cognitive functions which do not overlap entirely. All these conclusions should be, however, voiced with some reservations since RTs of the subjects in the experimental group after NF training, although significantly shorter in the retest than the test, were not significantly shorter than RTs of the subjects during the retest in the control group.

It may be assumed that the mechanism responsible for this improvement involves the upregulation of frontal brain regions that serve as neural substrates of attentional control, for example, the dorsolateral prefrontal cortex, anterior cingulate cortex, or supplementary motor areas (Liu et al., 2004; MacDonald, Cohen, Stenger, & Carter, 2000). This activity also manifests itself in beta oscillation (12–22 Hz). Our results support this hypothesis, although such an inference is only indirect since, due to its exploratory character, our study did not measure brain activity. That is why it cannot be now ruled out that the behavioral effects which we have demonstrated may result from other factors. For example, the research of Jurewicz et al. (2018) shows that NF training aimed at upregulating beta activity (12–22 Hz) not only affected the trained beta band but also the flanking untrained alpha activity (8–12 Hz). The authors conclude that parallel changes in these two bands challenge the idea of frequency-specific NF protocols. The interdependence of particular neural oscillations makes it difficult to in this way confirm the precise relation between the activity of specific brain regions and cognitive functions. This doubt also applies to our results. Furthermore, it is also often the case that the successful upregulation of particular oscillatory activity as a result of NF training is not matched by changes in cognitive performance (see, e.g., Jurewicz et al., 2018; Staufenbiel et al., 2013) which raises even more doubts concerning not only the mechanism of NF but also our knowledge of the particular neuropsychological interactions. That is why there is a constant need for further development in research using neuroimaging techniques such as functional magnetic resonance imaging or near infrared spectroscopy.

Conclusion

The results of our study provide preliminary evidence that beta NF training is associated with improvements in Stroop response inhibition and Simon motor inhibition in the elderly as aspects of their executive functioning. Therefore, it could be considered as an auxiliary tool to be developed, implemented, and popularized in order to improve cognitive skills and quality of life in the general elderly population. However, as the main limitation of the study is the lack of physiological assessment, further investigation is needed to provide insight into the potential mechanisms underlying the achieved results.

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