Biological Psychology 95 (2014) 74–85

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Effect of beta and gamma neurofeedback on memory and intelligence in the elderly

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ARTICLE INFO

Article history:
Received 31 August 2012
Accepted 30 May 2013
Available online 7 June 2013

Keywords:
Gamma neurofeedback
Beta neurofeedback
EEG
Memory
Intelligence
Aging

ABSTRACT

Recent research showed a correlation between cognitive decline and a decrease of EEG gamma activity. In the present double-blind randomized control study, we investigated whether gamma and beta neurofeedback protocols, that have been shown to modulate performance on cognitive control and memory in young adults, also leads to increased brain activity and cognitive performance in elderly. Twenty older adults either performed eight 30-min gamma neurofeedback session or beta neurofeedback session within a period of 21 days. Cognitive performance was determined before and after the training through an IQ and memory task and we added a subjective well-being questionnaire. Both neurofeedback training protocols resulted in a significant increase of the brain activity within each training session, suggesting that the aging brain is still trainable. However, we found no effects on cognitive performance or transfer of the feedback beyond the trainings. We discuss several possible reasons for the lack of training on rest measurements and cognition and ways to improve the feedback protocols for future studies.

1. Introduction

Normal aging has been frequently reported to decrease cognitive performance and to affect neural features and brain activity. Studies on cognitive functions in healthy aging (i.e. in individuals who are free of overt diseases) show that elderly people perform worse than young adults on tasks measuring fluid intelligence (Horn & Cattell, 1967), episodic memory (Craik, 2000), and working memory (McEvoy, Pellouchoud, Smith, & Gevins, 2001). Fluid intelligence is the ability to reason and deal with complex information, and to think logically and abstractly by perceiving relationships independent of previous specific practice or instructions (Cattell, 1963). Episodic memory involves memory for details from specific contexts and can be differentiated into two distinct processes, recollection and familiarity (Mandler, 1980; Migo, Mayes, & Montaldi, 2012). Recollection occurs when a stimulus cues the recall of details linked to it in a previous encounter. Familiarity is experienced as the feeling that one has been exposed to a stimulus before without the recall of any associated details from prior exposure(s). Both recollection and familiarity can lead to recognition.

Older adults perform as well as younger adults on memory tasks that require a judgment about whether a stimulus has been seen before or not (which can be based on familiarity and/or recollection – Craik & McDowd, 1987), but worse when retrieval of the context information is also required (for which recollection is needed – Spencer & Raz, 1995). Evans and Wilding (2012) showed by means of magnetoencephalography (MEG) that recollection and familiarity are not simply strong and weak versions of the same process but contribute independently to respectively remember and know judgments.

Not only cognitive performance changes with age, but also brain activity patterns, which are measured by means of electroencephalography (EEG). EEG is the recording of electrical activity at the scalp and can be decomposed in different EEG frequency bands that to some extent reflect different cognitive, sensory and motor processes.

EEG beta band activity (12–20 Hz) has been associated with memory (Hanslmayr, Staudigl, & Fellner, 2012), language processing (Weiss & Mueller, 2012), motor functions (Baker, 2007) and attention (Fan et al., 2007). Egner and Gruzelier (2001) showed that specific bands within the overall range of the beta band frequency are associated with different functions. Enhanced low beta band rhythm over the motor cortex (12–15 Hz; sensorimotor rhythm, SMR) was associated with fewer commission errors and improved perceptual sensitivity on a continuous performance task, while the opposite behavioral results were found with enhanced

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http://dx.doi.org/10.1016/j.biopsycho.2013.05.020

beta in a higher frequency band (beta1; 15–18 Hz). In a recent review, Hanslmayr et al. (2012) related successful memory encoding and retrieval to a decrease in beta power (not specified to a particular range within the beta band).

EEG gamma band activity (>30 Hz) has been linked with fluid intelligence (Jaušovec & Jaušovec, 2005, 2007; Stankov et al., 2006) and memory functions (Fell, Fernandez, Klaver, Elger, & Fries, 2003; Jensen, Kaiser, & Lachaux, 2007; Sederberg et al., 2003). While both gamma and beta have thus been found to be implicated in memory functions, Keizer, Verment, and Hommel (2010) found that more specifically familiarity and recollection are reflected by different EEG frequency ranges; beta band activity (12–20 Hz) was associated with familiarity and gamma band activity (36–44 Hz) was associated with recollection.

With age, fast rhythms such as gamma have been found to decrease (Werkle-Bergner, Shing, Müller, Li, & Lindenberger, 2009) while power in the beta band has been found to increase (Marciani et al., 1994). These changes might be related to some of the mentioned alterations in cognitive functions. Obrist (1976) proposed that, as fast activity is prevalent among intellectually well-preserved individuals at the beginning of old age, its presence in the EEG of an old adult could be considered a good sign for healthy aging. Loss of gamma band synchronization has been found in patients with dementia (Stam et al., 2002) and mild cognitive impairment (MCI, Missonnier et al., 2010). Park et al. (2012) also showed a link between gamma band activity and MCI, as well as between gamma band activity and clinical memory measures.

Beta and gamma activity have both been associated with cognitive and memory functioning in general and gamma with age related cognitive decline, therefore, increasing gamma or beta activity may help to improve or maintain cognitive functioning in elderly. This increase may be achieved by neurofeedback training. Within a neurofeedback protocol, individuals receive continuous, real time (visual or auditory) feedback over their brain activity patterns so they learn to modulate these signals in the desired direction (Heinrich, Gevensleben, & Strehl, 2007). The induced change in brain activity may subsequently lead to improvement of behavior and skills or to the recovery of a mental or physical disorder.

Neurofeedback as a training mechanism for altering brain activity has been used with both healthy persons and neurologically or mentally affected patients. Beta neurofeedback (aimed to increase beta band activity) has been shown to improve cognitive abilities in healthy individuals, for example in enhancing attentional performance with SMR (but not with beta1, Egner & Gruzelier, 2001, 2004). Alpha neurofeedback (aimed to enhance alpha activity) has been effective in enhancing relaxation (Dempster & Vernon, 2009; Gruzelier, 2002; van Boxtel et al., 2012). Moreover, different beneficial effects like improved creativity were found with increasing the theta (4–8 Hz)–alpha ratio (see Gruzelier, 2009 for a review). Neurofeedback has also been an effective tool for normalizing abnormal brain activity in cases of epilepsy, for example with SMR and slow cortical potentials (Tan et al., 2009), or in treating ADHD by increasing SMR relative to theta (Moriyama et al., 2012) and in reducing anxiety disorders by means of alpha neurofeedback (see Angelakis et al., 2007; Gruzelier, 2009, for overviews).

Recent studies with healthy young adults have differentiated effects of beta (12–20 Hz) and gamma neurofeedback (36–44 Hz) on intelligence and memory performance (Keizer, Verment, et al., 2010; Keizer, Verschoor, Verment, & Hommel, 2010). In the first study by Keizer, Verschoor, et al. (2010), a positive correlation was found between the change in gamma (as defined by the difference between before and after the training) and the change in performance on a fluid intelligence task. Comparable results were found in the concurrent study by Keizer, Verment, et al. (2010) on the effect of beta/gamma neurofeedback on episodic memory. The effect of neurofeedback training on performance on the episodic memory task was very specific; the gamma group improved significantly on recollection (as indicated by accuracy), whereas the beta group improved significantly on familiarity (as indicated by accuracy). It is currently unknown whether these results of gamma and beta neurofeedback on memory and intelligence found with young adults can also be generalized to, and replicated, in elderly people. Several attempts using neurofeedback to improve cognitive performance in the elderly have been applied with mixed success (Angelakis et al., 2007; Becerra et al., 2012; Lecomte & Juhel, 2011).

1.1. Present study

The current study will compare two types neurofeedback training (gamma and beta, double-blind, similar to the design by Keizer, Verment, et al., 2010; Keizer, Verschoor, et al., 2010) in elderly people in terms of enhanced brain activity subsequent to the training (within the frequency range that they were trained with), and performance on a fluid intelligence and episodic memory task, and subjective experience of daily living.

The present study deliberately adjusted the protocol of Keizer, Verment, et al. (2010) by providing feedback at F_z to specifically enhance frontal activity. The protocol used by Keizer, Verment, et al. (2010) showed that increased beta activity was found at electrode location F_z using both the F_z and O_z electrode for auditory feedback, and that increased gamma activity was found at electrode locations F_z and O_z after gamma neurofeedback using the O_z electrode for auditory feedback. McEvoy et al. (2001) proposed that in memorizing, older adults apply a more controlled, effortful strategy, relying on the processing ability of the frontal cortex, whereas younger people show activation in posterior areas that work more automatically. Grady (2008) found that older adults show increased activity in frontal lobes to compensate for decreased activity in occipital areas. While these studies indicate that elderly (have to) rely more on the frontal cortex to compensate for losses elsewhere, significant reductions in white and gray matter have been found in the brains of healthy elderly with the largest changes in, amongst other areas, the frontal cortex (Buckner, 2004; Fjell & Walhovd, 2010). Reduced frontal lobe functions have also been associated to age related impairments in episodic memory (Butler, McDaniel, Dornburg, Price, & Roediger, 2004). Moreover, Keizer, Verment, et al. (2010) showed a significant positive correlation between the percentage of change in frontal rather than occipital gamma band activity on the one hand and the percentage of change in recollection on the other hand, suggesting a more direct link between F_z and recollection, than between O_z and recollection. Therefore, we anticipated that by providing feedback at F_z rather than at O_z we would more specifically support the compensatory mechanism at the frontal cortex rather than trying to restore occipital activity.

We hypothesize that compared to the beta group, neurofeedback training in the gamma group will increase power in the gamma band, which will be associated with higher test scores on fluid intelligence and recollection. We hypothesize that compared to the gamma group, neurofeedback training in the beta group will increase power in the beta band which will be associated with improvement in familiarity scores.

2. Methods

2.1. Participants

Twenty right-handed participants, 14 males and 6 females, took part in this experiment. The mean age was for the group trained with gamma feedback was 69.2(SE +1.87) years (6 males, 4 females) and the mean age for the beta group was 66.4 (SE +1.90) years (8 males, 2 females). There was no significant age difference between the groups, $t(18) = -1.05$, $p = 0.31$. Participants were volunteers and enrolled via the participant's pool of TNO or via personal contacts. They received a monetary reward for their participation. Inclusion criteria for the participants were normal or corrected-to-normal hearing functions