Neurofeedback training improves attention and working memory performance

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HIGHLIGHTS

- This study examined the effect of neurofeedback training on attention and memory.
- Theta uptraining improved attention, working memory, and the resting theta activity.
- Theta uptraining is an effective intervention protocol in cognitive aging.

ABSTRACT

Objectives: The present study aimed to investigate the effectiveness of the frontal-midline theta (fmθ) activity uptraining protocol on attention and working memory performance of older and younger participants.

Methods: Thirty-two participants were recruited. Participants within each age group were randomly assigned to either the neurofeedback training (fmθ uptraining) group or the sham-neurofeedback training group.

Results: There was a significant improvement in orienting scores in the older neurofeedback training group. In addition, there was a significant improvement in conflict scores in both the older and young neurofeedback training groups. However, alerting scores failed to increase. In addition, the fmθ training was found to improve working memory function in the older participants. The results further showed that fmθ training can modulate resting EEG for both neurofeedback groups.

Conclusions: Our study demonstrated that fmθ uptraining improved attention and working memory performance and theta activity in the resting state for normal aging adults. In addition, younger participants also benefited from the present protocol in terms of improving their executive function.

Significance: The current findings contribute to a better understanding of the mechanisms underlying neurofeedback training in cognitive function, and suggest that the fmθ uptraining protocol is an effective intervention program for cognitive aging.

1. Introduction

As individuals age, their physical, physiological, and psychological functions begin to deteriorate, which results in the progressive loss of competence. Many studies have observed that normal aging is accompanied by various cognitive dysfunctions, such as a reduced perceptual processing speed (Madden, 2001; Salthouse, 1994), reduced useful field of view in visual searches (Ball et al., 1988), reduced ability to control partially activated but incorrect information (Spieler et al., 1996), reduced visual search efficacy under divided attention conditions (Madden et al., 1997), reduced working memory capacity (Grady and Craik, 2000; Salthouse, 1994; West, 1996), a deficit in inhibitory processing (Faust and Balota, 1997; Hasher and Zacks, 1988; Kramer et al., 1994), and an absence of cognitive flexibility (Kramer et al., 1999; Mayr, 2001). Globally, the number of older adults in most societies is increasing. The proportion of individuals 65 years or older will increase from 15% in 2009 to 26% in 2039, and the ratio of older adults to the employed population will increase from 25% in 2009 to 49% in 2039 (Central Bureau Statistiek, CBS, 2011). Because of this growing population, it becomes increasingly important to understand how cognitive functioning can be preserved and promoted in old age. Historically, humans have invested great effort into searching for effective methods of postponing (or even reversing) aging-induced decline and for methods to remain youthful. Biomedical methods are one such solution. However, only recently has a non-invasive method been developed (i.e., neurofeedback training), which we believe has the potential to become one of the best current candidates for enhancing the quality of life of the elderly.

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1.1. Neurofeedback training (NFT)

Neurofeedback training (NFT) uses monitoring devices to provide moment-to-moment information to an individual regarding the state of their physiological functioning, particularly the functioning of the central nervous system and brain. The mechanism of NFT is considered as an operant conditioning paradigm, in which the participants learn to influence their brains' electrical activity (Egner and Gruzelier, 2001; Vernon et al., 2003). During NFT, sensors are placed on an individual's scalp and then connected to sensitive electronics and computer software that detects, amplifies, and records specific brain activity. The resulting information is fed back to the trainee instantaneously with the understanding that changes in the feedback signal indicate whether the trainee's brain activity is within the designated range. Often, the trainee is not consciously aware of the mechanisms by which such changes are accomplished, although individuals routinely acquire a "felt sense" of these positive changes and are often able to access these states outside of the neurofeedback session. In conventional NFT, the trainee gradually develops mental strategies through trial and error that modify his or her brain activity to maximize the reward. In so doing, the trainee positively alters these activities for the better (i.e., they reach the designated range).

NFT has been shown through numerous scientific studies to significantly improve attention and provide improvements equivalent to those of stimulant medications for children with attention deficit hyperactivity disorder (ADHD) (Lubar, 1997; Kaiser and Othmer, 2000; for a review, see Lofthouse et al., 2012). Research has also documented the effectiveness of NFT in reducing or eliminating seizures (Sterman and Friar, 1972), and improving therapeutic outcomes for the treatment of alcohol abuse and post-traumatic stress disorder (PTSD) (Peniston and Kulkosky, 1989, 1990, 1999; Peniston et al., 1993). Several studies have shown the effectiveness of neurofeedback in remediating the effects of traumatic brain injury (Thornton, 2000; Thornton and Carmody, 2005, 2008, 2009; Tinius and Tinius, 2000). Initial studies have shown promising results in learning disabilities (Thornton and Carmody, 2005), anxiety (Hammond, 2005), obsessive–compulsive disorder (Hammond, 2003), depression (Hammond, 2005), and autism spectrum disorders (Jarusiewicz, 2002) (for a review, see Hammond, 2011).

1.2. NFT and cognitive improvement

NFT was gradually shown to be effective modifying abnormal brain function and generating improvements in clinical symptoms in certain clinical areas. In recent studies, increased interest focused on applying NFT to healthy individuals for better cognitive performance to explore the practicality in areas outside of clinical research (Egner and Gruzelier, 2001; Egner et al., 2004; Vernon et al., 2003; Vernon, 2005). When reviewing the NFT to enhance cognitive performance literature, most researchers had focused on some main neurofeedback protocols, including neurofeedback training to influence a specific aspect of the EEG, i.e., theta, alpha, alpha/theta ratio, beta, and gamma training (Keizer et al., 2010; see Vernon, 2005 for a review). Nevertheless, the outcome of these frequency trainings varied across studies.

For example, Beatty and colleagues (1974) discovered that individuals receiving theta (4–7 Hz) augmenting NFT decreased their radar detection performance, whereas individuals receiving theta-suppression training increased their radar detection performance. Beatty et al. (1974) concluded that an increase in theta, particularly in the left parietal–occipital region (e.g., O1 and P3 site), might be associated with a decrease in arousal. However, in contrast to the theta-suppression training at posterior sites to enhance sustained attention performance, several studies have demonstrated a close relationship between theta band synchronization (i.e., power increase) and good cognitive performance. For example, a theta band power increase has been associated with facilitating working memory, episodic memory, and encoding new information (for a review, see Klimesch, 1999; Karrasch et al., 2004). Moreover, theta band activity at the frontal midline (fmθ) has been associated with focused attention, concentration, and creativity, and it may reflect the outcome of meditation (Basar-Eroglu et al., 1992; Kubota et al., 2001; Missonnier et al., 2006; Gruzelier, 2009; Lagopoulos et al., 2009). Furthermore, increases in fmθ activity have been observed while performing a continuous attention task (Inouye et al., 1994; Gevins et al., 1979a,b,c), a task with an increasing working memory load, or a task with high cognitive demands (Grunwald et al., 2001; Jensen and Tesche, 2002).

Regarding alpha band activity, researchers have indicated that upper alpha band (9.5–12 Hz) activity was associated with semantic memory processes (Klimesch et al., 1997), and retrieval processes from long-term memory (Sauseng et al., 2002), whereas lower alpha band (alpha 1: 6–8 Hz and alpha 2: 8–10 Hz) activity was associated with attentional processes (Doppelmayr et al., 2002; Klimesch et al., 1998). Despite the high association between alpha activity and memory performance, Bauer (1976) directly examined the effect of alpha (8.5–12.5 Hz) activity uptraining on short-term memory performance, but failed to observe the effect of increasing alpha activity on participants' recall performance for either a verbal free recall task or digit span memory task. On the other hand, Hanslmayer et al. (2005) showed that participants who were capable of learning to increase their upper alpha band power with eyes open performed better on a mental rotation task after upper alpha NFT. In addition to alpha NFT, the alpha/theta ratio training protocol has also been developed. Boynton (2001) trained subjects to enhance theta over alpha to determine whether the training enhanced creativity and well-being. Although Boynton (2001) observed no effect of alpha/theta ratio NFT on well-being or creativity, she defended that the absence of effects was because of the confounding variables in the training program. Nevertheless, subsequent studies by Egner and Gruzelier (2003) had successfully demonstrated the effectiveness of alpha/theta ratio NFT on music performance.

Regarding beta training, Egner and Gruzelier (2001) have reported that SMR (12–15 Hz sensorimotor rhythm) conditioning resulted in reduced commission errors and improved perceptual sensitivity in a continuous performance task (CPT) [go/no-go CPT], whereas beta 1 (15–18 Hz) conditioning resulted in an opposite pattern. Egner and Gruzelier (2004) further suggested that SMR (12–15 Hz) training led to general improvements in attention performance that were not limited to impulsive response tendencies and that these effects may be accounted for in terms of reduced sensorimotor processing interference with higher cognitive function. Beta 1 (15–18 Hz) training effects were interpreted as reflecting a tendency toward fast (i.e., faster reaction times) but not necessarily accurate responses because of general arousal increments that were possibly mediated by increased activation in a noradrenergic alertness/vigilance network of attention. In addition to SMR training, there is also a neurofeedback protocol focusing on training SMR (12–15 Hz)/theta (4–8 Hz) ratio in relation to visual word recognition function (Barnea et al., 2005).

Regarding gamma training, Keizer and colleagues (2010) have demonstrated that gamma (36–44 Hz) enhancing neurofeedback on an occipital electrode site (Oz) could lead to increased flexibility in handling episodic bindings (i.e., bindings between two features of visual objects, such as their shape and location), which suggests a role of gamma band activity in top-down control of memory retrieval. Moreover, Keizer et al. (2010) also observed that gamma uptraining could improve memory recollection, which led them to conclude that gamma band activity is important for controlling

and organizing memory traces of relational information in both short-term binding and long-term memory.

1.3. NFT and cognitive aging

Despite the various studies showing the effectiveness of NFT on cognitive improvement for healthy young adults, few previous studies have provided evidence showing that NFT can improve cognitive function in the elderly (Angelakis et al., 2007; Becerra et al., 2012; Lecomte and Juhel, 2011). Angelakis et al. (2007) administered over 30 NFT sessions to 6 individuals from 70 to 78 years old. Three of the participants underwent a training process aimed exclusively at increasing the peak alpha frequency (PAF; experimental condition). Two other participants underwent an NFT protocol aimed at increasing the amplitude of the alpha wave (8–13 Hz; control condition 1). The sixth participant underwent a pseudo-NFT protocol (control condition 2). Angelakis et al. (2007) observed an increase of PAF (2 of the 3 individuals), which was particularly pronounced in the frontal areas in the PAF experimental condition. They also observed that the NFT of PAF training improved the speed of information processing and resistance to interference, whereas training the amplitude of the alpha band improves verbal memory performance. Becerra et al. (2012) likewise observed the effectiveness of NFT in cognitive aging, in which they administered an NFT protocol in reducing theta absolute power in normal elderly participants. They observed that the experimental group as compared to the control group (i.e., receiving a placebo treatment) exhibited greater improvement in both EEG and behavioral performance. The improved behavioral performance included increases in the Verbal Comprehension Index and Verbal IQ scores from the 3rd version of the Wechsler Adult Intelligence Scale, WAIS-III, and total scores on attention, executive function, and memory functions measured by a neuropsychological test developed by Ostrosky-Solís et al. (2007). In contrast to the clear evidence showing the effectiveness of NFT in cognitive aging, although Lecomte and Juhel (2011) could successfully train the elderly to modify the amplitudes of certain brain wave ranges according to the optimal model of regulation of EEG activity (the so-called "awakened mind" model), they failed to observe whether such EEG changes resulted in a positive effect on memory performance in the elderly. However, one possible reason for the null finding in Lecomte and Juhel's (2011) study could be due to their relatively few (only 4) training sessions which might underestimate the effectiveness of NFT. Despite the discrepancies among these previous studies regarding the effectiveness of NFT in cognitive aging, we believe that NFT is one of a number of interventions that can potentially generate substantial differences in the quality of life of the elderly. Hence, this study aimed to explore an effective NFT protocol to train the elderly to improve their brain and cognitive functions.

Because no comprehensive guideline for which EEG frequency training should be more effective to elevate elderly individuals' declined cognitive performance, and their wide range of age-related cognitive deteriorations, our strategies for developing a training protocol for the purpose of elevating cognitive aging were twofold. First, we utilized scalp EEG recordings as complementary information to understand brain EEG deviations in older participants compared to younger participants. This strategy had already been applied before by Becerra et al. (2012) in which they recorded each participant's EEG to determine which electrode site with the most abnormal theta activity, and then they applied the NFT on this abnormal electrode site. In addition, they recorded each participant's EEG before and after NFT for comparison and to assess the effects of NFT on cognition and brain electrical activity. Second, we selectively targeted cognitive functions that might be associated with age-related EEG deviations.

1.4. Age-related resting EEG changes in relation to age-related cognitive function changes

Many studies have verified that normal aging involves EEG patterns that are different from those of young adults in the resting state. For example, alpha activity (8–12 Hz) has been consistently observed to decrease with increasing age (Breslau et al., 1989; Matoušek et al., 1967; Matejcek, 1980; Nakano et al., 1992; but see Duffy et al., 1984 for a negative result). However, regarding slower waves, such as those in theta activity (4–7 Hz), the results regarding age-related changes are equivocal. Whereas some researchers have observed that theta activity increases with increasing age (Hughes and Cayaffa, 1977; Matejcek, 1980; Nakano et al., 1992; Obrist, 1954), others have observed that it decreases with increasing age (Breslau et al., 1989; Duffy et al., 1984; Hartikainen et al., 1992; Matoušek et al., 1967). Hence, one of the aims of this study is to clarify whether theta, particularly frontal-midline theta activity, decreases or increases with increasing age.

Recently, Cummins and Finnigan (2007) investigated the differences in EEG patterns between older and younger adults in resting conditions and during recognition-task conditions. Their results showed that older adults had lower theta activity in the resting state and lower task-related theta activity, particularly in the fronto-to-central midline region. Hence, Cummins and Finnigan (2007) proposed that the fmθ activity might function as a sensitive neurophysiological marker of cognitive aging. A follow-up study by Finnigan and Robertson (2011) reached the identical conclusion and observed that a higher resting fmθ activity was significantly correlated with better cognitive performance (e.g., sustained attention, delayed verbal recall, and executive function).

1.5. Attention and working memory task paradigms

Several studies have demonstrated a close relationship between theta activity and cognitive function. For example, theta activity has been associated with facilitating working memory, episodic memory, and encoding new information (for a review, see Klimesch, 1999; Karrasch et al., 2004). Moreover, fmθ activity has been observed to be associated with focused attention, concentration, and creativity, and it may reflect the outcome of meditation (Basar-Eroglu et al., 1992; Kubota et al., 2001; Missonnier et al., 2006; Gruzelier, 2009; Lagopoulos et al., 2009). Furthermore, increases in fmθ activity have been observed while performing either a continuous attention task (Inouye et al., 1994; Gevin et al., 1979a,b,c), a task with an increasing working memory load, or a task with high cognitive demands (Grunwald et al., 2001; Jensen and Tesche, 2002; Onton et al., 2005).

Based on these previous results, attention and working memory appear to be closely related to theta, particularly frontal-midline theta activity. In addition, attention and working memory dysfunction have been commonly observed with increasing age (e.g., Cabeza, 2002; Craik et al., 1990; Kramer et al., 1994; Madden et al., 1994, 1999; Salthouse, 1994; West, 1996). However, the term *attention* refers to many different cognitive abilities, such as orienting to sensory stimuli, maintaining an alert state, and orchestrating the computations required to perform the complex tasks of daily life (Fernandez-Duque and Posner, 1997; Fernandez-Duque and Black, 2006). Therefore, in this study, we used an attention task, which can measure the multi-facets of attention. In the literature, one commonly used task that enables researchers to evaluate the multi-facets of attention is the Attention Network Test (ANT; Fan et al., 2002; Fan et al., 2005). The ANT was designed to probe the efficiency of three attention networks (the three main functional components of attention; Posner and Petersen, 1990) within a single task: (1) the alerting component (i.e., the ability to prepare and sustain alertness for the processing of high-priority signals), which

involves the thalamic, frontal, and parietal areas; (2) the orienting component (i.e., the component that allows one to attend to target items overtly or covertly and thereby improve processing efficiency), which involves the superior parietal lobe, temporo-parietal junctions and superior frontal cortex; and (3) the executive attention component (i.e., conflict resolution), which involves the anterior cingulate cortex and lateral prefrontal cortex (Fan et al., 2002, 2005).

Mahoney and colleagues (2010) conducted the ANT to examine the efficiency of three visual attention networks of older adults. Their results showed that the average reaction time of older adults was generally slower than younger adults. Additionally, when the response target was flanked by the opposite direction arrows, the response conflict appeared to be more obvious in the older group, which indicated that the older adults showed a decline in executive function. However, other research results suggested that older adults showed significantly less alerting than younger adults in response to a warning cue, but there were no age differences in the orienting or executive functions once a general slowing was accounted for (Jennings et al., 2007; Gamboz et al., 2010). Hence, which aspects of attention would show age-related declines and therefore be subject to undergo NFT require investigation. Furthermore, although this study might not be the first to use the ANT in an NFT study, it seems to the first application with the elderly.

Regarding working memory function, there have been studies reporting significant age-related deteriorations (see Craik et al., 1990, and Zacks et al., 2000 for a review). One of the conventional working memory tasks is Sternberg's recognition task (1966), which has been used to examine participants' working memory performances (Chen and Desmond, 2005; Jonides and Nee, 2006; Manoach et al., 2001). Not only have many previous studies on healthy younger participants adapted the Sternberg recognition task to measure working memory function, but cognitive aging studies have also adapted this task (Van Gerven et al., 2004; Cummins and Finnigan, 2007).

1.6. The aims and hypotheses of this study

Because of the close relationship between fmθ activity and cognitive functions, and the inconsistent EEG patterns that accompany normal aging in the literature (i.e., decreases or increases in theta activity with age), the first aim of this study was to verify whether normal aging yields decreases or increases in theta activity in the resting state. In addition, considering that there are few studies in the literature that investigate whether NFT has a positive effect on cognitive enhancement in the elderly (Angelakis et al., 2007; Becerra et al., 2012; Lecomte and Juhel, 2011), the second aim of the present study was to examine the effect of NFT on cognitive performance by incorporating both ANT and Sternberg's recognition memory tasks, which are thought to involve attention, working memory and/or executive functions.

To our knowledge, no study has examined the effectiveness of fmθ activity uptraining in cognitive aging. Based on prior knowledge of the functional significance of fmθ activity and the deterioration of attention and memory functions associated with abnormal EEG patterns in normal aging populations, we hypothesized that fmθ activity uptraining might be effective in improving cognitive performance involving attention, working memory, and executive functions. We further hypothesized that cognitive improvement might be accompanied by the reconditioning of different EEG patterns. To achieve these goals, the present study employed a 2 (old vs. young) by 2 (neurofeedback vs. sham-neurofeedback) between-subjects factorial design to investigate the effectiveness of fmθ activity uptraining in cognitive aging and test the effects of training in cognitive performance (i.e., post-training performance opposed to pre-training performance) between the

two age groups with a special focus on attention and working memory. The following hypotheses were generated: (1) the resting EEG pattern in normal older adults would differ from that of healthy younger adults; (2) normal older adults would show deterioration in cognitive functions, such as attention and working memory; (3) after neurofeedback training of the fmθ activity, participants' attention and working memory performance would be improved, particularly in normal older adults; and (4) fmθ activity uptraining would also lead to changes in the resting EEG patterns, at least in older adults.

2. Methods

2.1. Participants

Thirty-two participants were recruited for this study; 16 older (5 females and 11 males) participants who were recruited from the local community and the 16 younger (5 females and 11 males) participants who were recruited from the National Cheng Kung University. Participants within each age group were randomly assigned to either the NFT group ($n = 8$) or the sham-neurofeedback training group ($n = 8$); this resulted in a total of four groups: the older NFT (ONFT) group (mean age of 65 ± 3.3 years, range: 61–72 years), the older sham-neurofeedback training (OSFT) group (mean age of 64.6 ± 2.4 years, range: 61–67 years), the younger NFT (YNFT) group (mean age of 21.8 ± 1.0 years, range: 21–24 years), and the younger sham-neurofeedback training (YSFT) group (mean age of 22.6 ± 1.6 years, range: 21–25 years). All participants were right-handed, free of neurological and psychological disorders, and had normal or corrected-to-normal vision. The Mini-Mental State Examination (MMSE; Folstein et al., 1975) was used to screen older participants for dementia based on the following screening criteria: 25–30 points = normal; 21–24 points = mild dementia; 14–20 points = moderate dementia; and $\leqslant 13$ points = severe dementia. The mean MMSE scores were 29.1 ± 1.0 for the ONFT group, 29.4 ± 0.9 for the OSFT group ($t(14) = 0.52$, ns), 29.9 ± 0.4 for the YNFT group, and 29.5 ± 0.5 for the YSFT group ($t(14) = -1.67$, ns). The Beck Depression Inventory (BDI-II; Beck et al., 1996) was used to screen all participants for depression based on the following screening criteria: 0–13 = normal; 14–19 = mild depression; 20–28 = moderate depression; 29–63 = severe depression. The mean BDI-II scores were 5.6 ± 6.7 for the ONFT group, 4.6 ± 5.3 for the OSFT group ($t(14) = -0.33$, ns), 5.1 ± 2.6 for the YNFT group, and 5.6 ± 4.5 for the YSFT group ($t(14) = 0.27$, ns). All participants provided consent prior to the experiment, and each participant was paid NT $2000–2400 (US $67–80) for participation.

2.2. Design and procedure

The design and procedure of the present study are illustrated in Fig. 1. All participants were first required to fill out an informed consent form and the MMSE, and BDI-II screening tests. They were then randomly assigned to either the NFT or SFT group. In the pre-training phase, participants were first required to perform two cognitive tests, (1) the Attention Network Test and (2) the Modified Sternberg recognition task. Upon completion of the tests, resting EEG data were acquired. The formal neurofeedback training phase, for both for the NFT and the SFT groups, started one day after the pre-training phase and continued over four consecutive weeks. Finally, the post-training phase commenced one day after the formal neurofeedback training phase. In the post-training phase, participants performed the two cognitive tests, and their resting EEG data were acquired again.
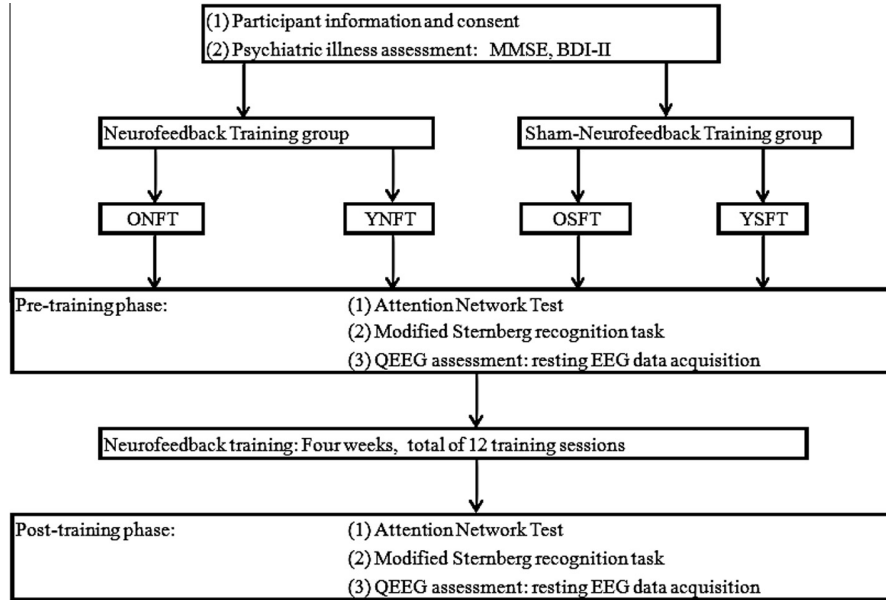
Fig. 1. A schematic illustration of the design and procedure in the present study.

2.3. The attentional network test (ANT)

Participants were instructed to fixate on a central cross for the entire experiment. The stimuli consisted of a row of five horizontal black arrows (0.58° in size, separately by 0.06°; the five arrow row covered a total of 3.27°) that appeared in either the upper or lower part of the screen and pointed either to the left or right. The target central arrow pointed either in the same direction as the other four flanking arrows (congruent condition) or in the opposite direction (incongruent condition) (Fig. 2). In one-fourth of the trials, the stimulus was preceded by a visual cue (an asterisk) that appeared at the central fixation cross (central cue condition). In another
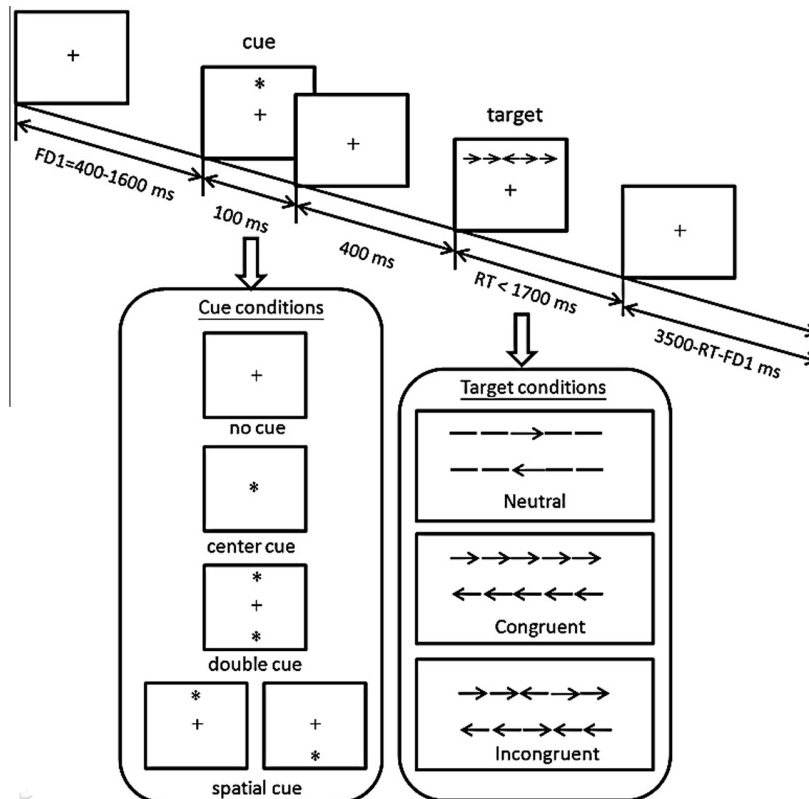

Fig. 2. The experimental procedure of ANT developed by Fan et al. (2002): a trial sequence of the ANT; the four cue conditions; and the three flanker conditions. (FD1: previous fixation cross duration; RT: reaction time).

fourth of the trials, the stimulus was preceded by a visual cue that was presented above or below the central fixation cross (at the same location as the stimulus would appear) (spatial cue condition) and indicated the stimulus would appear in the upper or lower part of the screen, respectively. In another fourth of the trials, the stimulus was preceded by two visual cues that were simultaneously presented above and below the central fixation cross (double cue condition). In the remaining forth of the trials, the stimulus was not preceded by any visual cue (no cue condition) (Fig. 2). An illustration of the trial sequence of the ANT is shown in Fig. 2.

The ANT consisted of four blocks composed of one practice block of 24 trials and three experimental blocks of 96 trials each. At the beginning of each trial, a fixation cross appeared in the center of the screen, followed by a visual cue that was presented for 100 ms. The target stimulus would appear 400 ms following the offset of the cue. The participants were asked to determine the direction of the central arrow of the stimulus by pressing one of the two buttons on a computer mouse as quickly and accurately as possible. Until a response had been made or 1700 ms had elapsed, a fixation cross appeared alone for a duration of 3500 ms (including response time (RT) and the previous fixation cross duration which randomly varied from 400 to 1600 ms), and then the next trial began. Performance scores for each of the three attentional networks were measured separately as follows. The alerting score was calculated by subtracting the mean RT of the double-cue condition from the mean RT of the no-cue condition; therefore, the changes in RT were positively correlated with increasing efficiency. The orienting score was calculated by subtracting the mean RT of the spatial cue condition from the mean RT of the center cue condition; therefore, the changes in RT were positively correlated with increasing efficiency. The conflict (exec-utive control) score was calculated by subtracting the mean RT of all congruent conditions across all cue types from the mean RT of the incongruent conditions; therefore, smaller differences in RT on this measure indicated greater efficiency (Fan et al., 2002, 2005).

2.4. The Sternberg recognition task

A modified Sternberg's recognition task was utilized. The procedural details of this task are illustrated in Fig. 3. Each of the words (two-character Chinese words) that appeared throughout the task had a normative frequency ranging from 5 to 50 occurrences per million (source: Mandarin dictionary database, Ministry of Education of Taiwan, 2000). Study list lengths were either four (low memory load) or eight (high load) words (length varied at random), and there were a total of 40 study-test trials for each load condition (80 trials altogether). Each study list was followed by a single test word. In 50% of cases, the test word appeared once in a random position (excluding the last word) in the study list that immediately preceded the test (old). In the other 50% of cases, the test word did not occur at any other time throughout the experiment (new). The task was divided into four blocks, and each block consisted of 10 study-test trials for each load condition.

Participants were informed of the load conditions and that they were required to determine whether each test cue word was in the previous study list (old) or not (new). Each trial started with a 2000 ms fixation cross, followed by a series of two-character Chinese words (either four or eight words) with the duration of 1800 ms for each word and with an interval of 500 ms between words. After all study words had appeared, a two-digit number (randomly selected) appeared on the screen, and the participant
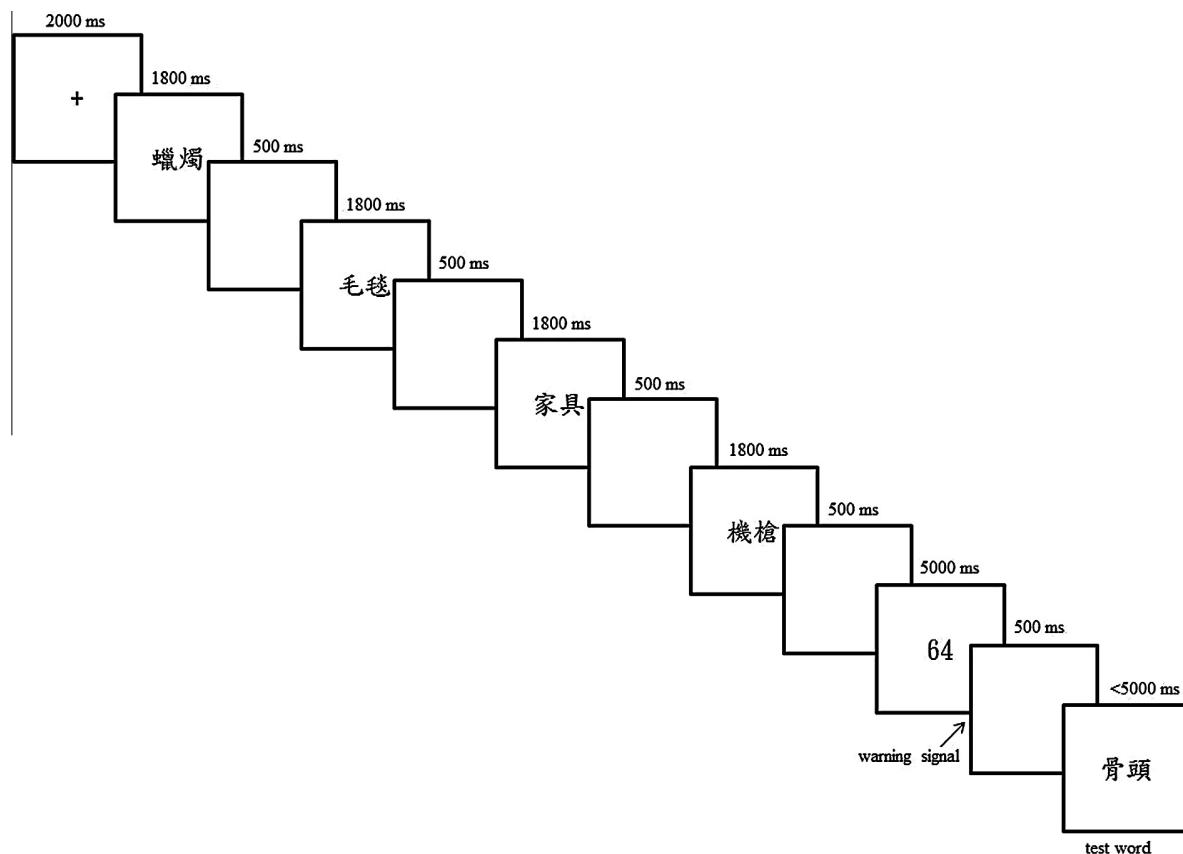

Fig. 3. The diagram of a four-word list trial (low memory load condition) in the modified Sternberg word recognition task.

was asked to orally read the number and count backward from that number by threes until the number disappeared (about 5000 ms following the appearance of the number). Thereafter, a warning signal appeared to remind the participant of the upcoming test word. Upon the appearance of the test word, participants were asked to judge if the test word had been present in the study phase (old) or not (new) by pressing either a key corresponding to "yes" or "no" (the "F" and "J" keys, respectively) on a standard keyboard.

2.5. EEG data acquisition

Electroencephalographic (EEG) activity was recorded using a Neuroscan Q-cap AgCl-32 electrode cap at 32 scalp locations (Neuroscan Inc., El Paso, TX, USA). EEG activity was recorded from 30 electrodes (FP1, FP2, F7, F3, FZ, F4, F8, FT7, FC3, FCZ, FC4, FT8, T7, C3, CZ, C4, T8, TP7, CP3, CPZ, CP4, TP8, P7, P3, PZ, P4, P8, O1, OZ, O2) according to the International 10–20 system. Horizontal EOGs (HEOG) were recorded with two electrodes placed 1 cm away from the lateral canthus of the left and right eyes. Vertical electro-oculograms (VEOGs) were recorded with two electrodes placed 1 cm above and 1 cm below the left eye. The EEGs from all electrode sites were initially referenced to the left mastoid and then re-referenced offline to the mean activity of the left and right mastoids. EEGs and EOGs were amplified using Synamps2 amplifiers and Scan 4.3 acquisition software (Neuroscan, Inc.) at a sampling rate of 500 Hz, high pass filtered at 0.1 Hz, and low pass filtered at 50 Hz. Electrode impedances were maintained below 5 kΩ.

EEG acquisition took place in a sound-attenuated room, and brain activity was recorded under two baseline conditions, an eyes-open baseline (EOB) condition and an eyes-closed baseline (ECB) condition. Each condition lasted for 3 min and was repeated twice. During the EOB condition, participants were required to minimize blinking to avoid eye movement artifacts and to stare at the fixation cross on the computer screen. During the ECB condition, participants were required to close their eyes but stay awake.

2.6. Neurofeedback training protocol

Neurofeedback training was conducted three times per week over 4 weeks resulting in a total of 12 training sessions. At the beginning of each training session, a 3-min eyes-open baseline evaluation was conducted, which was used as a threshold during the training periods. This baseline was followed by five 3-min training periods. The equipment employed for neurofeedback training consisted of a ProComp Infiniti differential amplifier and software (Thought Technology Ltd., Montreal, Quebec). An electrode was placed on the Fz according to the International 10–20 system with a reference and ground on the left and right earlobes, respectively. It was necessary to maintain all impedances below 5 kΩ. To prevent the augmentation of the signals by muscle artifacts, such as eye blinks, coughs, teeth clenching or movements, two inhibit bands were used. These inhibit bands were represented on the screen by horizontal scales showing EEG activities in the ranges of 0.5–2 and 43–59 Hz, which indicated eye blinks and high frequency disturbances, respectively. The raw EEG signal was sampled at 256 Hz and was A/D converted online for feedback. Using the BioGraph Infiniti software, an IIR (Infinite Impulse Response) filters were applied to the recorded signal to extract frequency-domain information. Spectral amplitude estimates were calculated for the active site (Fz) on raw 1-s EEG segments with a frequency resolution of 1-Hz. Bandpass filters were used to extract the reward EEG frequency bands (NFT: theta: 4–7 Hz; SFT: the randomly selected frequency bands: 10–13, 13–16, 16–20, or 20–25 Hz), and the two inhibit bands (0.5–2 and 43–49 Hz) through fast Fourier transformations (FFT).

Audio-visual feedback was provided in the form of a roller-coaster animation; if the participants achieved the goal, the roller-coaster moved forward and was accompanied by a pleasant sound. To the authors' knowledge, there is no strict guideline of which feedback type, e.g., visual only, auditory only, or visual-auditory, should be the most optimal for NFT. Because most of the studies (e.g., Egner and Gruzelier, 2001, Egner and Gruzelier, 2004; Vernon et al., 2003) using NFT to enhance cognitive performance used visual-auditory feedback, we decided to also use this type of feedback. The participants were encouraged to allow the roller coaster to move forward and maintain production of the sound for as long as possible. For the neurofeedback group (e.g., the ONFT and YNFT groups), the goal was to increase the theta (4–7 Hz) amplitude above the theta average amplitudes over the preceding 3-min eyes-open baseline recordings (i.e., immediate feedback), particularly the fmθ activity. Although we did not teach the participants any specific strategy of how to increase their frontal-midline theta activities, all our participants developed their own effective strategies to reach the specific goal of increasing their theta activity using visual-auditory feedback. This result is evident from our results in the training indices. The amplitude of the fmθ frequency was represented by the speed of the roller-coaster. The participants' task was to accelerate the roller coaster. The participants were instructed to attempt to maximize the point score that was based on roller coaster movement. For the sham-neurofeedback training group (e.g., the OSFT and YSFT groups), all conditions were exactly the same as in the neurofeedback group, except that in this group the goal was to enhance the activity of a frequency band (the participants were blind to the frequency band) that was randomly selected from 10–13, 13–16, 16–20, or 20–25 Hz for each session. All participants were not informed whether they would be assigned to the neurofeedback or sham-neurofeedback group. More importantly, during the debriefing, no participants in the sham group reported that they noticed the fake training. The outcome of the EEG training indices also suggests that the sham participant EEGs were not systematically modulated because of the sham training. The differences between the neurofeedback and sham groups in the pre-training of all three ANT scores were not statistically significant.

2.7. Statistical analyses

2.7.1. Behavioral data
2.7.1.1. Pre-training performance on the ANT and Sternberg recognition task. To determine whether performance on the ANT task differed between the older and younger groups and between the NFT and SFT groups within the same age group, an analysis of variance (ANOVA) was conducted with Age (old, young) and Neurofeedback (neurofeedback, sham-neurofeedback) as between-subjects factors and Cue type (no cue, central cue, double cue, spatial cue) and Flanker type (neutral, congruent, incongruent) as within-subject factors. Likewise, to examine performance on the Sternberg recognition task, an ANOVA was conducted with Age and Neurofeedback as between-subjects factors and Memory load (low, high) as a within-subject factor.

2.7.1.2. Post-training performance on the ANT and Sternberg recognition task. To evaluate the effects of neurofeedback training on ANT task performance, an ANOVA was conducted with Age and Neurofeedback as between-subjects factors and Phase (pre-training, post-training), Cue type, and Flanker type as within-subject factors. Moreover, to explore changes in three attentional networks after training, three further separate ANOVAs were performed: (1) for the alerting network, a 2 (Age) × 2 (Neurofeedback) × 2 (Alerting: no cue vs. double cue) ANOVA was performed, (2) for the orienting network, a 2 (Age) × 2 (Neurofeedback) × 2 (Orienting:

central cue vs. spatial cue) ANOVA was performed, and (3) for the conflict network, a 2 (Age) × 2 (Neurofeedback) × 2 (Conflict: congruent vs. incongruent) ANOVA was performed. Post-hoc simple effect tests were performed based on any significant interaction effects involving the factors of Neurofeedback or Phase.

To evaluate the effects of neurofeedback training on the Sternberg recognition task performance, an ANOVA was performed with Age and Neurofeedback as between-subjects factors and Phase, and Memory load as within-subject factors.

2.7.2. EEG data analyses

Data acquired from the EEGs were initially submitted to an ocular artifact reduction to acquire artifact-free data for further analysis. FFT analysis of the artifact-free, 2046 ms epochs was used to determine absolute EEG activity in the delta (1–4 Hz), theta (4–7 Hz), alpha (8–12 Hz) and beta (13–30 Hz) frequency bands. Estimates of absolute EEG activity are reported as microvolts (μV) in this study.

2.7.2.1. The EEG in the pre-training phase. To evaluate whether EEG patterns differed between the older and younger groups prior to the formal neurofeedback training phase, an ANOVA was performed with Age and Neurofeedback as between-subjects factors and Electrode (FP1, FP2, F7, F3, FZ, F4, F8, FT7, FC3, FCZ, FC4, FT8, T7, C3, CZ, C4, T8, TP7, CP3, CPZ, CP4, TP8, P7, P3, PZ, P4, P8, O1, OZ and O2) as a within-subject factor for each frequency band.

2.7.2.2. The EEG in the post-training phase. To evaluate the effects of formal neurofeedback training on resting EEG (i.e., EOB, ECB), an ANOVA was performed with Age and Neurofeedback as between-subjects factors and Phase and Electrode as within-subject factors for each frequency band.

2.7.2.3. Neurofeedback training index. To examine the learning curve of the theta amplitudes over the 12 sessions of training, we calculated the ratio of the mean theta amplitude during training relative to baseline for each session as training indices. Subsequently, a 2 (Age) × 2 (Neurofeedback) × 12 (Session) ANOVA on these training indices was performed. In addition, we also performed trend analyses on the original theta amplitudes over the 12 sessions.

3. Results

3.1. Behavioral data

The mean RTs and accuracies (and standard deviations) for each of the cue-type and flanker-type conditions for the older and younger groups in both pre- and post-training phases are presented in Tables 1 and 2 respectively.

3.1.1. Pre-training performance on the ANT and Sternberg recognition task
3.1.1.1. ANT: RT data. There was a significant main effect of Age ($F(1,28) = 46.04$, $p = .00$) on the reaction times in the ANT; overall, the RTs of the older group were slower than those of the young group in the pre-training phase. No significant interaction of Age and Neurofeedback ($F(1,28) = 4.00$, $p = .06$) was found; thus, within age groups, the neurofeedback and sham-neurofeedback training groups had similar RTs in the ANT (but see the Result section).

3.1.1.2. ANT: accuracy data. There was a significant main effect of Age ($F(1,28) = 10.7$, $p = .00$) on the accuracy in the ANT task; the older groups were more accurate than the younger groups in the

pre-training phase. No significant interaction of Age and Neurofeedback ($F(1,28) = 0.01$, $p = .91$) was found.

3.1.1.3. Sternberg recognition task: accuracy data. There was a significant main effect of Age ($F(1,28) = 22.12$, $p = .00$) on accuracy in the modified Sternberg recognition task; the overall accuracy of the older group was lower than that of the younger group in the pre-training phase. No significant interaction of Age and Neurofeedback ($F(1,28) = 0.00$, $p = 1.00$) was found; thus, within age groups, the neurofeedback and sham-neurofeedback training groups had similar initial performances in this task.

In summary, the accuracies in the ANT task were better in the older groups whereas the RTs in the ANT task were slower in the older groups as compared to the younger groups, suggesting a possible trade-off of speed and accuracy with the ANT in the older groups in the pre-training phase. However, there were no differences in performance on the ANT or Sternberg recognition task between the neurofeedback and sham-neurofeedback training groups within the older (ONFT and OSFT) or younger groups (YNFT and YSFT) in the pre-training phase.

3.1.2. Post-training performance in contrast to pre-training performance on the ANT and Sternberg recognition task
3.1.2.1. ANT: RT data. The results of a 2 (Age) × 2 (Neurofeedback) × 2 (Phase) × 4 (Cue type: no cue, central cue, double cue, spatial cue) × 3 (Flanker type: neutral, congruent, incongruent) ANOVA were as follows. The main effects of Age ($F(1,28) = 51.02$, $p = .00$), Phase ($F(1,28) = 16.55$, $p = .00$), Cue type ($F(2.16, 60.45) = 184.36$, $p = .00$), and Flanker type ($F(1.42, 39.84) = 239.90$, $p = .00$) were all significant. That is, older participants were significantly slower overall (636.6 ms) than young participants (445.1 ms). All participants' response times increased from the spatial cue (495.9 ms), double cue (524.5 ms), central cue (547.9 ms), and no cue (581.1 ms) conditions ($q(84,4) = 3.72$, $p < 0.05$). RTs also increased from the neutral flanker, congruent flanker, and incongruent flanker conditions ($q(56,3) = 3.41$, $p < 0.05$). Significant 2-way interactions of Age and Cue type ($F(2.16, 60.45) = 4.93$, $p = .01$), Age and Flanker type ($F(1.42, 39.84) = 9.63$, $p = .00$), Phase and Flanker type ($F(1.83, 51.11) = 14.87$, $p = .00$), and Cue type and Flanker type ($F(4.48, 125.4) = 10.83$, $p = .00$) were found. A 3-way interaction of Phase, Neurofeedback, and Flanker type ($F(1.83, 51.11) = 12.49$, $p = .00$) was also found. Of the main interest, post hoc simple interaction tests following this 3-way interaction showed that only the NFT groups exhibited a significant interaction of Phase and Flanker type ($F(2,56) = 27.30$, $p = .00$), but not the SFT groups ($F(2,56) = 0.05$, $p = .95$).

Please note, although we have claimed there was no significant difference in RTs between the NFT and SFT groups on the basis of no significant main effect of Feedback ($p = .19$) and interaction effect of Age and Neurofeedback. Nevertheless, the p value for the interaction effect was near significant ($p = .06$) and the mean RTs of the 12 conditions in the pre-training phase look generally faster for the OSFT than the ONFT group (see Table 1), hence we re-analyzed the data with an ANCOVA by using the pre-training performance as a covariate to adjust the pre-/post-training changes. The results of this ANCOVA yielded the same patterns as those reported by the original ANOVA.

To examine more directly the effect of neurofeedback training in the three attention networks of the ANT, three separate ANOVAs were conducted. Fig. 4 shows the mean RTs for the three attention network scores for younger and older participants in the pre- and post-training phases.

For the alerting network, the results showed significant main effects of Age ($F(1,28) = 49.24$, $p = .00$), Phase ($F(1,28) = 13.24$, $p = .00$, and Alerting (double cue vs. no cue, $F(1,28) = 203.70$,

Table 1
Mean RTs (standard deviations) according to cue and flankers types for each group in the pre- and post-training phases (OSFT: old sham-neurofeedback training group; ONFT: old neurofeedback training group; YSFT: young sham-neurofeedback training group; YNFT: young neurofeedback training group).

| Group | Flanker | Cue type | | | | | | | |
| | | No cue | | Double cue | | Center cue | | Spatial cue | |
Phase		Pre	Post	Pre	Post	Pre	Post	Pre	Post
OSFT	Neutral	706 (155.3)	647 (78.6)	665 (141.0)	617 (94.9)	672 (135.7)	621 (93.2)	622 (131.8)	568 (89.5)
	Congruent	721 (145.4)	666 (95.3)	673 (153.5)	619 (90.9)	674 (144.7)	624 (105.8)	633 (150.7)	575 (104.8)
	Incongruent	818 (137.3)	774 (122.6)	787 (147.4)	728 (131.0)	787 (131.8)	760 (124.3)	735 (168.7)	671 (123.1)
ONFT	Neutral	605 (63.1)	564 (90.7)	574 (70.5)	511 (84.4)	581 (72.2)	545 (111.5)	544 (60.3)	479 (74.9)
	Congruent	608 (72.2)	586 (90.3)	572 (79.9)	530 (95.3)	581 (86.4)	544 (100.5)	540 (69.8)	501 (84.1)
	Incongruent	705 (83.4)	636 (90.1)	685 (81.6)	612 (92.4)	705 (73.5)	627 (108.9)	647 (69.0)	541 (76.7)
YSFT	Neutral	463 (37.7)	468 (51.0)	412 (37.0)	404 (44.3)	416 (45.7)	408 (43.2)	382 (31.8)	374 (33.3)
	Congruent	484 (47.1)	476 (74.4)	414 (50.1)	408 (54.6)	422 (50.9)	420 (51.6)	385 (36.7)	375 (37.4)
	Incongruent	526 (50.3)	515 (86.5)	495 (57.8)	490 (60.8)	519 (56.4)	496 (68.7)	450 (55.5)	439 (62.0)
YNFT	Neutral	494 (34.0)	460 (34.0)	423 (46.3)	384 (28.4)	435 (43.1)	402 (40.7)	404 (43.6)	372 (26.1)
	Congruent	498 (44.8)	473 (44.8)	431 (49.3)	403 (38.1)	436 (60.5)	407 (39.4)	411 (55.0)	374 (27.6)
	Incongruent	557 (50.9)	497 (50.9)	526 (63.6)	465 (44.2)	525 (55.7)	469 (41.7)	466 (20.9)	414 (32.7)

Table 2
Mean accuracies (standard deviations) according to cue and flankers types for each group in the pre- and post-training phases (OSFT: old sham-neurofeedback training group; ONFT: old neurofeedback training group; YSFT: young sham-neurofeedback training group; YNFT: young neurofeedback training group).

| Group | Flanker | Cue type | | | | | | | |
| | | No cue | | Double cue | | Center cue | | Spatial cue | |
Phase		Pre	Post	Pre	Post	Pre	Post	Pre	Post
OSFT	Neutral	0.99 (.02)	0.98 (.02)	1.00 (.00)	1.00 (.00)	0.97 (.03)	1.00 (.00)	0.99 (.01)	0.98 (.03)
	Congruent	1.00 (.00)	1.00 (.00)	0.99 (.02)	1.00 (.00)	0.99 (.02)	0.99 (.01)	0.99 (.01)	1.00 (.00)
	Incongruent	0.98 (.03)	0.99 (.02)	0.97 (.03)	0.99 (.02)	0.97 (.04)	1.00 (.00)	0.98 (.02)	0.99 (.01)
ONFT	Neutral	0.99 (.02)	1.00 (.00)	0.99 (.01)	1.00 (.00)	0.99 (.01)	0.99 (.02)	0.99 (.01)	0.98 (.02)
	Congruent	0.99 (.02)	0.99 (.02)	1.00 (.00)	1.00 (.00)	0.99 (.01)	0.99 (.02)	1.00 (.00)	0.99 (.02)
	Incongruent	0.99 (.02)	1.00 (.00)	0.98 (.04)	0.99 (.01)	0.99 (.02)	0.98 (.05)	0.98 (.03)	0.99 (.02)
YSFT	Neutral	0.97 (.04)	0.98 (.03)	0.99 (.01)	0.98 (.03)	0.98 (.02)	0.99 (.03)	0.99 (.01)	1.00 (.00)
	Congruent	0.99 (.01)	0.98 (.02)	0.99 (.02)	0.98 (.03)	1.00 (.00)	0.99 (.01)	1.00 (.00)	0.99 (.01)
	Incongruent	0.92 (.09)	0.94 (.09)	0.88 (.11)	0.92 (.09)	0.92 (.06)	0.92 (.10)	0.93 (.07)	0.96 (.05)
YNFT	Neutral	0.96 (.05)	0.98 (.02)	0.99 (.02)	1.00 (.00)	0.98 (.04)	0.98 (.03)	0.99 (.01)	0.99 (.02)
	Congruent	0.98 (.02)	0.99 (.01)	1.00 (.00)	1.00 (.00)	1.00 (.00)	0.98 (.02)	1.00 (.00)	0.99 (.02)
	Incongruent	0.96 (.05)	0.94 (.06)	0.91 (.07)	0.97 (.04)	0.91 (.13)	0.95 (.06)	0.96 (.05)	0.96 (.03)

$p = .00$). There was a significant interaction of Age and Alerting ($F(1,28) = 6.14$, $p = .02$), indicating that the younger adults benefited more from the double cue condition relative to the no cue condition than did older adults. No other significant interactions involving Neurofeedback with Age, Phase, or Cue type were found, suggesting that NFT has no effect on the alerting effect.

For the orienting network, the results showed significant main effects of Age ($F(1,28) = 52.12$, $p = .00$), Phase ($F(1,28) = 20.03$, $p = .00$), and Orienting (central cue vs. spatial cue, $F(1,28) = 134.10$, $p = .00$). There was a significant interaction of Age and Orienting ($F(1,28) = 4.68$ $p = .04$; indicating that young adults benefited more from the spatial cue relative to the central cue than did older adults), a significant interaction of Phase, Neurofeedback, and Orienting ($F(1,28) = 6.21$ $p = .02$), and a significant interaction of Age, Phase, Neurofeedback, and Orienting ($F(1,28) = 4.65$ $p = .04$). A post hoc test revealed that the interaction of Phase and Cue was only significant in the ONFT group ($F(1,28) = 10.03$ $p = .00$), suggesting that only the ONFT group was able to improve orienting function (i.e., increasing orienting score) via NFB training.

For the conflict network, there were significant main effects of Age ($F(1,28) = 48.52$, $p = .00$), Phase ($F(1,28) = 18.77$, $p = .00$), and Conflict (congruent vs. incongruent, $F(1,28) = 228.78$, $p = .00$). There was a significant interaction of Age and Conflict ($F(1,28) = 10.05$, $p = .00$; indicating that incongruent flankers relative to congruent flankers interfered more strongly in older adults),

and a significant interaction for Phase and Conflict, $F(1,28) = 34.11$, $p = .00$. A post hoc simple effect test of the interaction of Age and Conflict showed that incongruent flankers (relative to congruent flankers) produced more interference in older adults ($F(1,28) = 167.37$, $p = .00$). A post hoc simple effect test for the interaction of Phase and Conflict showed that the overall conflict effects was reduced in the post-training phase ($F(1,28) = 151.70$, $p = .00$). Finally, the 3-way interaction of Phase, Neurofeedback, and Conflict was significant ($F(1,28) = 32.59$, $p = .00$). Post-hoc simple effect tests showed a significant 2-way interaction of Phase and Conflict only for the neurofeedback group ($F(1,28) = 66.69$, $p = .00$), suggesting that both neurofeedback groups (ONFT and YNFT) were able to improve executive function (i.e., reducing conflict score) through 12 sessions of NFB training.

To summarize, there was a significant improvement in orienting scores in the ONFT group after NFT. In addition, there was a significant improvement in conflict scores (i.e., decreased scores) after NFT in both the ONFT and YNFT groups. However, alerting scores failed to increase in this study.

3.1.2.2. ANT: accuracy data. The result of the ANOVA on the mean accuracies showed significant main effects of Age ($F(1,28) = 11.31$, $p = .00$; i.e., the older adults had greater accuracy rates) and of the Flanker type ($F(1.15,32.29) = 27.16$, $p = .00$; i.e., accuracy rates decreasing from the congruent (99.5%) to neutral (99.0%) to incongruent (96.1%) Flanker conditions). No significant
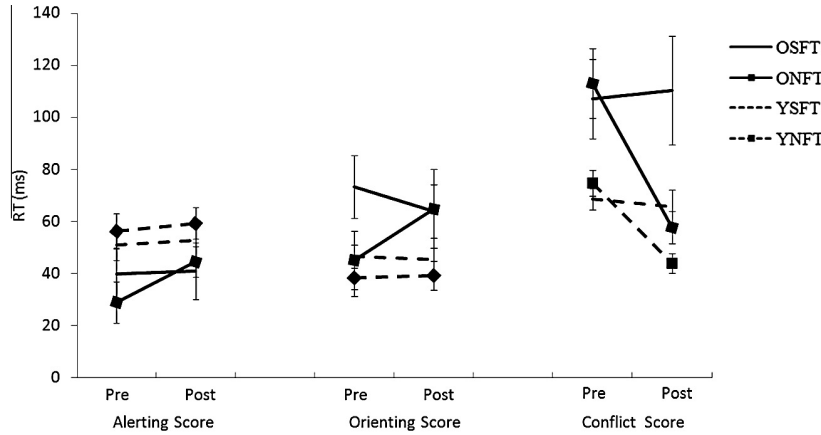
Fig. 4. The RT (ms) scores of alerting, orienting and conflict in the pre- and post-training phases (standard error is illustrated).
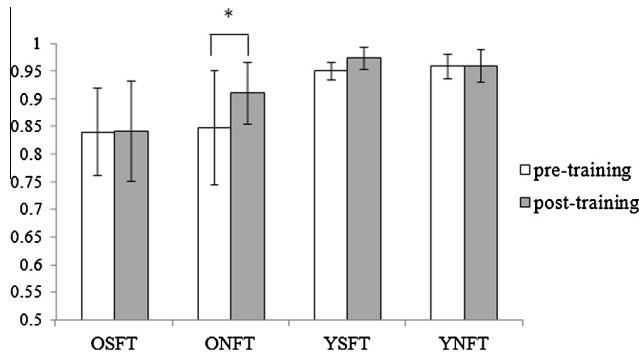

Fig. 5. The overall accuracy in the modified Sternberg recognition task for each group between the pre- and post-training phases (standard error is illustrated). OSFT: the older sham-neurofeedback training group; ONFT: the older neurofeedback training group; YSFT: the younger sham-neurofeedback training group; and YNFT: the younger neurofeedback training group.

Table 3
Statistical results for each frequency band in the eyes-open and eyes-closed conditions in the pre-training phase *: p<.05; **: p<.01.

Pre-training phase	Delta	Theta	Alpha	Beta
Eyes-open				
Age	<.01**	<.01**	>.05	>.05
Age × electrode	>.05	<.01**	>.05	>.05
Age × feedback	>.05	>.05	>.05	>.05
Eyes-closed				
Age	<.01**	<.01**	>.05	>.05
Age × electrode	<.05*	<.01**	>.05	>.05
Age × feedback	>.05	>.05	>.05	>.05

interactions involving Neurofeedback and Age, Phase, Cue type, or Flanker type were found. This result suggests that NFT has no effect on accuracy in the ANT.

3.1.2.3. Sternberg recognition task: accuracy data. A 2 (Age) × 2 (Neurofeedback) × 2 (Phase) × 2 (Memory load: low vs. high) ANOVA was performed on recognition accuracy data. There were significant main effects of Age ($F(1,28) = 27.05$, $p = .00$), Phase ($F(1,28) = 5.24$, $p = .03$), and Memory load ($F(1,28) = 25.15$, $p = .00$). That is, the overall accuracy was lower in the older groups than the younger groups, and the mean accuracies of all participants decreased with increasing memory load. More importantly, there was a significant 3-way interaction of Age, Phase, and Neurofeedback. Post-hoc tests showed that only the ONFT group had a simple main effect of Phase ($F(1,28) = 10.32$, $p = .00$) (see Fig. 5).

3.2. EEG data

3.2.1. The EEG in the pre-training phase
Prior to neurofeedback training, we examined whether the NFT and SFT groups among the older participants (ONFT and OSFT) or among the younger participants (YNFT and YSFT) had the same initial EEG patterns. Moreover, to test the hypothesis that EEG patterns would differ between older and younger participants, we also examined the main effect of Age on each of the frequency bands during the pre-training phase. Table 3 shows the statistical

results of 2 (Age) × 2 (Neurofeedback) × 30 (Electrode) ANOVAs for each frequency band in the eyes-open and eyes-closed conditions in the pre-training phase. Because only the delta and theta frequency bands (and not the alpha or beta frequency bands) yielded significant main effects of Age and interactions involving Age, and because we targeted only theta frequency band training, we report statistical details about only the theta frequency band. Furthermore, because the neurofeedback training was performed during eyes-open state, for brevity, we herein only report statistical details regarding eyes-open theta data. As for the delta data in the pre-training phase, the results of the ANOVA showed a significant main effect of Age ($F(1,28) = 10.87$, $p = .00$), indicating an overall decrease in the absolute delta in the older groups as compared to the younger groups. No other main effects or interactions were significant (all ps > .05).

3.2.1.1. Eyes-open theta data in the pre-training phase. A significant main effect of Age ($F(1,28) = 9.13$, $p = .01$) and an interaction of Age and Electrodes ($F(3.81,106.66) = 5.25$, $p = .00$) were found in the pre-training eyes-open theta amplitude. Previous studies have found that older adults show decreased theta, particularly in the fronto-central midline region. A post hoc simple effect test showed significant simple main effects of Age at the following electrodes: FP1, FP2, F7, F3, FZ, F4, FT7, FC3, FCZ, FC4, FT8, T7, C3, CZ, C4, TP7, CPZ, CP3, CP4, P3, PZ, P4, and P8. The eyes-open theta amplitude of the older adults as compared to the younger group was mostly decreased at the fronto-central midline region (old: $1.31 \pm 0.30 \mu V$ vs. young: $1.80 \pm 0.38 \mu V$ at FCZ site; old: $1.25 \pm 0.29 \mu V$ vs. young: $1.72 \pm 0.39 \mu V$ at FZ site). Furthermore, neither a significant main effect of Neurofeedback ($F(1,28) = 0.34$, $p = .57$) nor a significant interaction of Age and Neurofeedback was found ($F(1,28) = 0.19$, $p = .66$), indicating that the neurofeedback and sham-neurofeedback training groups within either the

older (ONFT and OSFT) or younger groups (YNFT and YSFT) had the same eyes-open theta patterns in the pre-training phase.

3.2.2. The EEG in the post-training phase

The pre-training EEGs demonstrated that the older group showed significantly lower activities in the delta and theta bands. To test for training effects, further analyses investigated the changes in the eyes-open theta band between the pre- and post-training phases using 2 (Age) × 2 (Neurofeedback) × 2 (Phase) × 30 (Electrode) ANOVAs. To further clarify whether the concurrently trained inhibit bands of 0.5–2 and 43–59 Hz might also contribute to the NFT effectiveness, we also investigated the changes in these two bands between the pre- and post-training phases using similar ANOVAs.

3.2.2.1. Eyes-open theta data in the post-training phase. A significant main effect of Age was found ($F(1,28) = 9.84$, $p = .00$). Additionally, there was a significant interaction of Phase and Neurofeedback ($F(1,28) = 8.14$, $p = .00$). A post hoc simple effect test showed that there was a significant simple main effect of Phase in the neurofeedback groups (i.e., ONFT and YNFT groups) ($F(1,28) = 8.37$, $p = .01$) but not in the sham-neurofeedback groups (i.e., OSFT and YSFT groups) ($F(1,28) = 1.30$, $p = .26$). Fig. 6 shows changes in EEG topography of the resting eyes-open theta amplitude after neurofeedback or sham-neurofeedback training with respect to the pre-training phase for the older and younger groups.

According to the results described in the pre-training findings, fmθ activity was found to be the most strongly decreased in the older adults. In addition, the NFT protocol in the current study also focused on fmθ enhancement. Hence, our main interest was to analyze whether fmθ changed after NFT. The results of a 2 (Age) × 2 (Neurofeedback) × 2 (Phase) ANOVA at electrode Fz revealed significant main effects of Age ($F(1,28) = 16.52$, $p = .00$) and Phase ($F(1,28) = 6.40$, $p = .02$). Moreover, a significant interaction of Phase and Neurofeedback on theta amplitude was also observed ($F(1,28) = 10.39$, $p = .00$). A post hoc simple effect test showed that there was a significant simple main effect of Phase in the neurofeedback group ($F(1,28) = 16.55$, $p = .00$), suggesting that the neurofeedback group was able to increase fmθ in the post-training phase. However, no interaction of Age, Phase and Neurofeedback was found ($F(1,28) = .78$, $p = .38$). To investigate whether there were significant improvements specifically in the ONFT and YNFT groups, paired *t*-tests were applied to explore the differences between the pre- and post-training phases. The results showed that fmθ increased in the ONFT ($t(7) = -3.43$, $p = .01$) and YNFT groups ($t(7) = -2.69$, $p = .03$). Fig. 7 shows the mean eyes-open theta amplitude electrode Fz for each group for the pre- and post-training phases.

3.2.2.2. The inhibit bands of 0.5–2 and 43–59 Hz data in the post-training phase. For the inhibit band of 0.5–2 Hz, the results of the ANOVA for the main effect of Phase; Phase and Age; Phase and Neurofeedback; and Phase, Age and Neurofeedback were not significant (all ps > .05). Identical ANOVA results were also observed for the inhibit band of 43–59 Hz. These results preclude the possibility that the effectiveness of NFT on cognitive functions might be attributed to these two inhibit band modulations.

3.2.3. Neurofeedback training index

For each training session, the ratio of the mean theta amplitude during training compared to baseline was obtained as a training index. The results of a 2 (Age) × 2 (Neurofeedback) × 12 (Session) ANOVA on the training indices showed significant main effects of Neurofeedback ($F(1,28) = 57.07$, $p = .00$) and Session ($F(5.25, 146.89) = 15.60$, $p = .00$). Moreover, there were significant interactions between Neurofeedback and Session ($F(5.25, 146.89) = 10.25$, $p = .00$) and Age, Neurofeedback and Session ($F(5.25, 146.89) = 2.49$, $p = .03$). A post hoc test following the 3-way interaction of Age, Neurofeedback and Session showed that there was a significant simple main effect of Session in the ONFT ($F(11,308) = 8.11$, $p = .00$) and YNFT ($F(11,308) = 21.81$, $p = .00$) groups. This result suggests that both the ONFT and YNFT groups exhibited improved training indices over the sessions.

We further performed trend analyses on the training indices over the 12 sessions for each group. The results are consistent with the ANOVA; namely, the trend analyses demonstrated significant linear increases in the theta ratio with session for the two NFT
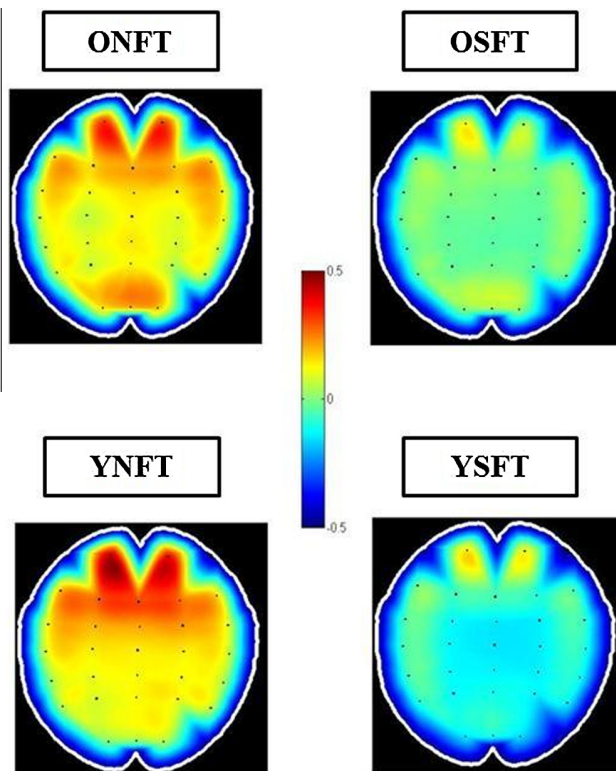

Fig. 6. Maps of the average differences of eyes-open resting theta amplitudes after the NFT with respect to the pre-training phase in each group. OSFT: the older sham-neurofeedback training group; ONFT: the older neurofeedback training group; YSFT: the younger sham-neurofeedback training group; and YNFT: the younger neurofeedback training group.
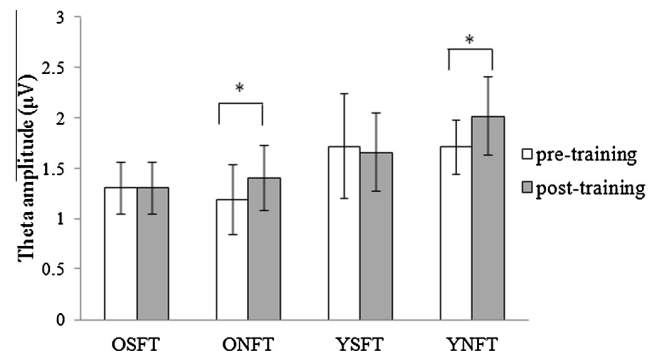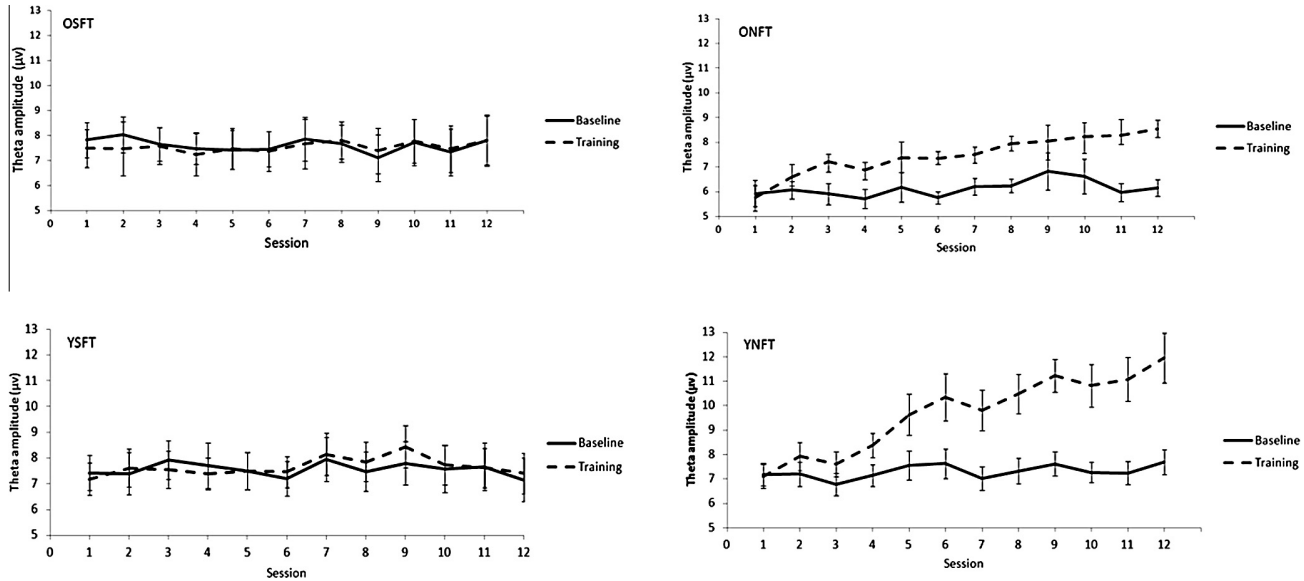

Fig. 7. The mean amplitude (μV) of eyes-open theta changes at electrode Fz between the pre- and post-training phase for each group (standard error is illustrated). OSFT: the older sham-neurofeedback training group; ONFT: the older neurofeedback training group; YSFT: the younger sham-neurofeedback training group; and YNFT: the younger neurofeedback training group.

Fig. 8. The training indices of the original mean amplitudes during the training and baseline periods as a function of the twelve sessions for each group (standard error is illustrated). OSFT: the older sham-neurofeedback training group; ONFT: the older neurofeedback training group; YSFT: the younger sham-neurofeedback training group; and YNFT: the younger neurofeedback training group.

groups (ONFT: $F(1,7) = 8.864$, $p < .05$; YNFT: $F(1,7) = 11.625$, $p < .05$) and no significant increase for the two sham-neurofeedback groups (OSFT & YSFT: ps > .05).

We also plotted the original mean theta amplitudes over the 12 sessions during the training and baseline periods for each of the four groups (see Fig. 8) to consider that there might be incremental effects on the session baselines that influence the tonic EEG, which might be masked by the ratio measure. Trend analyses on these mean amplitudes were also performed. The results showed that for only the two NFT groups, the training periods showed significant linear increases in the theta amplitude with session (ONFT: $F(1,7) = 7.295$, $p < .05$; YNFT: $F(1,7) = 26.504$, $p < .01$), whereas no significant linear trends were observed for any other condition (all ps > .05).

4. Discussion

This study aimed to investigate the effectiveness of the fmθ activity uptraining protocol on attention and working memory performance of older and younger participants. The main result of this study showed a significant increasing trend of the theta amplitudes and the training indices in the course of 12 sessions for the neurofeedback training groups, but not for the sham-neurofeedback training groups. Furthermore, the eyes-open resting theta activity was found to be significantly increased in the post-training phase as compared to the pre-training phase for the neurofeedback training groups only. These EEG findings provide strong evidence for the success of our fmθ uptraining protocol. More critically, the present study demonstrated the effectiveness of fmθ neurofeedback training in the attention and working memory functions of older and younger participants.

In previous decades, many studies have shown that normal aging processes result in cognitive and EEG deviations. The present study observed that older participants showed inferior alerting and executive functioning in the ANT and decreased performances in the modified Sternberg recognition task before neurofeedback training, as was previously reported. Regarding the EEG deviations, the older participants in the present study showed decreased amplitudes in the delta and theta, but not alpha (also peak alpha)

and beta, frequency bands in the resting state. The present results appear to be inconsistent with previous studies, which showed decreased alpha activity at posterior sites (i.e., the occipital or temporo-parietal sites) during normal aging (Breslau et al., 1989; Matoušek et al., 1967), but are nevertheless consistent with other studies, which showed no decrease in the resting alpha activity with increasing age (e.g., Duffy et al., 1984). Similarly, the present results showing decreased eyes-open and eyes-closed theta activity which, on one hand, was consistent with previous results showing decreased theta activity (Breslau et al., 1989; Cummins and Finnigan, 2007; Duffy et al., 1984; Matoušek et al., 1967), and on the other hand, was consistent with other studies showing increased theta activity (Matejcek, 1980; Nakano et al., 1992) with increasing age. The discrepancies among these studies deserve research attention; however, this problem cannot be directly addressed in this study with the current design. How the EEG was recorded (e.g., eyes-closed or eyes-open; during the resting state or task condition), the activity that the participants might be asked to engage in (e.g., did nothing or passively listened to a tape recorded story), the sample population's age range (e.g., wide vs. narrow age range) and so on might contribute to the discrepancies. Nevertheless, we believe that the current results contribute to the accumulation of additional empirical evidence in the literature regarding age-related EEG deviations.

To our knowledge, no study has yet examined the effectiveness of fmθ uptraining in cognitive aging. The results of this study showed that the fmθ activity uptraining protocol benefitted the older participants in terms of orienting and conflict (executive function) scores in the ANT, whereas the younger participants only benefitted in the conflict score. However, why would fmθ training benefit the older participants in both the orienting and conflict scores, but benefit the younger participants only in the conflict score of the ANT in this study? One possibility is that the RT in the spatial cue condition (post-training mean RT = 386.6 ± 25.4 ms) for the YNFT group had been in the optimal performance which might mask the gain of NFT on the orienting score (pre-training mean RT = 426.8 ± 43.9 ms) because there was also a near-equivalent gain in speed in the center cue condition (post-training mean RT = 425.7 ± 39.2 ms; pre-training mean RT = 465.1 ± 49.4 ms). The mean RT for the ONFT group was generally slower than the YFT

group, which might increase the observation of the effectiveness of the NFT. Future studies with increasing task demand to slower response speed for younger participants may help clarify this problem. Another possibility in explanation of the age differences in the effectiveness of NFT in cognitive performance may be related to different characterizations between the two sampling age groups. In the current study, the younger participants were mainly university students whereas the older participants were recruited from the local community. We had tried to minimize the cohort effect by recruiting the older participants with near equivalent years of education (e.g., similar university-level education background) as the younger participants. In addition, the majority of our older participants were either retired from the government or universities, and at the time of joining this study also participating in some volunteer works in either a local hospital or community. As such, the older participants in the current study could be considered as high-functioning elders. All of these potential protective factors for our older participants should be taken into account while evaluating the outcome of the fmθ uptraining NFT.

More critically, why would fmθ training contribute to the orienting and conflict scores but not the alerting score? The executive control of attention, particularly in conflict situations (e.g., the Stroop task), involves the detection and resolution of conflict in mental operations between brain regions and has been suggested to be mediated mainly by the anterior cingulate cortex (ACC) and medial frontal cortex (MFC) (Fan et al., 2002), which are the brain regions that correspond to the current training site (i.e., the frontal-midline site). The orienting function refers to the selection of information and shifting of attention toward the direction of an incoming stimulus (Posner and Petersen, 1990) and appears to be mediated mainly by the superior parietal lobe, frontal eye fields, superior colliculus and temporoparietal junction (Corbetta and Shulman, 2002). Hence, fmθ enhancement may be particularly effective in facilitating the brain processes involving the frontal eye fields. Whereas the alerting function is associated with the frontal and parietal regions specifically in the right hemisphere (Fan et al., 2002), the current frontal-midline region uptraining may not be effective in modulating this function.

Furthermore, the current results show the effectiveness of the fmθ NFT on conflict (for both younger and older groups) and orienting (only for older group) scores of ANT but not the alerting score of ANT, which may also imply that the fmθ NFT is more associated with the dopaminergic system. Neuropharmacological researchers have shown that although alerting was associated with the cholinergic system (e.g., Tales et al., 2006; Thiel et al., 2005), visuo-spatial orienting attention, conflict, and working memory, are more associated with the dopaminergic system (Colzato et al., 2010; Mitchell et al., 2008). Therefore, these results suggest that fmθ (such as hippocampal theta) uptraining NFT may be associated with the dopaminergic system, which resulted in an improvement of executive attention.

A final remark regarding the effectiveness of NFT in ANT performance for the older participants is that our older participants exhibited a seemly trade-off of speed and accuracy in the pre-training phase. Interestingly, although NFT improved the RT performance of ANT in the older participants, it did not modulate such a trade-off of speed and accuracy pattern. This implies that the fmθ training effectively improved the older participants' response speed without influencing response accuracies.

In addition to the contribution to attentional functions, the fmθ training in this study was observed to improve working memory function (i.e., recognition task performance) in the older participants. This result replicates previous results by Finnigan and Robertson (2011) who suggested that cognitive functions (e.g., attention, memory, and executive function) are associated with greater frontal theta activity. The result also replicates the afore-

mentioned dopaminergic hypothesis regarding the effect of fmθ training on working memory (Mitchell et al., 2008). We reason that the fmθ NFT in this study did not improve the memory function of younger participants partially because of the ceiling performance (>95%) (see Lofthouse et al., 2012 for the guidelines of choosing the desired accuracy for optimal learning). To further evaluate whether NFT can modulate resting EEG, we examined whether the participants in the neurofeedback groups (ONFT and YNFT), but not those in the sham-neurofeedback groups (OSFT and YSFT), exhibited a significant increase in theta activity in the frontal-midline region between the pre- and post-training phases. After 4 weeks (12 sessions) of fmθ uptraining, only the neurofeedback participants were able to enhance their fmθ activity. Therefore, together with evidence showing improvement in cognitive performance and increased fmθ activity, we suggest that the NFT protocol may function as a reconditioning process for older participants. Based on Finnigan and Robertson (2011), high resting fmθ power, which is positively correlated with better cognitive performance, can serve as a sensitivity index of healthy cognitive aging that is free of severe cognitive deterioration or impairment. This idea implies that the current training protocol, i.e., uptraining the fmθ, may prevent or decrease cognitive deterioration. For the younger participants, we suggest that the NFT protocol may function as practice for executive function or inner focused enhancement. Furthermore, because some previous studies have shown that theta activity is associated with the integration of several brain regions and a deeply internalized state and quieting of the body, emotions, and thoughts (Green and Green, 1977), we suggest that uptraining theta activity may have a positive effect on mindfulness or concentration in healthy individuals.

Although this study demonstrates that uptraining fmθ activity during the resting state can improve subsequent cognitive performance, future studies may consider evaluating task-relevant fmθ activity instead of resting-state theta activity. Previous studies have shown that normally aging adults have lower fmθ during task conditions, and this measure may serve as a more sensitive marker of cognitive aging than task performance (Cummins and Finnigan, 2007). Furthermore, the uptraining protocol developed in this study focused mainly on fmθ enhancement, but activity in other frequency bands, such as delta, also deserve further investigation. We focused mainly on uptraining fmθ activity because previous studies have suggested that this activity is related to several cognitive functions (e.g., working memory and attention) in which older adults may show impairments and, more recently, researchers have suggested that a higher resting fmθ is significantly correlated with better cognitive performance (Finnigan and Robertson, 2011). However, the present results showed not only significantly lower theta activity but also significantly lower delta activity in the older participants in the pre-training phase. Therefore, alternative methods for evaluating the effect of reconditioning delta activity as a neurofeedback training protocol should be considered in future studies.

In conclusion, our study demonstrated that fmθ uptraining might improve attention, working memory performance and theta activity in the resting state for normal aging adults after twelve sessions of neurofeedback training. In addition, younger participants also benefited from the present protocol in terms of improving their executive function.

References

Angelakis E, Stathopoulou S, Frymiare JL, Green DL, Lubar JF, Kounios J. EEG neurofeedback: a brief overview and an example of peak alpha frequency training for cognitive enhancement in the elderly. Clin Neuropsychol 2007;21:110–29.

Ball KK, Beard BL, Roenker DL, Miller RL, Griggs DS. Age and visual search: expanding the useful field of view. J Opt Soc Am A, Opt Image Sci 1988;5:2210–9.

Barnea A, Rassis A, Zaidel E. Effect of neurofeedback on hemispheric word recognition. Brain Cogn 2005;59:314–21.

Basar-Eroglu C, Basar E, Demiralp T, Schurmann M. P300-response: possible psychophysiological correlates in delta and theta frequency channels. A review. Int J Psychophysiol 1992;13:161–79.

Bauer RH. Short-term memory: EEG alpha correlates and the effect of increased alpha. Behav Biol 1976;17:425–33.

Beatty J, Greenberg A, Diebler WP, O'Hanlon JF. Operant control of occipital theta rhythm affects performance in a radar monitoring task. Science 1974;183:871–3.

Becerra J, Fernandez T, Roca-Stappung M, Diaz-Comas L, Galan L, Bosch J, et al. Neurofeedback in healthy elderly human subjects with electroencephalographic risk for cognitive disorder. J Alzheimers Dis 2012;28:357–67.

Beck AT, Steer RA, Brown GK. Manual for the beck depression inventory. 2nd ed. San Antonio, TX: The Psychological Association; 1996.

Boynton T. Applied research using alpha/theta training for enhancing creativity and well-being. J Neurother 2001;5:5–18.

Breslau J, Starr A, Sicotte N, Higa J, Buchsbaum MS. Topographic EEG changes with normal aging and SDAT. Electroencephalogr Clin Neurophysiol 1989;72:281–9.

Cabeza R. Hemispheric asymmetry reduction in older adults: the HAROLD model. Psychol Aging 2002;17:85–100.

CBS, Central Bureau Statistiek. Bevolkingsprognose 2010–2060: sterkere vergrijzing, langere levensduur. 2011; available at: <http://www.cbs.nl/NR/rdonlyres/389D62E2-7205-42C3-956F-33E17CFE6433/0/2011-k1b15p16art.pdf>.

Chen SH, Desmond JE. Cerebrocerebellar networks during articulatory rehearsal and verbal working memory tasks. Neuroimage 2005;24:332–8.

Corbetta M, Shulman GL. Control of goal-directed and stimulus-driven attention in the brain. Nat Rev Neurosci 2002;3:201–15.

Colzato LS, Pratt J, Hommel B. Dopaminergic control of attentional flexibility: inhibition of return is associated with the dopamine transporter gene (DAT1). Front Hum Neurosci 2010;4:53.

Craik FIM, Morris RG, Gick M. Adult age differences in working memory. In: Vallar G, Shallice T, editors. Neuropsychological impairments of short-term memory. Cambridge: Cambridge University Press; 1990. p. 247–67.

Cummins TD, Finnigan S. Theta power is reduced in healthy cognitive aging. Int J Psychophysiol 2007;66:10–7.

Doppelmayr M, Klimesch W, Stadler W, Polhuber D, Heine C. EEG alpha power and intelligence. Intelligence 2002;30:289–302.

Duffy FH, Albert MS, McAnulty G, Garvey AJ. Age-related differences in brain electrical activity of healthy subjects. Ann Neurol 1984;16:430–8.

Egner T, Gruzelier JH. Learned self-regulation of EEG frequency components affects attention and eventrelated brain potentials in humans. Neuroreport 2001;12:4155–9.

Egner T, Gruzelier JH. Ecological validity of neurofeedback: modulation of slow wave EEG enhances musical performance. Neuroreport 2003;14:1221–4.

Egner T, Gruzelier JH. EEG Biofeedback of low beta band components: frequency-specific effects on variables of attention and event-related brain potentials. Clin Neurophysiol 2004;115:131–9.

Egner T, Zech TF, Gruzelier JH. The effects of neurofeedback training on the spectral topography of the electroencephalogram. Clin Neurophysiol 2004;115:2452–60.

Fan J, McCandliss BD, Fossella J, Flombaum JI, Posner MI. The activation of attentional networks. NeuroImage 2005;26:471–9.

Fan J, McCandliss BD, Sommer T, Raz A, Posner MI. Testing the efficiency and independence of attentional networks. J Cogn Neurosci 2002;14:340–7.

Faust ME, Balota DA. Inhibition of return and visuospatial attention in healthy older adults and individuals with dementia of the Alzheimer type. Neuropsychology 1997;11:13–29.

Fernandez-Duque D, Black SE. Attentional networks in normal aging and Alzheimer's disease. Neuropsychology 2006;20:133–43.

Fernandez-Duque D, Posner MI. Relating the mechanisms of orienting and alerting. Neuropsychologia 1997;35:477–86.

Finnigan S, Robertson IH. Resting EEG theta power correlates with cognitive performance in healthy older adults. Psychophysiology 2011;48:1083–7.

Folstein MF, Folstein SE, McHugh PR. Mini-mental state. A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189–98.

Gamboz N, Zamarian S, Cavallero C. Age-related differences in the attention network test (ANT). Exp Aging Res 2010;36:287–305.

Gevins AS, Zeitlin GM, Doyle JC, Schaffer RE, Callaway E. EEG patterns during 'cognitive' tasks. II. Analysis of controlled tasks. Electroencephalogr Clin Neurophysiol 1979a;47:704–10.

Gevins AS, Zeitlin GM, Doyle JC, Yingling CD, Schaffer RE, Callaway E, et al. Electroencephalogram correlates of higher cortical functions. Science 1979b;203:665–8.

Gevins AS, Zeitlin GM, Yingling CD, Doyle JC, Dedon MF, Schaffer RE, et al. EEG patterns during 'cognitive' tasks. I. Methodology and analysis of complex behaviors. Electroencephalogr Clin Neurophysiol 1979c;47:693–703.

Grady CL, Craik FI. Changes in memory processing with age. Curr Opin Neurobiol 2000;10:224–31.

Green E, Green A. Beyond biofeedback. New York: Delacorte Press; 1977.

Grunwald M, Weiss T, Krause W, Beyer L, Rost R, Gutberlet I, et al. Theta power in the EEG of humans during ongoing processing in a haptic object recognition task. Cogn Brain Res 2001;11:33–7.

Gruzelier J. A theory of alpha/theta neurofeedback, creative performance enhancement, long distance functional connectivity and psychological integration. Cogn Process 2009;10:101–9.

Hammond DC. QEEG-guided neurofeedback in the treatment of obsessive compulsive disorder. J Neurother 2003;7:25–52.

Hammond DC. Neurofeedback treatment of depression and anxiety. J Adult Dev 2005;12:131–7.

Hammond DC. What is neurofeedback: an update. J Neurother 2011;15:305–36.

Hanslmayer S, Sauseng P, Doppelmayr M, Schabus M, Klimesch W. Increasing individual upper alpha by neurofeedback improves cognitive performance in human subjects. Appl Psychophysiol Biofeedback 2005;30:1–10.

Hartikainen P, Soininen H, Partanen J, Helkala EL, Riekkinen P. Aging and spectral analysis of EEG in normal subjects: a link to memory and CSF AChE. Acta Neurol Scand 1992;86:148–55.

Hasher L, Zacks RT. Working memory, comprehension, and aging: a review and a new view. In: Gordon HB, editor. Psychology of learning and motivation. Academic Press; 1988. p. 193–225.

Hughes JR, Cayaffa JJ. The EEG in patients at different ages without organic cerebral disease. Electroencephalogr Clin Neurophysiol 1977;42:776–84.

Inouye T, Shinosaki K, Iyama A, Matsumoto Y, Toi S, Ishihara T. Potential flow of frontal midline theta activity during a mental task in the human electroencephalogram. Neurosci Lett 1994;169:145–8.

Jarusiewicz B. Efficacy of neurofeedback for children in the Autistic spectrum: a Pilot study. J Neurother 2002;6:39–49.

Jennings JM, Dagenbach D, Engle CM, Funke LJ. Age-related changes and the attention network task: an examination of alerting, orienting, and executive function. Aging Neuropsychol Cogn 2007;14:353–69.

Jensen O, Tesche CD. Frontal theta activity in humans increases with memory load in a working memory task. Eur J Neurosci 2002;15:1395–9.

Jonides J, Nee DE. Brain mechanisms of proactive interference in working memory. Neuroscience 2006;139:181–93.

Kaiser DA, Othmer S. Effect of neurofeedback on variables of attention in a large multi-center trial. J Neurother 2000;4:5–15.

Karrasch M, Laine M, Rapinoja P, Krause CM. Effects of normal aging on event-related desynchronization/synchronization during a memory task in humans. Neurosci Lett 2004;366:18–23.

Keizer AW, Verment RS, Hommel B. Enhancing cognitive control through neurofeedback: a role of gamma-band activity in managing episodic retrieval. NeuroImage 2010;49:3404–13.

Klimesch W. EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res Rev 1999;29:169–95.

Klimesch W, Doppelmayr M, Russegger H, Pachinger T, Schwaiger J. Induced alpha band power changes in the human EEG and attention. Neurosci Lett 1998;244:73–6.

Klimesch W, Doppelmayr M, Schimke H, Ripper B. Theta synchronisation and alpha desynchronisation in a memory task. Psychophysiology 1997;34:169–76.

Kramer AF, Hahn S, Gopher D. Task coordination and aging: explorations of executive control processes in the task switching paradigm. Acta Psychol 1999;101:339–78.

Kramer AF, Humphrey DG, Larish JF, Logan GD, Strayer DL. Aging and inhibition: beyond a unitary view of inhibitory processing in attention. Psychol Aging 1994;9:491–512.

Kubota Y, Sato W, Toichi M, Murai T, Okada T, Hayashi A, et al. Frontal midline theta rhythm is correlated with cardiac autonomic activities during the performance of an attention demanding meditation procedure. Cogn Brain Res 2001;11:281–7.

Lagopoulos J, Xu J, Rasmussen I, Vik A, Malhi GS, Eliassen CF, et al. Increased theta and alpha EEG activity during nondirective meditation. J Altern Complement Med 2009;15:1187–92.

Lecomte G, Juhel J. The effects of neurofeedback training on memory performance in elderly subjects. Psychology 2011;2:846–52.

Lofthouse N, Arnold LE, Hersch S, Hurt E, DeBeus R. A review of neurofeedback treatment for pediatric ADHD. J Atten Disord 2012;16:351–72.

Lubar JF. Neocortical dynamics: implications for understanding the role of neurofeedback and related techniques for the enhancement of attention. Appl Psychophysiol Biofeedback 1997;22:111–26.

Madden DJ. Speed and timing of behavioral processes. In: Birren JE, Schaie KW, editors. Handbook of the psychology of aging. 5th ed. San Diego: Academic Press; 2001. p. 288–312.

Madden DJ, Connelly SL, Pierce TW. Adult age differences in shifting focused attention. Psychol Aging 1994;9:528–38.

Madden DJ, Gottlob LR, Allen PA. Adult age differences in visual search accuracy: attentional guidance and target detectability. Psychol Aging 1999;14:683–94.

Madden DJ, Turkington TG, Provenzale JM, Hawk TC, Hoffman JM, Coleman RE. Selective and divided visual attention: age-related changes in regional cerebral blood flow measured by H_2 ^{15}O PET. Hum Brain Mapp 1997;5:389–409.

Mahoney JR, Verghese J, Goldin Y, Lipton R, Holtzer R. Alerting, orienting and executive attention in non-demented older adults. J Int Neuropsychol Soc 2010;27:1–13.

Manoach DS, Halpern EF, Kramer TS, Chang Y, Goff DC, Rauch SL, et al. Test-retest reliability of a functional MRI working memory paradigm in normal and schizophrenic subjects. Am J Psychiatry 2001;158:955–8.

Matejcek M. Some relationships between occipital E.E.G. activity and age. A spectral analytic study. Rev Electroencephalogr Neurophysiol Clin 1980;10:122–30.

Matoušek M, Volavka J, Roubicek J, Roth Z. EEG frequency analysis related to age in normal adults. Electroencephalogr Clin Neurophysiol 1967;23:162–7.

Mayr U. Age differences in the selection of mental sets: the role of inhibition, stimulus ambiguity, and response-set overlap. Psychol Aging 2001;16:96–109.

Mitchell DJ, McNaughton N, Flanagan D, Kirk IJ. Frontal-midline theta from the perspective of hippocampal "theta". Prog Neurobiol 2008;86:156–85.

Missonnier P, Deiber MP, Gold G, Millet P, Gex-Fabry Pun M, Fazio-Costa L, et al. Frontal theta event-related synchronization: comparison of directed attention and working memory load effects. J Neural Transm 2006;113:1477–86.

Nakano T, Miyasaka M, Ohtaka T, Ohmori K. Longitudinal changes in computerized EEG and mental function of the aged: a nine-year follow-up study. Int Psychogeriatr 1992;4:9–23.

Obrist WD. The electroencephalogram of normal aged adults. Electroencephalogr Clin Neurophysiol 1954;6:235–44.

Onton J, Delorme A, Makeig S. Frontal midline EEG dynamics during working memory. NeuroImage 2005;27:341–56.

Ostrosky-Solís F, Gómez-Pérez ME, Matute E, Rosselli M, Ardila A, Pineda D. Neuropsi attention and memory: a neuropsychological test battery in Spanish with norms by age and educational level. Appl Neuropsychol 2007;14:156–70.

Peniston EG, Kulkosky PJ. Alpha–theta brainwave training and beta-endorphin levels in alcoholics. Alcohol Clin Exp Res 1989;13:271–9.

Peniston EG, Kulkosky PJ. Alcoholic personality and alpha-theta brainwave training. Medical Psychother 1990;3:37–55.

Peniston EG, Kulkosky PJ. Neurofeedback in the treatment of addictive disorders. In: Evans AJR, editor. Introduction to quantitative EEG and neurofeedback. San Diego: Academic Press; 1999. p. 157–79.

Peniston EG, Marrinan DA, Deming WA, Kulkosky PJ. EEG alpha-theta brainwave synchronization in Vietnam theater veteran with combat-related posttraumatic stress disorder and alcohol abuse. Med Psychother: An Int J 1993;6:37–50.

Posner MI, Petersen SE. The attention system of the human brain. Annu Rev Neurosci 1990;13:25–42.

Salthouse TA. The aging of working memory. Neuropsychology 1994;8:535–43.

Sauseng P, Klimesch W, Gruber W, Doppelmayr M, Stadler W, Schabus M. The interplay between theta and alpha oscillations in the human electroencephalogram reflects the transfer of information between memory systems. Neurosci Lett 2002;324:121–4.

Spieler DH, Balota DA, Faust ME. Stroop performance in younger adults, healthy adults, and individuals with senile dementia of the Alzheimer's type. J Exp Psychol Hum Percept Perform 1996;22:461–79.

Sterman MB, Friar L. Suppression of seizures in anepileptic following sensorimotor EEG feedback training. Electroencephalogr Clin Neurophysiol 1972;33:89–95.

Sternberg S. High-speed scanning in human memory. Science 1966;153:652–4.

Tales A, Snowden RJ, Brown M, Wilcock G. Alerting and orienting in Alzheimer's disease. Neuropsychology 2006;20:752–6.

Thiel CM, Zilles K, Fink GR. Nicotine modulates reorienting of visuospatial attention and neural activity in human parietal cortex. Neuropsychopharmacology 2005;30:810–20.

Thornton KE. Improvement/rehabilitation of memory functioning with neurotherapy/QEEG biofeedback. J Head Trauma Rehabil 2000;15:1285–96.

Thornton KE, Carmody DP. Electroencephalogram biofeedback for reading disability and traumatic brain injury. Child Adolesc Psychiatr Clin N Am 2005;14:137–62.

Thornton KE, Carmody DP. Efficacy of traumatic brain injury rehabilitation: interventions of QEEG-guided biofeedback, computers, strategies, and medications. Appl Psychophysiol Biofeedback 2008;33:101–24.

Thornton KE, Carmody DP. Traumatic brain injury rehabilitation: QEEG biofeedback treatment protocols. Appl Psychophysiol Biofeedback 2009;34:59–68.

Tinius TP, Tinius KA. Changes after EEG biofeedback and cognitive retraining in adults with mild traumatic brain injury and attention deficit hyperactivity disorder. J Neurother 2000;4:27–44.

Van Gerven PW, Paas F, Van Merrienboer JJ, Schmidt HG. Memory load and the cognitive pupillary response in aging. Psychophysiology 2004;41:167–74.

Vernon DJ. Can neurofeedback training enhance performance? an evaluation of the evidence with implications for future research. Appl Psychophysiol Biofeedback 2005;30:347–64.

Vernon D, Egner T, Cooper N, Compton T, Neilands C, Sheri A, et al. The effect of training distinct neurofeedback protocols on aspects of cognitive performance. Int J Psychophysiol 2003;47:75–85.

West RL. An application of prefrontal cortex function theory to cognitive aging. Psychol Bull 1996;120:272–92.

Zacks RT, Hasher L, Li KZH. Human memory. In: Craik FIM, Salthouse TA, editors. Handbook of cognitive aging and cognition. Mahwah, NJ: Lawrence Erlbaum Associates; 2000. p. 293–357.