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Influence of electroencephalography neurofeedback training on episodic memory: A randomized, sham-controlled, double-blind study

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The relationships between memory processes and oscillatory electroencephalography (EEG) are well established. Neurofeedback training (NFT) may cause participants to better regulate their brain EEG oscillations. The present study is a double-blind sham-controlled design investigating the effect of NFT on memory. NFT included up-training upper alpha (UA) band, up-training sensory-motor rhythm (SMR) band and sham protocol. Thirty healthy adult volunteers were randomly divided into three treatment groups. NFT sessions (30 min each) took place twice weekly for a total of 10 sessions while memory testing took place pre- and post-training. The results indicate dissociation between SMR and UA NFT and different memory processes. While the SMR protocol resulted in improving automatic, item-specific and familiarity-based processes in memory, the UA protocol resulted in improved strategic and controlled recollection. The implications of the results are discussed.

Keywords: Neurofeedback; Memory; Familiarity; Recollection; Randomized control design.

The integration of distinct aspects of experience into cohesive episodes is considered fundamental to future recollection of those events. Episodic memory refers to one's capacity to explicitly recall information concerning past events, including a concept of *what* happened and *where* and *when* it occurred. Tulving (1983) described episodic recollection as a form of mental time travel by which one figuratively relives past experiences. Efficient episodic memory is a prerequisite for successful real life functioning. Finding ways to improve episodic memory functioning has therefore become an important research goal.

Electroencephalography (EEG) biofeedback, also referred to as neurofeedback training (NFT), is a non-invasive technique, based on principles of operant conditioning. This method involves placement of electrodes that transduce brain activity at predetermined locations on an individual's scalp. When a specific form of brain wave activity is recorded, a reward is offered to the subject. Typically, rewards are offered when the amplitude of a specific frequency band is measured above or below a predetermined threshold. The most commonly employed rewards are video or audio signal, either singly or in combination. Over time, an

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individual can be trained to regulate his or her brain oscillations and maintain the amplitude of these oscillations within a predetermined bandwidth. The location of the electrodes on the scalp and the specific frequencies selected for a study define the experimental protocol. The present study focuses on the effect of up-training of the sensory-motor rhythm (SMR, 13–15 Hz) and the upper alpha (UA, 10–12 Hz) NFT on episodic memory in healthy young adults.

Previous studies have suggested that NFT may be therapeutically beneficial in certain neurological disorders, including epilepsy (e.g., Sterman & Egner, 2006), attention-deficit/hyperactivity disorder (e.g., Lubar, 2003) and autistic spectrum disorders (e.g., Coben, Linden, & Myers, 2010). Moreover, the relationship between certain cognitive functions and particular EEG oscillations is well established (Basar, 2006; Basar & Güntekin, 2008; Herrmann, Sensowski, & Röttger, 2004).

NFT and episodic memory

In healthy individuals, NFT has been shown to improve certain forms of memory (Escolano, Aguilar, & Minguez, 2011; Gruzelier, Egner, & Vernon, 2006; Hanslmayr, Sauseng, Doppelmayr, Schabus, & Klimesch, 2005; Vernon et al., 2003; Zoefel, Huster, & Herrmann, 2011). For example, memory processes were found to be improved when theta and alpha band activity was enhanced through various conditioning protocols (Klimesch et al., 2001; Klimesch, 1999, 1997). It has been suggested that UA activity is relevant to the interplay between working/short-term memory (WM/STM) and long-term memory (LTM) and more specifically retrieval from LTM (Klimesch, 1997; Vernon, 2005). Taken together, these associations between particular EEG frequencies and various aspects of cognitive processing, including memory, provide a plausible rationale for the use of NFT to modulate EEG oscillations with the goal of enhancing specific cognitive processes.

Previous studies examining the effects of NFT on memory in healthy individuals (Escolano et al., 2011; Keizer, Verment, & Hommel, 2010; Nan et al., 2012; Vernon et al., 2003) have produced inconclusive results. Therefore, generalisation cannot currently be made concerning a recommended protocol, the ideal number of sessions or the nature of memory functions to be targeted by NFT. Nevertheless, these studies do suggest that NFT may have at least some effect on both STM/WM and LTM. For example, Vernon et al. (2003) found that NFT was associated with improved performance on the semantic STM component of WM. This improvement was noted in subjects who received SMR training but not in those who received theta NFT or in NFT naive controls. Ten SMR NFT sessions were also found to be effective in improving declarative memory (Hoedlmoser et al., 2008). Finally, Keizer et al. (2010) trained participants using a remember/know paradigm in which memory testing requires the participant to indicate whether he or she has a recollection of the item ("remember") or only a vague sense of familiarity ("know"). This study revealed improved "remember" responses following gamma-band activity training (36–44 Hz), while beta-band activity training (12–20 Hz) appeared to increase the rate of "know" responses.

Non-interventional studies have shown that young adults' memory performance is positively correlated with UA power measured at rest (Doppelmayr, Klimesch, Stadler, Pöllhuber, & Heine, 2002; Klimesch, Vogt, & Doppelmayr, 1999). These observations led to the notion that UA NFT might enhance memory performance. In this regard, Escolano et al. (2011) found a significant improvement in semantic WM in subjects who received five sessions of UA NFT, as compared to a control group. In addition, a recent study by Nan et al. (2012) showed a significant WM improvement following UA NFT. In this study, 20 sessions of alpha NFT were administered and the effects on WM were assessed using the Forward and Backward Digit Span task. Study participants were asked to learn and retrieve items according to the order in which the items were presented; this requires them to continuously bind both to their context, as well as with respect to one another. This study also found a correlation between memory enhancement and the UA power increase which resulted from NFT.

In contrast to the positive effects on memory described above, Lecomte and Juhel (2011) reported that a null effect of UA increases training on memory performance in elderly participants. They tested the effect of four NFT sessions on a delayed recall test comprised six images, as well as an immediate recall test consisting of eight words. Similarly, Angelakis et al. (2007), who rewarded peak alpha activity in their NFT protocol (around 35 sessions) involving elderly participants, reported mixed results in the memory tests. Specifically, while the experimental group showed no change in their memory for words, their visual

memory and story recall were actually impaired compared to pre-NFT.

Given the above results, we hypothesise that an SMR protocol may be suitable for improving performance in memory tasks that are less effortful and less strategic in nature, such as semantic, short-term/immediate and item-specific memories (Vernon et al., 2003). Conversely, a UA protocol might improve performance in tasks that involve strategic (top-down) retrieval and memory-binding processes, as well as executive processes (Nan et al., 2012).

This hypothesis, which distinguishes general and less-effortful processing from strategic and controlled processes, is consistent with the dual process theory of memory (Jacoby, 1991; Yonelinas, 2002), according to which memory retrieval requires two distinct processes: familiarity and recollection. The former is associated with a vague experience of remembering and is relatively automatic in nature, while the latter is strategic, involves executive functioning and is associated with a clear sense of remembering, including the context in which the memory was formed. This distinction, which is supported by numerous cognitive and neuroimaging studies, postulates that recollection, which is the recovery of specific contextual information, involves the prefrontal cortex, the hippocampus and the parahippocampus, which encode and bind relations between components of events (Eichenbaum, Yonelinas, & Ranganath, 2007; Yonelinas, 2002; Yonelinas, Otten, Shaw, & Rugg, 2005), whereas familiarity has been linked to the perirhinal cortex, which encodes representations of individual items (Yonelinas, 2002). Thus, the crucial distinction between recollection and familiarity depends on the presence or absence of contextual associations (Greve, Evans, Graham, & Wilding, 2011), which are presumably formed using effortful/laborious processes (e.g., Hockley & Consoli, 1999; Meiser, Sattler, & Weißer, 2008; Xu & Malmberg, 2007), such as those measured by executive functions tests.

Following the literature presented above, in the present study we examined the effects of two NFT protocols targeting UA and SMR on the performance of memory tasks defined by the processes used for their execution. Specifically, we tested the hypothesis that UA NFT will improve performance on tasks requiring recollection and associative processes, while SMR, which reflects general attentional processing, will contribute to more perceptual and familiarity-based processes.

To test this hypothesis, we used an item and an associative recognition task as well as an immediate vs. delayed item recognition task. It is important to note here that item recognition may rely on both familiarity and recollection, whereas associative recognition dominantly relies on recollection processes (see Old & Naveh-Benjamin, 2008, for review). The second memory task that we administered was an immediate vs. delayed item recognition memory test, which targets item recognition in STM vs. LTM. According to our analysis, these tasks do not heavily rely on recollection processes (although such processes may be involved despite not being required). Thus, our main prediction is that associative tasks will benefit mainly from UA NFT, and that item recognition tasks will benefit mainly from SMR NFT.

METHOD

Participants

Thirty healthy students (20 females) from a community college voluntarily participated in this study. Each received 50$ for their participation and was able to withdraw from the study at any time. Mean age was 23.63 (SD = 2.79) years and average education was 12.73 (SD = .52) years. Potential subjects who self-reported Axis I psychiatric disorders, history of significant head trauma or other organic brain syndrome, or use of psychotropic medications were excluded. All participants received a detailed explanation regarding the study and its course. The study was performed with written informed consent according to a protocol approved by the Soroka University Medical Center institutional review board for studies involving human subjects.

Procedure

Each participant was randomly assigned to one of the following groups: SMR, UA or sham. Prior to NFT, participants' digital quantification of the EEG (QEEG) signal was assessed (see below), and they were given questionnaires including the Spielberger State-Trait Anxiety Inventory (STAI; Spielberger, 1983), the Beck Depression Inventory (BDI; Beck, 1987), a demographic questionnaire

and the memory tests (see below). The administration of NFT began from one to three days following the initial assessment, and lasted for five weeks, consisting of two weekly sessions of 30 min each. A week after the end of the NFT sessions, participants were given the post-tests (including similar, though different, memory tasks) and their QEEG signal was assessed once more.

Digital quantification of the EEG

For the QEEG assessment, the Deymed Truescan 32 acquisition device was used (www.deymed.com). Recordings were done with 19 channels and a rate of 128 samples per second was chosen. Three different sizes (large, medium or small) of 10/20 EEG caps (www.electro-cap.com) were used and electrodes were referenced to FCZ locations (according to the 10/20 system) with ground electrode on PCZ location. Impedances were kept around or under 5 kΩ. The procedure was comprised of two conditions of 3 min each: one with eyes closed and one with open eyes, for a total of approximately 6 min for each recording. The QEEG recording was administered twice in this study, once prior to training period and again during the week following the end of the training period, both recordings took place in a quiet air-condition room.

Analyses of the QEEG files were done using the NeuroGuide Software (www.appliedneuroscience.com), according to the following procedure: first, an automatic artifacting of drowsiness and eye blinks was done. This was then followed by an eye examination of the full file, deleting all sections that contained artefacts. Analyses were done both with a low pass filter (40 Hz) and with a high pass filter (1 Hz). Analysis was done after re-referencing the signal to the link ear montage.

Neurofeedback training

NFT was done with the Brainmaster 2EBII module in combination with the Brainmaster 3 software (www.brainmaster.com). All electrode (gold electrodes) impedances were kept under 5 kΩ. This is a two-channel system. In order to ensure that participants are blind to the treatment, both channels were connected to each participant. The first channel was connected to C4 and referenced to the left earlobe and the second channel was connected to Pz and also referenced to the left earlobe. The ground channel was connected to the right earlobe. The electrodes were connected to the scalp using Ten20 paste (http://www.weaverandcompany.com) and a hair band.

For each participant in the SMR and UA groups, the protocol consisted of feedback based on the real EEG signal (with a 13–15 Hz threshold recorded at C4 for the SMR group and a threshold of 10–12 Hz recorded at Pz location for the UA group). The protocol for participants in the sham (control) group included a simulated protocol of SMR that is available in Brainmaster 3SE software. In other words, participants in the sham group were reinforced not according to their real EEG signals, but rather, based on a simulation that provided a similar feedback experience. The calculation of the power in the different frequencies was done using a Butterworth filter, quadrature type, as was described by Collura (1990).

For the training sessions, participants watched an episode from the comedy television show *Friends* for 30 min, while the electrical activity of their brain was recorded. At the first training session, participants were told that possible changes in screen brightness and sound volume are good signs and that no specific effort on their part is required since the learning process is mostly unconscious. The training sessions were held separately for each participant in an isolated room. The participant sat on a comfortable chair in front of a 17-inch monitor and speaker sets used for video/audio feedback, that is to say that the reward for the training were both the level of the sound as well as the brightness of the video picture. The scalp locations were prepped with Nuprep gel. EEG was recorded at 256 samples per second with a 50-Hz Notch filter. If power within the specific frequencies was above the threshold, participants were rewarded with an increase of screen brightness and sound volume. Feedback thresholds were automatically and dynamically adjusted every 180 s to keep power above the threshold of 80% of time. This configuration enabled both the participants and the neurofeedback (NF) technician to be blind to the exact protocol used for each participant. Both the technician and the participants were aware that this kind of threshold was used so even if an electrode was taken off the scalp, the rewards would continue because the system would adjust itself automatically. Therefore using this option was the only way to avoid participants "testing" the system in order to reveal if they are getting a true or sham protocol.

A theoretical limitation of using this dynamic approach is that the detection threshold might vary

in response to vicissitudes in the overall brain activity, rather than in response to a particular EEG pattern. We therefore elected to perform our analysis on full cap EEG tracings, rather than on EEG in real time during the sessions.

An additional significant methodological limitation of our approach, which incorporated artefact rejection analysis with a threshold of 240 μV, is that artefacts caused by eye blinking and scalp muscle activity could not be fully excluded. Adding delta band and low beta inhibition filtering might have partially eliminated these confounders. However, such modifications would have resulted in an unwieldy protocol and complicated interpretation of our findings because of possible interactions with the bands under study. We therefore deliberately chose to use a more simplified protocol, despite its recognised but perhaps more predictable limitations.

Memory tasks

Item and associative recognition. This procedure consisted of a learning phase followed by two memory tests (an item recognition task and an associative recognition task). Four lists were created, two for the pre-NFT assessment and two for the post-NFT assessment. Pre–post learning lists and test order were counterbalanced across participants. The stimuli order in the learning phase was pseudo randomly determined. Learning phase: participants studied a list of 19 emotionally neutral word pairs. Stimuli were compiled from high-frequency common Hebrew nouns of unrelated objects like lemon–car (based on norms by Rubinsten, Anaki, Henik, Drori, & Faran, 2005). Words within each pair were unrelated semantically (e.g., excluding pairs like "grass–green"), phonologically or orthographically (i.e., the words in the pair did not comprise the exact same letters in a different order, which, in Hebrew, often creates a different word). For each list, the participants viewed 19 word pairs on a 17-inch computer monitor with a stimulus approximate size of 2 cm × 6 cm. The stimuli were presented one at a time, at a rate of 4 sec per pair (3 sec and 1 sec pause, see Figure 1).

Participants were instructed to try to learn both the individual words and the pairs for the upcoming item and associative recognition tests. The learning phase was followed by a 30-sec interpolated activity (counting backwards in steps of seven, starting from a randomly determined number) to eliminate recent effects on memory (Glanzer & Cunitz, 1966).

Item recognition test. In this test, participants viewed 12 words on the computer screen, one at a time. Of these, six were targets (original stimuli that had appeared during the study phase, derived randomly from six different studied pairs)

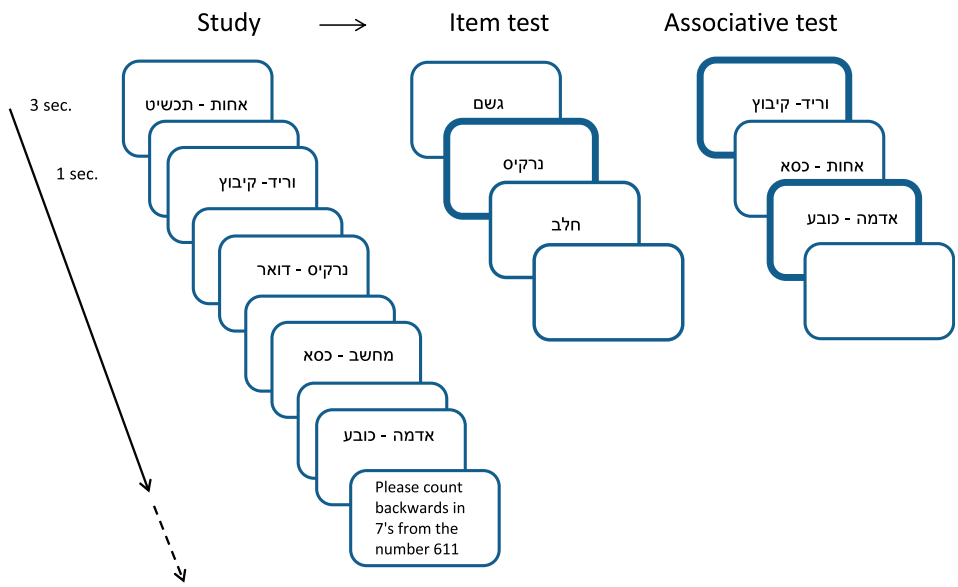

Figure 1. Experimental paradigm. Participants were presented with a study list of unrelated (visually or semantically) pairs of words, one at a time. In the item recognition task, participants were instructed to respond to each stimulus on the keyboard with a designated "yes" key for targets and a "no" key for distractors. In the associative recognition task, participants viewed stimuli pairs and were instructed to respond on the "yes" key for intact pairs (targets) and on the "no" key for the recombined pairs (distractors).

and six were distractors (had not appeared in the study phase), mixed randomly. The participants were informed that the list included targets and distractors and they were instructed to respond to each word on the computer keyboard with a designated "yes" key for targets (studied words) and a "no" response key for distractors.

Associative recognition test. In this test, participants viewed 12 word pairs on the monitor, one at a time. Six of these were intact pairs from the study phase. The other six pairs were rearranged pairs; that is, all the items had appeared in the study phase but the items were now recombined into novel pairs and served as distractors. The participants were informed that the list included intact and recombined pairs of stimuli and were instructed to press the "yes" key for intact pairs (targets) and press the "no" key for the recombined pairs (distractors).

Scoring. To assess differences between the item and associative recognition tests, we computed a measure for the percentage of hits minus the percentage of false alarms (a false alarm occurs where a non-target stimulus is identified as a target; Pollack & Norman, 1964) for each participant and test. This measure of memory accuracy removes the influence of a general tendency to respond "yes" or "no". Moreover, since the scores are presented in proportion, they equate the item and association scales in terms of scale and also in terms of what the score zero means (chance level) and 1.00 means (perfect performance). A preliminary analysis of variance (ANOVA) yielded no main effect or interaction effect for the order of test administration with any of the independent variables; thus, we collapsed the results across order in all subsequent analyses.

Immediate and delayed verbal recognition memory. In this verbal memory test, we used the Hebrew version of immediate and delayed recognition taking from the Mindstreams-Computerized Cognitive Tests (NeuroTrax Corp., NY; Dwolatzky et al., 2003). This task was designed to evaluate STM and LTM by presenting 10 word pairs in the study phase followed by a forced-choice recognition test in which target presented together with four possible alternatives (distractors) for the other member of the pair. Responses were made using the keyboard number pad to indicate which member of the pair was previously presented. Up to four consecutive study/test repetitions follow immediately, and an additional recognition test was administered following two other Mindstreams tests for a delay period of approximately 10 min.

Statistical analysis

Statistical analysis was performed using STATISTICA 9.0 software. A series of one-way ANOVAs and post hoc comparisons were conducted to assess the comparability of the groups in the questionnaires' scores. A series of repeated measures ANOVAs were used to test memory tasks' performances pre–post NFT in the three groups. Planned comparisons were performed on the interactions in order to assess specific differences. Another series of repeated measures ANOVAs were conducted for the QEEG data in order to compare pre–post training differences between groups.

RESULTS

Questionnaires

Table 1 presents the summary statistics for the questionnaire results. In order to assess the comparability of the groups, we conducted a series of one-way ANOVAs with Group as the between-participant independent variable and questionnaire scores as dependent variables. None of the analyses indicated a significant result. A similar conclusion was reached based on pairwise comparisons between the groups. Such a pairwise comparison increases the statistical power and would have been inappropriate had we tried to find a difference between the groups. However, in the present case, this analytic approach is relatively conservative since it increases the likelihood to find group differences before the NFT, a result that would undermine any subsequent claims. Moreover, the (completely non-significant) trend of means shows that the control group was less depressed and anxious than the experimental groups, a trend that once again works against our hypothesis. Thus, we can conclude with reasonable confidence that any benefits of NFT in the post-test are not to be attributed to unfortunate group inequality in the pre-test.

TABLE 1
Descriptive statistics, scores and standard deviations, at pre-test and post hoc comparisons (*t*-tests) for BDI, STAI-S and STAI-T questionnaires

	BDI		*STAI-S*		*STAI-T*	
	M	*SD*	*M*	*SD*	*M*	*SD*
Sham-control	4.27	4.45	30.00	7.38	31.09	8.87
SMR	6.33	6.10	34.88	10.58	36.44	11.17
Alpha	5.30	5.85	33.10	9.33	32.70	9.32
Group main effect	ns		ns		ns	
Control vs. SMR	ns		ns		ns	
Control vs. alpha	ns		ns		ns	
SMR vs. alpha	ns		ns		ns	

Item and associative memory performance

Descriptive statistics are presented in Table 2. To specifically address the hypothesis regarding pre- to post-performance improvement after NFT, we created a training gain index which was calculated as performance (hits minus false alarms) in the post-test minus performance in the pre-test. These gain scores were computed separately for item and associative memory. Higher gain scores reflect a greater training-related improvement. A two-way repeated measures ANOVA with a 3 (Group) × 2 (Memory Test: item vs. association) was conducted on the training gain indices. Results indicated one significant interaction effect between Group and Test, $F(2, 26) = 3.54$, $p < .05$, $\eta_p^2 = .21$. Follow-up planned comparisons showed that on the item test, the SMR group presents a significant improvement compared to the sham-control group, $F(1, 26) = 4.47$, $p < .05$, $\eta_p^2 = .12$, but the alpha group did not differ from the sham-control group, $F < 1.00$. By contrast, on the associative test, this pattern was reversed. The alpha group presents a significant improvement compared to the sham-control group, $F(1, 26) = 5.03$, $p < .05$, $\eta_p^2 = .16$; while the SMR group did not reach a significant advantage over the placebo-control group, $F(1, 26) = 3.08$, ns, $\eta_p^2 = .10$ (see Figure 2). It should be noted that the mean gain scores in the sham-control group did not differ significantly from zero (*t*s < 1.00). Additionally, the gain scores were significantly larger than zero in the item test following SMR NFT and in the association test, following UA NFT ($p < .05$).

TABLE 2
Memory performance (hit minus false alarms)

		Item memory						*Associative memory*					
		Hit		*FA*		*Hit – FA*		*Hit*		*FA*		*Hit – FA*	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
SMR	Pre-training	.60	.16	.27	.22	.32	.24	.65	.16	.53	.23	.12	.30
	Post-training	.78	.14	.15	.14	.63	.20	.63	.15	.35	.16	.28	.26
	Pre–post difference	.18	.25	−.12	.14	.30	.32	−.01	.25	−.18	.32	.16	.52
Alpha	Pre-training	.71	.17	.08	.12	.62	.26	.66	.27	.22	.19	.44	.30
	Post-training	.71	.08	.07	.10	.64	.11	.89	.05	.20	.20	.69	.24
	Pre–post difference	.00	.16	−.01	.12	.01	.17	.23	.24	−.02	.28	.25	.26
Sham	Pre-training	.66	.12	.17	.23	.51	.23	.70	.15	.31	.21	.38	.14
	Post-training	.70	.19	.10	.09	.59	.24	.64	.22	.40	.22	.24	.24
	Pre–post difference	.04	.20	−.06	.17	.07	.22	−.06	.22	.08	.19	−.14	.29

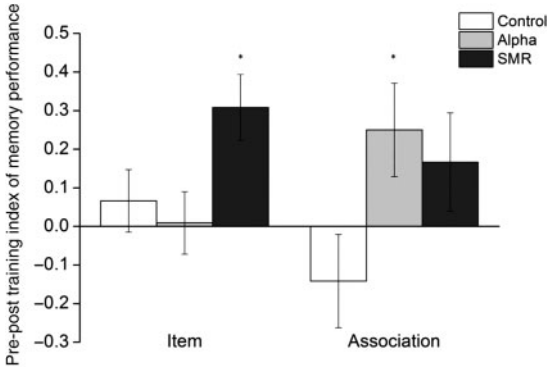

Figure 2. Pre–post training index (in percentage) for item and associative recognition in the three groups.

Immediate and delayed memory performance

Descriptive statistics are presented in Table 3. The immediate-memory accuracy score was calculated as the total correct answers across the initial four repetitions (MindStream, NeuroTrax Corp., NY; Dwolatzky et al., 2003). To specifically address the hypothesis regarding pre–post performance gain in immediate and delayed recognition after NFT, a three-way repeated measures ANOVA was conducted with the following independent variables: 3 (Group) × 2 (Memory Test; immediate vs. delayed) × 2 (Time; pre-post NFT). Results indicated two significant effects. Time, $F(1, 26) = 14.48$, $p < .05$, $\eta_p^2 = .35$, reflecting the overall improvement in memory performance from Time 1 to Time 2 (M = 93.11 and 97.57, respectively); and the interaction between Time and Group $F(2, 26) = 6.05$, $p < .05$, $\eta_p^2 = .31$. All other effects had $F < 1.00$ means that no effect was found between the immediate and the delayed memory test. Follow-up planned comparisons on the interaction between Time and Group indicated that only the SMR group showed a significant improvement from pre- to post-test, $F(1, 26) = 19.95$, $p < .05$, $\eta_p^2 = .42$; while neither the UA NFT nor the sham-control group reached a significant improvement ($F < 1.00$ and $F(1, 26) = 3.49$, ns, respectively). The authors are aware that ceiling effect might hide some possible differences and suggest taking caution in the interpretation of these results.

Digital quantification of the EEG

In a series of ANOVAs analyses for repeated measures with point of examination as the pre–post factor and protocol as between-participant factors, we found no differences between different protocols in the effect of NF treatment has on high-alpha at the Pz [$F(2, 26) = .27$, ns] and at C4 [$F(2, 26) = .311$, ns] as well as on high-beta power in the Pz [$F(2, 26) = 1.05$, ns] and at C4 electrodes [$F(2, 26) = .76$, ns]. To be more certain in accepting the null hypothesis concerning no Group effect, we conducted a series of ANOVAs on the results recorded at F3, F4, C3, C4 and Cz, such that each ANOVA was conducted on the power difference in a 1 Hz range, covering the entire range of 1–50 Hz. None of these ANOVAs approached significance, indicating no Group effect whatsoever.

TABLE 3
Memory performance and percentage accuracy in immediate and delayed recognition (means and standard deviations) in the pre–post-test for the three NF groups

		Immediate recognition		*Delayed recognition*	
		M	*SD*	*M*	*SD*
SMR	Pre-training	88.77	17.18	88.88	13.64
	Post-training	98.22	2.04	97.77	6.66
	Pre-post difference	9.44	15.79	8.88	9.27
Alpha	Pre-training	95.44	8.58	96.66	5.00
	Post-training	96.77	8.21	96.66	5.00
	Pre-post difference	1.33	5.31	.00	7.07
Sham	Pre-training	95.90	4.45	93.00	6.74
	Post-training	97.00	4.83	99.00	3.16
	Pre-post difference	1.10	4.28	6.00	6.99

SUMMARY AND DISCUSSION

As discussed above, previous research yielded mixed results regarding the effects of NFT on memory performance, using a variety of training protocols and different populations; few deal with whether NFT can improve memory performance among young healthy adults (Angelakis et al., 2007). In this work, our aim was to test the effectiveness of two NFT protocols for memory performance in young adults. We designed an original memory test battery, relying on the well-established dissociation between recollection and familiarity (Jacoby, 1991; Yonelinas, 2002). We also used a commercial test of item recognition that employs the familiar distinction between immediate and delayed testing.

According to the literature, alpha synchronisation and UA enhancement are considered as indicative of an active top-down process (Basar, 2006; Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Hummel, Andres, Altenmuller, Dichgans, & Gerloff, 2002; Nan et al., 2012), while SMR is likely to improve processes that are less strategic in nature (Vernon et al., 2003). Following this analysis, we hypothesised that while a UA protocol would mostly affect associative tasks that fundamentally require recollection processing for their execution, an SMR protocol will enhance performance in immediate/delayed item recognition tasks that can rely on familiarity processes.

To test this hypothesised dissociation, we conducted a randomized, sham-controlled, double-blind study. The inclusion of a sham-control group is necessary in order to demonstrate that the positive results of NF are not merely a placebo effect.

As predicted by our general hypothesis, our results indicate that only SMR training, and not UA training, improved item memory. In contrast, while both training protocols improved associative memory, this trend reached significance only in the UA group. Furthermore, only the SMR group showed improvement in item recognition memory when tested with the MindStream battery. Thus, our results indicate that SMR enhances familiarity-based memory, whereas the UA protocol enhances recollection, as demonstrated in the associative memory test.

These results are consistent with the findings of Egner and Gruzelier (2001), which showed an association between SMR and increased perceptual sensitivity. These data also corroborate Hoedlmoser et al. (2008), who—using a cued recall task—found improvement in declarative memory following 10 SMR NFT sessions. In their study, Hoedlmoser et al. encouraged participants to use visualisation in order to encode stimuli during the study phase and scored their performance not only for the right response but also for the related responses (e.g., "flow" or "stream" instead of "river"), which, to our understanding, encourages familiarity-based responses. The data of this study are consistent with our findings that SMR contributes to familiarity-based processes that rely more on perceptual, rather than conceptual processing.

The results obtained for the UA group are also compatible with the understanding that enhanced UA is indicative of top-down inhibitory processes (Cooper et al., 2003). In order to successfully perform the associative task, the participant must be able to reject and inhibit very familiar stimuli, namely, the distractors (which are the recombined pairs, that include words that had appeared during the learning phase, albeit in different pairs/combinations), and to carefully choose the target.

Furthermore, the current findings are consistent with the neuroanatomical and neurocognitive knowledge regarding the dissociation between recollection and familiarity. It has been shown that recollection and familiarity involve different brain areas: while recollection has been associated with the prefrontal cortex, the hippocampus and the parahippocampus, which encode and bind relations between event components, familiarity has been linked to the perirhinal cortex (Yonelinas, 2002; Yonelinas et al., 2005). Our results converge with this dissociation, suggesting that frontal brain circuits may be the origin of the behavioural effects of UA NFT, as they enhance top-down, strategic and associative binding in memory. In contrast, SMR NFT reflects a control-free mechanism that underlies familiarity. This dissociation between UA and SMR NFT joins other factors known to differentially affect recollection and familiarity such as ageing, divided attention, effects of benzodiazepines and modality changing between study and test (Yonelinas, 2002 for review).

The null effect on QEEG measures was unexpected, as it suggests that NFT did not actually change EEG power. Then again, it is perhaps not entirely surprising, given that the QEEG was only measured pre- and post-training, and hence, does not truly reflect the actual EEG patterns during training. Perhaps, our young normal participants

somehow learned to modify their EEG when needed. Thus, this ability was not observed when passively recorded a number of days after training. Moreover, it should also be noted that previous research addressing the relation between NFT protocol and brain activity either found no spectral effects at all, or these effects did not correspond to the frequencies addressed by the training (Egner, Zech, & Gruzelier, 2004; Lansbergen, van Dongen-Boomsma, Buitelaar, & Slaats-Willemse, 2011; Nan et al., 2012; Vernon, 2005; Vernon et al., 2003). One should also keep in mind the difference between NF training conducted on controls compared with training done with patients. Theoretically it could be that training in controls cannot produce long-lasting affects compared to training in patients suffering from various disorders. The long-term changes of the EEG signal after NF training in controls were not been subject to research according to our knowledge.

Possible implications and limitations of the study

In addition to our results with younger adults, we suggest further research that will target recollection processes in other populations. One population known to have memory recollection deficits (Balota, Dolan, & Duchek, 2000; Craik, 1994), and hence likely to benefit from NFT, are older adults. Specifically, older adults exhibit deficits in associative memory (Naveh-Benjamin, Guez, & Marom, 2003; Old & Naveh-Benjamin, 2008). A possible application of UA NFT for such a population could be the use of the protocol to improve their ability to create more cohesive episodes in memory. However, since the present study was conducted on young adults, further research must determine if the elderly, too, could benefit from UA NFT.

Several limitations of the present study should be acknowledged. First, the MindStream-computerized cognitive battery (Dwolatzky et al., 2003) was designed to assess mild cognitive impairment, dementia (Doniger et al., 2005; Dwolatzky et al., 2003) and other conditions, such as Gaucher disease and schizophrenia (Elstein et al., 2005; Ritsner, Blumenkrantz, Dubinsky, & Dwolatzky, 2006). This test is *not* designed to detect performance differences in healthy adults, which is probably the reason for the apparent ceiling effects in this test. Second, our participants were all tested within one week following the final NFT session and so the long-term effects of NFT were not assessed. It is also important to evaluate NFT effects for a number of weeks following the end of the training. Third, because we adopted a double-blind paradigm with an automatic threshold, we could not adjust the NFT protocol individually, as is generally the procedure in a clinical setting. Finally, the statistical power of our data was quite low, suggesting that the number of participants in our study may not have been sufficient to provide a robust conclusion; nonetheless, our findings are consistent with most of the studies in this field.

CONCLUSION

In conclusion, this paper presents a double-blind sham-controlled design study testing the effects of NFT on episodic memory. We have shown that young healthy participants, trained twice a week for 30 min of NFT, can present particular memory improvement after 10 sessions. Specifically, we showed that (1) administration of SMR NFT can improve performance on tasks that rely on familiarity processes and (2) UA NFT improves performance on tasks that require recollection processes for their execution.

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