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Neuromodulating Attention and Mind-Wandering Processes with a Single Session Real Time EEG

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Abstract

Our minds are continuously alternating between external attention (EA) and mind wandering (MW). An appropriate balance between EA and MW is important for promoting efficient perceptual processing, executive functioning, decision-making, auto-biographical memory, and creativity. There is evidence that EA processes are associated with increased activity in high-frequency EEG bands (e.g., SMR), contrasting with the dominance of low-frequency bands during MW (e.g., Theta). The aim of the present study was to test the effects of two distinct single session real-time EEG (rtEEG) protocols (SMR up-training/Theta down-training—SMR⇑Theta⇓; Theta up-training/SMR down-training—Theta⇑SMR⇓) on EA and MW processes. Thirty healthy volunteers were randomly assigned to one of two rtEEG training protocols (SMR⇑Theta⇓; Theta⇑SMR⇓). Before and after the rtEEG training, participants completed the attention network task (ANT) along with several MW measures. Both training protocols were effective in increasing SMR (SMR⇑Theta⇓) and theta (Theta⇑SMR⇓) amplitudes but not in decreasing the amplitude of down-trained bands. There were no significant effects of the rtEEG training in either EA or MW measures. However, there was a significant positive correlation between post-training SMR increases and the use of deliberate MW (rather than spontaneous) strategies. Additionally, for the Theta⇑SMR⇓ protocol, increase in post-training Theta amplitude was significantly associated with a decreased efficiency in the orientation network.

Keywords Neurofeedback · Real-time EEG · Mind wandering · Attention

Introduction

Our minds are in constant flow, alternating between external attention (Petersen and Posner 2012) and instances of mind wandering (Smallwood and Schooler 2015). The benefits of maintaining an efficient external attention (EA) have been widely demonstrated in perceptual (Eldar et al. 2016) and motor control tasks (Lohse et al. 2014). However, there is also consistent evidence that mind wandering (MW) may be important in several psychological processes, namelly episodic auto-biographical memory (Baird et al. 2011), creativity (Baird et al. 2012) and mental time travel (Corballis 2017). Even though EA and MW are often seen as orthogonal, their relationship is complex and dependent on the attention task (Gonçalves et al. 2017), nature and content of mind wandering thoughts (Gonçalves et al. 2017), or mind wandering intentionality (Seli et al. 2016).

In terms of brain functioning, EA tasks have been associated with task positive networks (e.g., dorsal attention network) while MW seems to be supported by task negative networks (e.g., default mode network) (Fox et al. 2005). Different EA processes and MW categories were related with distinctive neural mechanisms (Fan et al. 2005; Stawarczyk et al. 2011). Brain oscillatory rhythms show an increased activity of low-frequency EEG bands (e.g., theta and delta) and a decrease of high-frequency (e.g., alpha and beta) when individuals start mind

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wandering drifting away from a current task (Braboszcz and Delorme 2011). Interesting to note that this dominance of low-frequency bands (e.g., theta; theta/alpha ratio) is a characteristic of some psychological processes closely associated with MW, such as creativity (Gruzelier 2014) or autobiographical memory (Tóth et al. 2012).

Consistent with the research reported above, studies using real-time EEG (rtEEG) showed that up-training SMR (13–15 Hz) and down-training theta (4–8 Hz) significantly impacted different attention tasks, such as performance in the attention network task (Hill et al. 2009), or dichotic listening task (Gadea et al. 2016). Even though we are not aware of any rtEEG studies aimed at increasing MW per se, there is evidence for the effects of up-training theta (or theta/alpha ratio) and down-training rhythms within the beta spectrum (13–35 Hz) in promoting processes associated with MW, such as creativity (Gruzelier et al. 2014) and memory consolidation (Reiner et al. 2014).

Altogether, more than mutual exclusive processes, EA and MW seem to be part of a consciousness continuum. Efficient psychological functioning may depend on maintaining an appropriate balance between different EA and MW strategies (Allen et al. 2013; Smallwood and Andrews-Hanna 2013). Given that EA and MW are associated with contrasting high-frequency (e.g. SMR for EA) and low-frequency (e.g., theta for MW) EEG bands, it makes sense to hypothesize that SMR and Theta up-training may increase EA and MW processes, respectively. Therefore, the objective of the present study was twofold: (1) testing the viability of two rtEEG single-session training protocols (SMR⇑Theta⇓; Theta⇑SMR⇓) in up-regulating or down-regulating the SMR and Theta amplitudes; and (2) researching at the effects of these two rtEEG training protocols in EA and MW.

Method

Participants

Thirty healthy college students (21 women, 9 men) with normal or corrected to normal vision participated in the study. Their age ranged from 18 to 32 years ($M = 20.7$, $SD = 3.7$). Exclusion criteria included: metal implants on the head; history of neurological or psychiatric illness, electroconvulsive treatment, drug or alcohol abuse in the past year; and current medication that would impact EEG. All participants provided signed informed consent and the study was approved by the local review board and carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki).

Materials

Attention Network Task (ANT)

Before and after the rtEEG, all participants completed the ANT (Fan et al. 2002). ANT requires participants to maintain their focus on a central fixation cross and responding, as quickly and accurately as possible, to the target (i.e., identifying if a central arrow, appearing either below or above a fixation cross, is pointing right or left). The targets were preceded by three types of cues: a spatially informative cue announcing that the target will appear either above or below the fixation cross; a center cue or double cue condition (above and below the fixation cross) alerting that the target will be presented soon; and, finally, a no cue condition. The target arrow may be presented alone or surrounded by three types of flankers: arrows pointing in the same direction of the target (congruent condition), pointing in opposing direction of the target (incongruent condition), or traces without arrows (neutral condition). ANT was designed to assess three attentional networks: alert, orienting and conflict (c.f., Petersen and Posner 2012). ANT effects (alerting, orienting, and conflict) were calculated using a computational algorithm that potentiates the independence of each attention system while taking into account the RT baseline (Wang et al. 2014). The following average scores were calculated: center cue incongruent (cci), center cue congruent (ccc), no-cue incongruent (nci), no-cue congruent (ncc), spatial cue incongruent (sci) and spatial cue congruent (scc). Network effects were then calculated using the following formulas:

$$Alerting = \frac{meanRT(ccc, cci) - meanRT(ncc, nci)}{meanRT(ncc, nci)}$$

$$Orienting = \frac{meanRT(scc, sci) - meanRT(ccc, cci)}{meanRT(ccc, cci)}$$

$$Conflict = \frac{meanRT(nci, cci, sci) - meanRT(ncc, ccc, scc)}{meanRT(ncc, ccc, scc)}$$

Negatives values in the alert and the orienting networks are evidence for effective alerting (i.e., RT to “no cue” is larger than RT to “central cue”) and orienting effects (RT to “central cue” is larger than RT to “spatial cue”) while positive values for the executive network confirm a conflict effect (RT for the “incongruent cue” is larger than RT to the “congruent cue”).

In the current version, ANT was programed and presented via E-Prime 2.0 SP2 (Psychology Software Tools, Sharpsburg, PA) in a desktop computer equipped with a 15 LED monitor according to following parameters: (1) a fixation cross appeared in the center of the screen all the time; (2) depending on the cue condition, a cue (none, center, double or spatial) appeared for 200 ms; (3) after a variable duration (300–1500 ms fully jittered), the target (the center arrow) and flankers (congruent, incongruent or neutral) were presented until the participant responded with a time limit of 2000 ms (responses were provided by pressing either the right or the left side of the computer mouse); (4) after the response, the target and flankers were replaced by the central fixation cross (the time lapse between the onset of the target and the start time of the next trial was jittered between 300 and 1500 ms). Each session consisted of five blocks (one full-feedback practice block and four experimental blocks without feedback). Each block consisted of 24 trials (4 cue conditions × 2 target locations × 3 flanker conditions). Trials were presented in a random order.

Type of MW: Thought Identification Task (TIT)

After each ANT block, participants went through the TIT requiring to identify which type of thoughts (derived from Stawarczyk et al. 2011) were predominant during the preceding block by choosing one among the following four options: (1) On task (OT)—participant was focused on the task (i.e., cues and direction of the arrows); (2) Task related interference (TRI)—participant was focused on side aspects of the task (e.g., task duration, concerns about overall performance, rumination over a mistake, etc.); (3) External distractions (ED)—participant was focused on stimuli from the current environment but not related to the experimental task, such as overall exteroceptive conditions (e.g., light, temperature) or interoceptive conditions (e.g., physical sensation, hunger, thirsty, etc.); (4) Task-unrelated and stimulus-independent experience (SITUT)—the participant wandered through thoughts dissociated either from the task or current exteroceptive or interoceptive conditions (e.g., past experience; future plans, etc.).

Content of MW: Resting State Questionnaire (ReSQ)

After completing the ANT and TIT tasks, participants were asked to fill an adapted version of the ReSQ (Delamillieure et al. 2010), reporting the percentage of time spent in each of the following mental activity contents: focusing on the task (FT); visual mental imagery (IMAG); inner language (LANG); somatosensory awareness (SOMA); inner musical experience (MUSI); and mental processing of numbers (NUMB).

MW Intentionality: Mind Wandering Deliberate and Spontaneous Scales (MW-D/S)

The Mind Wandering Deliberate and Spontaneous Scales (MW-D/S) (Carriere et al. 2013) was used to evaluate if MW thoughts during the ANT were product of either deliberate or spontaneous MW. Following the ReSQ, participants were instructed to read the following statements (slightly changed from the original in order to adapt to the current experimental task) and scored them in a 7-point Likert scale (i.e., 1-not at all true; 7-very true): mind wandering spontaneous statements (MW-S)—"During this task, I found my thoughts wandering spontaneously", "During this task, when I mind-wandered my thoughts tended to be pulled from topic to topic", "During this task, it felt like I didn't have control over when my mind wandered", "I mind-wandered in spite of being supposed to be focused on the task"; mind wandering deliberate statements (MW-D)—"During the task I allowed my thoughts to wander on purpose", "During the task, I enjoyed mind-wandering", "During the task, I found mind-wandering to be a good way to cope with boredom", "During the task I allowed myself to get absorbed in pleasant fantasy".

Visual Analogue Scale (VAS)

Finally, VAS was used to measure the subjective impact of the training in terms of tiredness, sleepiness, sadness, concentration and agitation before and after the rtEEG training. Participants' ratings were provided on a 10 cm scale, with 0 indicating absence of and 10 the worst possible feeling/sensation.

Experimental Procedure

The experiment followed a one independent variable random group design in which participants, after providing signed informed consent, were randomly assigned to one of the two rtEEG training protocols: (1) SMR⇑Theta⇓, and (2) Theta⇑SMR⇓. Before and after the rtEEG training, participants completed the attention (ANT), the MW tasks (TIT, ReSQ, MW-D/S) and rated the subjective impact of the training (VAS).

For both groups, the rtEEG training was conducted with open-eyes with the participants comfortably sat, facing 15 LED monitor (participant's feedback screen). Silver/silver chloride electrodes were secured using a Nexus Mini-Cap with an EXG cable (attached to EEG disks) and fixed to the skin with the help of 10–20 paste and ear clips attached to the ear lobes. A referential montage was used, with the active electrode placed on C_z (10–20 system), the reference electrode on the left ear lobe (A_1) and the ground electrode on the right ear lobe (A_2). The EEG signal was registered with a 512 Hz sampling rate using a Nexus-32 amplifier with a 24-bit A-D converter (MindMedia, Netherlands). BioTRace + software (MindMedia, Netherlands) was used for EEG signal processing and feedback programing. The EEG signal was digitally filtered in order to extract the training bands (SMR:

13–15 Hz; Theta: 4–8 Hz) and artifact control bands (EMG—electromyogram artifact wave; EOG electroculogram artifact wave). Impedance was kept below 5 Ω. All the data was corrected for artifacts using the Automatic Artifact Rejection option available in BioTRace+, rejecting all amplitudes above 100 µv.

Training was conducted in a single session consisting of 3′ baseline without feedback, followed by 5 blocks (5′ each) of rtEEG training interleaved with 1′ resting between blocks. Participants were instructed to try to increase SMR and decrease Theta amplitudes (SMR⤊Theta⤋ protocol) or increase Theta and decrease SMR (Theta⤊SMR⤋ protocol). The amplitudes of Theta and SMR waves were presented in a feedback screen by means of bar graphs connected to the SMR and Theta amplitude data channels, respectively. Training thresholds were established calculating the mean amplitude of the training bands in each block (starting with baseline) and establishing the threshold 10% above the mean of the previous block for the up-trained band (SMR for the SMR⤊Theta⤋ protocol; Theta for the Theta⤊SMR⤋ protocol) and 10% below the mean of the previous block for the down-trained band (Theta for the SMR⤊Theta⤋ protocol; SMR for the Theta⤊SMR⤋ protocol). Two types of reinforcement were provided. First, bar graph colors changed from red to green every time participants were able to maintain the signal above or below the threshold (dependent if it was up-training or down-training) for 500 ms. Second, a video animation with a car (SMR⤊Theta⤋ protocol) or a delta-glider (Theta⤊SMR⤋ protocol) would be inhibited (i.e., come to a stop) every time participants were not reaching the threshold targets. Additionally, the animation was inhibited, in both protocols, for EMG and EOG amplitudes for more than 500 ms above the established thresholds (respectively 10 and 80 µv).

Results

The Effects of rtEEG in SMR and Theta Amplitudes

First, to test the efficacy of the two rtEEG protocols in modulating the targeted bands (SMR and Theta), we analyzed changes for SMR and Theta mean amplitudes across training blocks. The mixed model ANOVAs showed a main effect of training for the SMR [$F(1,28) = 14.328$, $p < .01$] and Theta [$F(1,27) = 15.723$, $p < .001$]. As shown in Fig. 1, and confirming the effectiveness of up-training strategies, there was a steady increment across training blocks in the mean SMR amplitude for the SMR⤊Theta⤋ protocol (1A) along with an increase in Theta mean amplitude for the Theta⤊SMR⤋ protocol (1B). Intragroup analyses with paired samples *t* tests, between baseline and block 5, showed a significant increase in the SMR amplitude for the SMR⤊Theta⤋ protocol [$t(14) = 4.99$, $p < .0001$] and Theta amplitude for the Theta⤊SMR⤋ protocol [$t(13) = 3.19$, $p < .01$]. However, down-training was not effective in decreasing the mean amplitudes of SMR or Theta. Comparing baseline with block 5, there were no significant differences in the mean SMR amplitude for the Theta⤊SMR⤋ protocol [$t(14) = 0.81$, $p = .43$] and, against our expectations, there was even a significant increase in mean Theta Amplitude in the SMR⤊Theta⤋ protocol [$t(14) = 2.30$, $p < .05$].

The Effects of rtEEG in Attention

In order to assess the effects of the rtEEG training in the ANT networks (i.e. alert, orienting and conflict), independent samples *t* tests were used to test group differences between pre- and post-training for each training protocol. There were no significant changes in the ANT between pre- and post-training neither for the SMR⤊Theta⤋ [Alert: $t(14) = -4.11$, $p = .687$; Orienting: $t(14) = 1.00$, $p = .331$; Conflict: $t(14) = 2.00$, $p = .064$] nor for Theta⤊SMR⤋ protocols

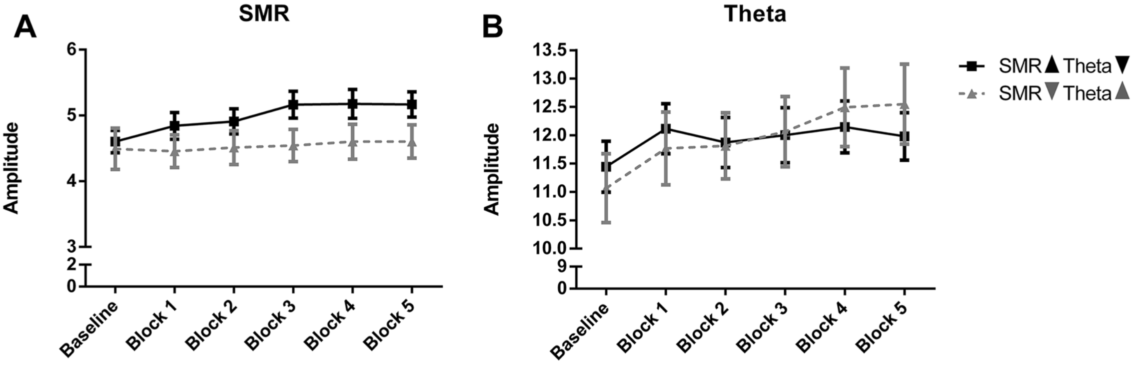

Fig. 1 Change in SMR (**a**) and Theta (**b**) mean amplitudes across training blocks

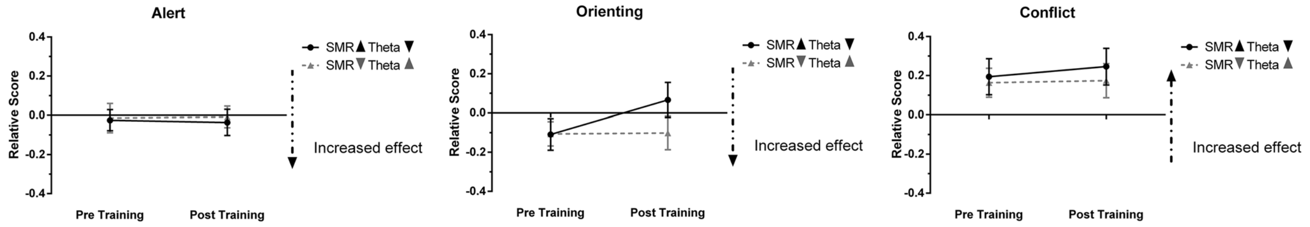

Fig. 2 The effects of the two rtEEG training protocols in the three attention networks (alert, orienting, conflict)

Table 1 Pearson correlation between variation in SMR and theta and ANT

		Alerting		Orienting		Conflict	
		r	*p* value	*r*	*p* value	*r*	*p* value
SMR⇑Theta⇓	SMR	0.14	0.960	0.029	0.917	0.505	0.055
	Theta	−0.127	0.651	0.176	0.530	−0.201	0.472
Theta⇑SMR⇓	SMR	−0.038	0.892	0.055	0.846	−0.046	0.871
	Theta	−0.424	0.130	0.709	0.005**	−0.163	0.578

$^{**}p < .010$

[Alert: $t(14) = 0.221$, $p = .828$; Orienting: $t(14) = 0.205$, $p = .840$; Conflict: $t(14) = 0.355$, $p = .728$] (see Fig. 2).

A Pearson correlation between variation in SMR and Theta (mean amplitude at post-training—mean amplitude at pre-training) and ANT effects at post-training for each training protocol, showed that increases in Theta amplitude in the Theta⇑SMR⇓ were significantly and positive correlated with the orientation scores ($r = .709$, $p = .005$), meaning that increases in mean Theta amplitude are associated with difficulties in taking advantage from orientation cues in the attention task (see Table 1).

The Effects of rtEEG in MW

Table 2 presents the Median (IQR) for each MW variables (TIT, ReSQ, MW-D/S) in the different rtEEG protocols before and after training. Mann–Whitney U tests were used to explore differences in groups before rtEEG training. Given that no differences were found on any variable between groups, we presented here the results of the Mann–Whitney U tests comparing the results after each training protocol for type of MW (i.e., TIT), content of MW (i.e., ReSQ) and MW intentionality (i.e., S/D-MW). Finally, a Spearman correlation analysis was performed to assess the relationship between changes in the SMR and Theta amplitude and MW measures (see Table 3).

Table 2 Effects of rtEEG in mind wandering

	SMR⇑Theta⇓		Theta⇑SMR⇓	
	Pre	Post	Pre	Post
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)
OT	75 (50)	25 (50)	50 (50)	50 (50)
TRI	25 (25)	25 (50)	25(25)	25 (50)
ED	0 (25)	0 (50)	0 (25)	0 (25)
SITUT	0 (0)	0 (0)	0 (0)	0 (0)
FT	80 (20)	70 (30)	80 (5)	70 (30)
IMAG	0 (10)	0 (15)	0 (5)	0 (10)
LANG	10 (5)	15 (15)	10 (22.5)	10 (13)
SOMA	0 (5)	0 (0)	5 (8)	5 (10)
MUSI	0 (0)	0 (5)	0 (0)	0 (2)
NUMB	0 (0)	0 (0)	0 (0)	0 (0)
MW-D	4 (11)	9 (9)	12 (7)	10 (11)
MW-S	10 (10)	13 (10)	18 (13)	17 (9)

OT on task, *TRI* task related interference, *ED* external distractions, *SITUT* stimulus independent and task unrelated thoughts, *FT* focused on the task, *IMAG* visual mental imagery, *LANG* inner language, *SOMA* somatosensory awareness, *MUSI* musical experience, *NUMB* mental processing of numbers, *MW-D* deliberate mind wandering, *MW-S* spontaneous mind wandering

Type of MW

As shown in Table 2, participants reported to be on task (OT) about half of the blocks (Pre-training—$Mdn = 75.00$; $IQR = 50$; Post-training—$Mdn = 37.50$; $IQR = 75$). No significant differences were found between rtEEG training protocols in terms of OT ($U = 78.50$, $p = .147$), TRI ($U = 98.50$, $p = .545$), ED ($U = 106.50$, $p = .781$), and SITUT ($U = 106.50$, $p = .701$).

Table 3 Spearman correlation between SMR and theta variation and mind wandering

	SMR⤊Theta⤋				Theta⤊SMR⤋			
	SMR		Theta		SMR		Theta	
	rho	*p* value	*rho*	*p* value	*rho*	*p* value	*rho*	*p* value
OT	−0.155	0.582	0.134	0.634	−0.035	0.902	−0.063	0.831
TRI	−0.365	0.181	−0.070	0.804	0.136	0.630	0.005	0.987
ED	0.387	0.154	−0.280	−0.313	0.042	0.881	0.073	0.805
SITUT	0.317	0.249	0.174	0.535	−0.024	0.932	0.036	0.903
FT	−0.248	0.371	0.028	0.922	0.099	0.726	0.171	0.560
IMAG	−0.227	0.416	0.134	0.633	0.363	0.183	−0.378	0.183
LANG	0.054	0.847	−0.047	0.868	−0.193	0.490	−0.070	0.811
SOMA	0.296	0.284	−0.163	0.562	−0.263	0.344	−0.324	0.258
MUSI	0.169	0.547	0.021	0.942	0.151	0.591	−0.306	0.288
NUMB	0.318	0.248	0.272	0.326	−0.062	0.827	0.310	0.281
MW-D	0.481	0.069	0.121	0.667	−0.020	0.944	−0.035	0.904
MW-S	0.083	0.770	0.323	0.240	−0.299	0.279	−0.108	0.713

OT on task, *TRI* task related interference, *ED* external distractions, *SITUT* stimulus independent and task unrelated thoughts, *FT* focused on the task, *IMAG* visual mental imagery, *LANG* inner language, *SOMA* somatosensory awareness, *MUSI* musical experience, *NUMB* mental processing of numbers, *MW-D* deliberate mind wandering, *MW-S* spontaneous mind wandering

Content of MW

After completing the ANT, the participants confirmed, as assessed by the ReSQ, having been predominantly focusing on the task (FT) when comparing to non-task related thoughts, both before (Z = 4.253, $p < .001$) and after (Z = 3.730, $p < .001$) rtEEG training. Again, no significant differences were found regarding rtEEG training protocols in terms of FT ($U = 108.00$, $p = .850$), IMAG ($U = 102.50$, $p = .645$), LANG ($U = 85.00$, $p = .247$), MUSI ($U = 112.00$, $p = .979$), and NUMB ($U = 106.00$, $p = .605$). However, participants undergoing the Theta⤊ SMR⤋ training reported an increased in SOMA thoughts at post-training when compared with participants in the SMR⤊Theta⤋ group ($U = 51.50$, $p = .005$).

MW Intentionality

Participants reported that, when out of the task, MW occurred mostly spontaneously both before (Z = 3.151, $p < .01$) and after (Z = 3.627, $p < .001$) rtEEG training. No significant differences were found between rtEEG training protocols neither for MW-S ($U = 84.50$, $p = .244$) nor for MW-D.

A Spearman correlation tested if increases in SMR and Theta amplitudes (post-training–pre-training) in each training protocol were associated with MW indexes at post-training. As can been seen in Table 3, the overall correlations were low with only a moderate positive correlation in the SMR⤊Theta⤋ group between increases in SMR amplitude and Deliberate MW ($r = 481$, $p = .069$).

Finally, the impact of each training protocol in the VAS is presented in Table 4. Both training protocols had an identical significant impact in in terms of tiredness: SMR⤊Theta⤋ [$t(14) = -3.781$, $p = .002$] and the Theta⤊SMR⤋ [$t(14) = 3.537$, $p = .003$]. As expected, only the Theta⤊SMR⤋ protocol was responsible for a significant increase in sleepiness [$t(14) = 2.697$, $p = .017$].

Discussion

The first aim of this study was to research the feasibility of increasing and decreasing the mean amplitudes of SMR and Theta in a single session using two rtEEG protocols (up-training SMR and down-training Theta; up-training Theta and down-training Theta). Both protocols were effective in increasing the mean amplitudes of the up-trained bands but not in decreasing the down-trained rhythms. Previous studies

Table 4 Spearman correlation between SMR and theta variation and subjective training impact (visual analogue scale)

	SMR⤊Theta⤋		Theta⤊SMR⤋	
	Pre	Post	Pre	Post
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Tiredness	4.73 (2.25)	6.33 (1.88)	3.87 (2.13)	5.13 (2.26)
Sleepiness	4.60 (2.47)	5.33 (1.76)	3.80 (2.27)	5.13 (1.96)
Sadness	1.60 (2.29)	1.60 (2.17)	1.33 (1.72)	1.93 (1.67)
Concentration	6.20 (1.78)	5.53 (1.06)	6.33 (2.13)	5.53 (1.46)
Agitation	3.07 (1.94)	4.00 (2.36)	3.67 (2.55)	3.933 (2.71)

have already shown that SMR (Gadea et al. 2016) and Theta (Reiner et al. 2014) can be up-trained in the course of a single session. However, similarly to Gadea et al. (2016) our SMR⇑Theta⇓ protocol did not have the expected effect in terms of Theta reduction and, in our case, was responsible for an increase in Theta amplitude. Other training protocols, that were effective in inhibiting Theta, took place across several training sessions (Vernon et al. 2003). In the present study the Theta⇑SMR⇓ protocol was effective in stabilizing but not reducing SMR amplitude. Contrasting with SMR up-training, there is few data concerning the effectiveness of SMR inhibiting strategies (Kleinnijenhuis et al. 2008). Our Theta⇑SMR⇓ protocol was conducted with eyes open which may have required a level of vigilance only compatible with moderate SMR amplitudes.

Contrary to our initial hypothesis, there was no significant effect of the SMR⇑Theta⇓ on any of the attentional networks. This contrasts with findings from Hill et al. (2009) who found the effectiveness of SMR⇑Theta⇓ training over several scalp regions, on a different version of the attention network task (i.e., lateralized attention network test). The authors found an increased orienting effect for SMR⇑Theta⇓ training over the same region targeted in our study (i.e., C_z). However, it is important to point out two major differences between these studies. First, while our study was conducted with a healthy sample, Hill et al. (2009) carried out their training in a learning-disorders sample. It is possible that their participants started-up with lower SMR amplitudes, turning the effects of their training more sensitive. A second important difference is that while we conduct our study in a single session, participants in Hill et al. (2009) completed 20 sessions over a 8 week period. However, as reported before, other authors could find an impact of SMR⇑Theta⇓ on attention with only one session protocol. However, contrary to us, Gadea et al. (2016) were able to increase SMR while stabilizing Theta. Additionally, they used a dichotic listening task intended to measure attentional conflict. It is possible that their measure is more sensitive in targeting attentional conflict. In fact, several authors have been questioning the reliability of network scores in the ANT (Macleod et al. 2010). Even though we used a different computation system intended to potentiate network independence (Wang et al. 2014) there are still cofounding effects due to ANT's event-related design (i.e., different networks tested in the same block) (Wang et al. 2015). Finally, Gadea et al. (2016) target C_3 and not C_z. While looking at lateralization effects (i.e., dichotic listening tasks) C_3 or C_4 may be more appropriate locations than C_z and as such potentiating the effects of rtEEG training. As previously shown, the same SMR⇑Theta⇓ protocol, at different scalp locations, can produce different attentional effects Hill et al. (2009).

While the increases in the SMR amplitude in SMR⇑Theta⇓ protocol were not associated with any effects in the ANT, the increase in Theta in the Theta⇑SMR⇓ protocol significantly impaired participants ability to take advantage of orientation cues in the attention task. Orientation network is known to be a cholinergic system (Fossella et al. 2002). Acetylcholine is an excitatory transmitter associated with active awake with important modulatory effects in several cognitive functions. It is possible that Theta increase in the Theta⇑SMR⇓ group contributed to downregulate cholinergic transmission (Platt and Riedel 2011). This would explain why only in this protocol participants reported significant increase in sleepiness. Theta training seems to be less demanding but more prone to induce sleepiness (Schütze and Junghanns 2015).

However, despite the association between increases in Theta with decreased orientation effects in Theta⇑SMR⇓ group, no effects were found for any rtEEG protocol in the different MW measures. Participants remained focused about half of the time during the attention task, and reported mostly OT thoughts. Neither the type (reported online) nor content (reported offline) of MW thoughts was significantly impacted by rtEEG training, with the exception of an increased in somatosensorial awareness in Theta⇑SMR⇓ group. Contrary to our expectations, Theta⇑SMR⇓ training did not increase MW phenomena. This may be explained by the fact that the Theta⇑SMR⇓ protocol was not effective in decreasing SMR amplitudes. As stated before, probably due to the fact that the training was conducted eyes open, the stabilization of SMR amplitudes were probably instrumental to facilitate the level of vigilance required to complete the training.

Finally, the two rtEEG protocols did not differentially affected MW intentionality. While out of focus, our participants seem to MW spontaneously rather than deliberately. MW exists in a continuum of deliberate constrains (Christoff et al. 2016). While in deliberate MW the individual intentionally escapes into mind wandering as a way to promote the benefits of mental time–space travel, in spontaneous MW the individual faces the intrusive nature of distractive thoughts, image, sensations or fantasies. Therefore, our participants seemed, while out of task focus, to be particularly vulnerable to intrusive unwanted thoughts. However, a moderate positive correlation was found in the SMR⇑Theta⇓ group between increases in SMR amplitude and increases in deliberate MW, suggesting that when individuals are able to increase SMR they tend to be more intentional in their MW, probability as a way for potentiating the benefits of either personal (e.g., rest) or task effects (e.g., memory consolidation).

The current sample did not allow the possibility of looking at differences between male and female participants. Future studies should balance male and female participants in order to assess the effects of gender differences in neurofeedback training.

Summing, the present study showed that two single session rtEEG protocols were effective in increasing the amplitude of the targeted bands (SMR in SMR⇑Theta⇓; Theta in Theta⇑SMR⇓) but fail to decrease (SMR in Theta⇑SMR⇓) or inhibit (Theta in SMR⇑Theta⇓). Additionally, no significant effects were found for the rtEEG training in either EA or MW measures. However, post-training SMR increase in the SMR⇑Theta⇓ group was positively correlated with the use of deliberate MW (rather than spontaneous) strategies; and a post-training Theta increase in Theta⇑SMR⇓ group was significantly associated with a decreased efficiency in taking advantage of orientation cues during the attention task. Future studies, should extended the number of training sessions and test the effect of training in more sensitive EA and MW measures.

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Compliance with Ethical Standards

Conflict of interest The authors report no conflict of interests.

Ethical Approval All participants provided signed informed consent and the study was approved by the local review board and carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki).

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