Respiratory Physiology & Neurobiology 249 (2018) 23–31

Contents lists available at ScienceDirect

Respiratory Physiology & Neurobiology

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

Neurophysiological study on the effect of various short durations of deep breathing: A randomized controlled trial

Kok Suen Cheng[a], Ray P.S. Han[b], Poh Foong Lee[a,*]

[a] Lee Kong Chien Faculty of Engineering & Science, University Tunku Abdul Rahman, Bandar Sungai Long, Selangor, Malaysia
[b] College of Engineering, Peking University, Beijing, 100871, China

ARTICLE INFO

Keywords:
Deep breathing duration
EEG
Randomized controlled trial
Mean power
Topography

ABSTRACT

The study aims to study the effects of short duration deep breathing on the EEG power with topography based on parallel group randomized controlled trial design which was lacking in prior reports. 50 participants were split into 4 groups: control (CONT), deep breathing (DB) for 5 (DB5), 7 (DB7), and 9 (DB9) minutes. EEG recordings were obtained during baseline, deep breathing session, after deep breathing, and a follow-up session after 7 days of consecutive practice. Frontal theta power of DB5 and DB9 was significantly larger than that of CONT after the deep breathing session ($p = 0.027$ and $p = 0.006$, respectively) and the profound finding showed that the theta topography obtained a central-focused distribution for DB7 and DB9. The result obtained was consistent with previous literature, albeit for certain deep breathing durations only, indicating a possible linkage between the deep breathing duration and the neurophysiology of the brain.

1. Introduction

Deep breathing involves intense engagement of the diaphragm muscle, allowing more air to enter the lungs to mix with the residual air in the lungs and reducing the wastage of air due to the dead space (Bindu et al., 2013). Previous studies on deep breathing have shown its effectiveness in improving the psychological and physiological effects on humans: reducing stresses (Brown and Gerbarg, 2005; Kimura et al., 2005; Paul et al., 2007) decreasing pain perception (Busch et al., 2012; Zautra et al., 2010), improving blood flow (Bindu et al., 2013; Kennedy et al., 2011; Mori et al., 2005; Pramanik et al., 2009), and increasing the heart rate variability (Krasnikov et al., 2013; Lin et al., 2014; Song and Lehrer, 2003; Tharion et al., 2012; Wang et al., 2010). Recently, there is a rising interest in the effects of deep breathing on the neurophysiological level of humans and its implication in the cognitive domain. As proposed by Heck et al. (2017), the act of breathing may play a fundamental role in modulating the ongoing brain function such as the retention of a newly learned motor skill (Yadav and Mutha, 2016), attention (Telles et al., 2008; Simpson and Nelson, 1974), emotion (Bloch et al., 1991; Homma and Masaoka, 2008), and mental health (Chung et al., 2010; Kan and Lee, 2015).

To gain a further insight into the effects of deep breathing at the neurophysiology level, EEG is often employed to study the brain oscillations which consist of the delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma band (> 30 Hz) (Teplan, 2002), and changes in these bands gives information on the state of mind of an individual. One of the early studies on deep breathing and EEG was done by Stancak et al. (1993), who investigated how different breathing frequencies affects the theta, alpha and beta mean power and their variabilities. They found that at the lower end of the breathing frequencies (0.14 Hz, 0.10 Hz, and 0.06 Hz) there was no difference in terms of the mean power for all three bands; however, at 0.10 Hz there was a decrease in the variability of the alpha power in the parietal and occipital locations. The presence of a more regular alpha power was interpreted as a lower activity of the brain and hence, this supports the notion that deep breathing can be used to reduce stress. A similar study by Bušek and Kemlink (2005) further established the relationship between the breathing frequency and the mean power in the theta, alpha and beta bands, whereby a decrease in the breathing frequency led to an increase in the mean power and vice versa. Fumoto et al. (2004) and Yu et al. (2011) utilized a modified study by fixing the breathing frequency at approximately 3–4 breaths per minute to mimic the breathing technique employed in the Zen meditation and investigated the effects on the log-transform relative power for the same three bands. Furthermore, they investigated the effects of the breathing duration by comparing the log-transform relative power at different intervals (e.g. 5, 10, 15, and 20 min) to an initial resting period. From their results, the breathing duration played an important role in the theta and alpha bands whereby the initial theta power was significantly larger than that at the 15th and 20th-min mark and the alpha power

* Corresponding author.
E-mail address: leepf@utar.edu.my (P.F. Lee).

https://doi.org/10.1016/j.resp.2017.12.008
Received 1 August 2017; Received in revised form 17 December 2017; Accepted 28 December 2017
Available online 30 December 2017
1569-9048/

showed a marked increment that was evident starting at the 5th-min mark and remained the same until the 20th-min mark.

Majority of the studies on deep breathing with EEG did not conduct a randomized controlled trial (RCT), for example, the studies by Fumoto et al. (2004) and Yu et al. (2011) or had utilized an RCT but with a cross-over design (e.g. Stancak et al., 1993; Bušek and Kemlink, 2005; Gaurav et al., 2016). RCT serves as the golden standard for evaluating the effectiveness of an intervention (Mills et al., 2007) and within an RCT, there are several experimental designs being employed, among which two of the most popular designs are the parallel group design and the cross-over design. It is relatively simple to implement the parallel group design but its statistical power is not as high as the other designs; whereas the required sample size for the cross-over design may be smaller as each participant serves as his/her own control. However, the carry-over of the previous experimental condition's effect onto the next condition is a significant problem (Stedman et al., 2011). Since each participant in the cross-over design goes through the control and intervention condition in a random manner, the possible carry-over effects of the intervention can confound the results obtained in the later control condition. In studies that investigated the immediate effects of a deep breathing session, the measurements at the post-intervention period of 5 min are significantly different from that of the baseline and this is an indication of a carry-over effect lasting even after 5 min (Prinsloo et al., 2013; Sherlin et al., 2010). Thus, the use of a cross-over design with a resting period (typically 3–5 min) between each breathing conditions seems to be inappropriate.

In this study, a parallel group design was employed to investigate the effects of three different deep breathing durations (5, 7, 9 min, and a control group with no deep breathing) on the mean relative power in the theta, alpha, and beta bands. This ensured that any possibility of carry-over effects would not be present. Further, the topographical distributions of each power bands were investigated as well. The aims of this study were two-fold. First, previous results in the current literature were recreated here using a different experimental design. Second, the differences across the control and deep breathing groups in terms of the mean power and topography were assessed during deep breathing, immediately after and a follow-up after 7 days of consecutive practice.

2. Materials and methods

2.1. Participants

56 Undergraduates as participants from the university were recruited via a distribution of flyers for the study. Three exclusion criteria were used to select the participants: (1) those who have been ill for the past two weeks prior to the experiment, (2) those on long-term medication or are on drug prescription, and (3) those who are unable to take deep breathing for 5 min or more. In accordance to self-reported questionnaires, all participants had a normal or corrected-to-normal vision and no respiratory diseases or psychiatric disorder. All of the participants do not smoke as confirmed through verbal confirmation, however, their drinking habit was not known. Five participants did not come for the follow-up session and hence, the total number of participants who completed the protocol was 51. Furthermore, one participant's data was not analyzed due to having too many artifacts. Thus, the total final participants were 50 (age: 22.04 ± 1.65, 22% females), with 92% Malaysian Chinese, 4% Malaysian Indian, 2% Aryan and 2% Sino-Kadazan. The flowchart of the participants is shown in Fig. 1.

2.2. Description of deep breathing session

The participants were guided to perform deep breathing through a video (Fig. 2). The breathing frequency was set to 0.1 Hz to achieve a resonance between respiration and heartbeat, and producing the largest amplitude in the rhythm sinus arrhythmia (RSA) (Vaschillo et al., 2006). The top-right corner of the video showed the number of completed breathing cycles while the bottom-left showed how much time has passed. At the center of the video, there was a yellow smiley face with appearing and disappearing petals for five in total with each lasting for one second. When the petals appeared, the participants were required to inhale and exhale when the petals disappeared. Both inhalation and exhalation were done continuously without break. The participants were also instructed to focus on the video and to feel the air going in and out of their body. The video used in this study was created by the authors themselves and the rationale behind using a visual guidance instead of an auditory guidance is that it is easier to follow a video guide than an auditory guide whenever the surrounding noise level is high. Hence, this video enables one to perform the deep breathing easily at anywhere at any time.

2.3. Experimental procedure

The research procedures have been approved by the university's Scientific and Ethical Review committee (Ref. No: U/SERC/04/2017). The participants understood the whole procedure and an informed consent was obtained prior to the experiment. The participants were randomized based on their chosen timeslot for the experiment into one of the four groups: Control group (CONT, n = 12), Deep breathing for 5 min (DB5, n = 12), Deep breathing for 7 min (DB7, n = 13), and Deep breathing for 9 min (DB9, n = 13).

The experiments took place in a laboratory room with ample ambient lighting. On arrival at the laboratory, the participants rested for 15 min to ensure their physiological state was stable. A baseline reading of 5 min (R1) was taken, followed by a Go/NoGo task. After performing the task, the participants in the DB groups underwent the deep breathing session (INT) following the video for either 5, 7 or 9 min. For the CONT group, they were instructed to rest for 9 min without showing them any video. After the deep breathing session, all the participants were requested to rest again for another 5 min (R2) and was followed by a second Go/NoGo task. During each time section (R1, INT, and R2), the participants remained in an opened-eye state while the EEG signals were being acquired. This concluded the first session.

During the one-week gap between the first session and the follow-up session, the DB participants were instructed to practice the deep breathing following the video guide every day once at any time convenient for them. Messages were sent to remind the participants on a daily basis to practice the deep breathing and a reply message was requested to confirm the practice. In total, the participants had performed the deep breathing 7 times (the first session was counted as once). On day 8 (with the first session as day 1), the participants returned to the laboratory for the follow-up session EEG recording. During the follow-up session, the participants first rested for 15 min while the recording equipment was being applied. After that, a baseline reading of 5 min (R3) was recorded followed by a third Go/NoGo task at opened-eyes conditions. No deep breathing was performed in this follow-up session.

2.4. EEG acquisition and analysis

The NCC Medical 32 Channels Type A Routine EEG System (Model no.: Nation 7128W-A32) was used to acquire the EEG signals. The 32 Ag/AgCl electrodes in the electrode cap was placed in accordance with the International 10–20 system (site: Fp1, Fp2, AF3, AF4, F7, F3, Fz, F4, F8, FT7, FC3, FC4, FT8, T3, C3, Cz, C4, T4, CP7, CP3, CP4, CP8, P3, Pz, P4, PO3, PO4, T5, O1, Oz, O2, T6) with the reference electrode at Cz and the ground electrode at Fpz. The electrode cap was then connected to the Type-A EEG amplifier with a sampling rate of 256 Hz and the signals were stored in a computer. The raw EEG signals were processed for bad channels and artifacts using FASTER (Nolan et al., 2010) which acts as a plug-in EEGLAB (Lopez-Calderon and Luck, 2014). The high-pass, low-pass, and notch filter frequencies were 1 Hz, 30 Hz, and

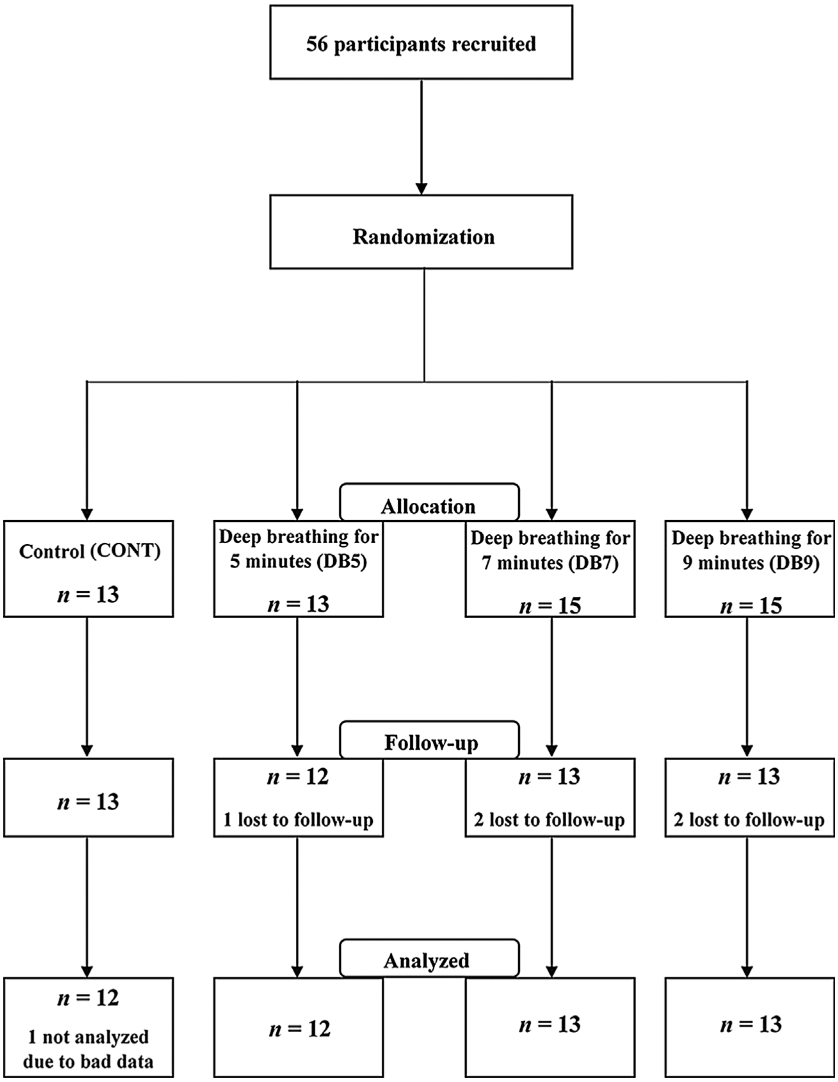

Fig. 1. Flowchart of the participants.

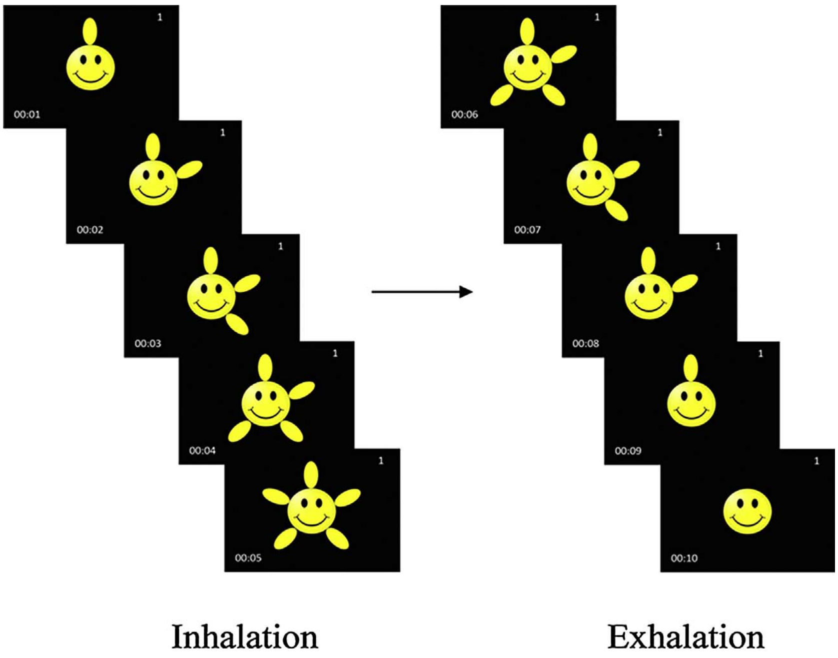

Fig. 2. Screenshots from the deep breathing video. The video has two sections, one with appearing petals for the inhalation and one for the exhalation with disappearing petals. The breathing rate was set to 6 breaths per minute.

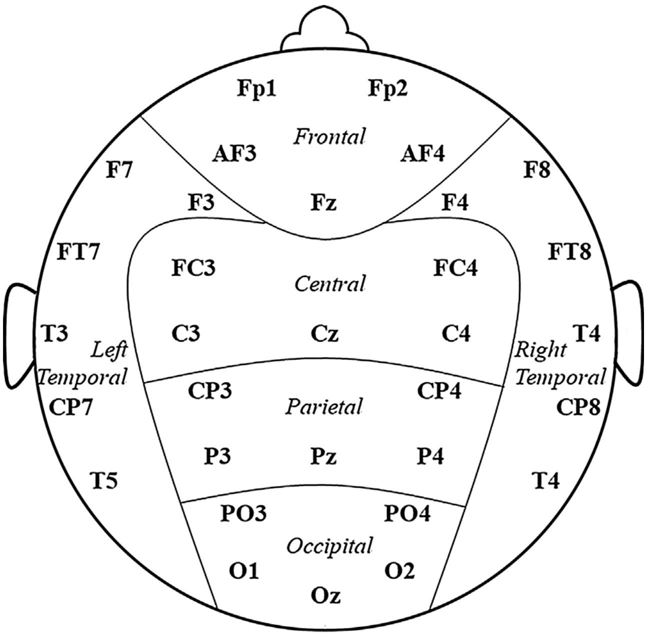

Fig. 3. The placement and groupings of the 32 electrodes. The electrodes are grouped into the frontal, central, parietal, occipital, left temporal, or right temporal location.

50 Hz, respectively. Bad channels were detected and interpolated whereas artifacts in the channels, epochs, decomposed independent components, and single-channel single-epochs were removed using a statistical thresholding of $z = \pm 3$. Subsequently, any epochs that contained signals that had an amplitude greater than 75 μV were removed as these signals are likely due to movement artifacts. The processed EEG signals were then segmented into epochs of 1 s and 200 epochs were randomly selected using a random number generator for analysis. The mean power of each electrode was extracted using the Welch periodogram method with 50% overlap and a resolution of 1 Hz., followed by the computation of the relative mean power (power in a particular band/total power in all three bands; no unit). In order to reduce the data and to study the EEG topography, the processed signals were grouped into 6 different locations following Ahani et al. (2014): frontal (Fp1, Fp2, AF3, AF4, Fz), central (C3, C4, FC3, FC4, Cz), parietal (P3, P4, CP3, CP4, Pz), occipital (O1, O2, PO3, PO4, Oz), left temporal (F3, F7, T3, T5, FT7, CP7), and right temporal (F4, F8, T4, T6, FT8, CP8). The placement and groupings of the 32 electrodes are shown in Fig. 3.

2.5. Statistical analysis

The mean powers were analyzed using a 4 × 3 × 6 repeated measure ANCOVA with the Group (CONT, DB5, DB7, and DB9) as the between-subject factor and the Time (INT, R2, R3) and Location (frontal, central, parietal, occipital, left temporal, and right temporal) as the within-subject factor. The baseline readings at R1 were used as the covariates. The sphericity correction using the Greenhouse-Geisser (when $\varepsilon < 0.75$) or Huynh-Feldt (when $\varepsilon > 0.75$) method was applied whenever necessary. For the posthoc test for any main effects or interactions involving the between-subject factor Group, a planned contrast with Bonferroni correction was performed such that the CONT group was compared to each DB groups (i.e., CONT with DB5, CONT with DB7, and CONT with DB9). No comparisons were done between the DB groups as this was not in line with the aim of this article. For the other factors, a pairwise comparison with Bonferroni correction was used to find the specific significant changes. A $p < 0.05$ was considered as statistically significant and a $p < 0.10$ was reported as a trend.

3. Results

The behavioral results and event related potentials obtained during the Go/NoGo task sessions have been reported elsewhere (Cheng et al., 2017) and thus, only the EEG power and topography data during R1, INT, R2, and R3 are presented here. The mean and topography of the relative power of the theta, alpha, and beta bands for each group during each time section are shown in Table 1 and Fig. 4.

3.1. Theta band

There was a significant Location main effect ($F(2.743, 126.163) = 27.367$, $p < 0.001$, $\eta_p^2 = 0.373$), a significant Time × Location interaction ($F(5.803, 266.917) = 2.316$, $p = 0.036$, $\eta_p^2 = 0.048$), and a significant Time × Location × Group interaction ($F(17.671, 235.613) = 1.782$, $p = 0.029$, $\eta_p^2 = 0.118$). In terms of group differences, posthoc analysis with Bonferroni correction revealed that during R2, the frontal theta power for DB5 was larger than that of CONT ($p = 0.027$), whereas for DB9 there was a larger power at both frontal and left temporal as compared to CONT ($p = 0.006$ and $p = 0.021$, respectively). During R3, a significant difference was evident at the central location with DB7 showing a larger theta power than CONT ($p = 0.006$). Besides that, the central theta power for DB7 was larger in R3 than R2 ($p = 0.006$). The statistical testing for the Location for each Group and Time is shown in Table 2 along with the relative difference and the p values. For CONT, the distribution of the relative theta power was generally stable at each time points, with the frontal theta power being smaller than all the other locations. Among the DB groups, there were differences at the frontal and central locations. As the breathing duration increases from 5 min to either 7 or 9 min, there was a greater significant difference between the frontal and central with the rest of the locations. The difference between 7 and 9 min was not obvious. However, this trend was shown only during INT and R2. For R3, the differences at the frontal location across the three groups disappeared but the differences at the central location remained. For DB7 and DB9, the central relative theta power was larger than the majority of the other locations, showing a central dominance locus.

3.2. Alpha band

There was a significant Location main effect ($F(4.856, 223.395) = 23.381$, $p < 0.001$, $\eta_p^2 = 0.337$) and a significant Time × Location interaction ($F(4.791, 220.376) = 5.011$, $p < 0.001$, $\eta_p^2 = 0.098$). Posthoc analysis with Bonferroni correction showed that when collapsed across the four groups, the relative alpha power at the central location was larger during R3 as compared to R2 and INT ($p = 0.004$ and $p = 0.025$, respectively). A similar result was obtained at the occipital location as well ($p = 0.001$ and $p = 0.009$, relative to R2 and INT, respectively). Besides that, there was a significant Location × Group interaction ($F(15, 200) = 1.919$, $p = 0.023$, $\eta_p^2 = 0.126$). It was reported that there was no intergroup difference for the 6 brain regions but the distribution of the relative alpha power for the DB groups in general was different (Fig. 4). For the CONT group, the distribution of the alpha power was larger at the parietal location compared to the frontal ($p < 0.001$), central ($p = 0.014$) and left and right temporal (both $p = 0.001$). In comparison to the CONT group, there was a shift from the central location towards the occipital region in the DB groups. For all three DB groups, the occipital relative alpha power was larger than that of the central location ($p \leq 0.001$). In addition, for DB5, the occipital and left temporal power were larger than the right temporal location ($p = 0.040$ and $p = 0.030$, respectively) while for DB7, the occipital power was larger than both left and right temporal locations (both $p = 0.001$). These topographical comparisons are summarized in Table 3. Lastly, there was also a Time × Group interaction trend ($F(6,80) = 2.099$, $p = 0.062$, $\eta_p^2 = 0.136$).

Table 1
The adjusted relative mean theta, alpha, and beta power for each groups at each time sections. The values are reported as the adjusted means and standard deviations in parenthesis.

		INT						R2						R3					
		Frontal	Central	Parietal	Occipital	LTem	RTem	Frontal	Central	Parietal	Occipital	LTem	RTem	Frontal	Central	Parietal	Occipital	LTem	RTem
Theta	CONT	0.452	0.587	0.538	0.545	0.550	0.561	0.414	0.576	0.538	0.527	0.513	0.557	0.410	0.585	0.530	0.508	0.531	0.544
		(0.027)	(0.021)	(0.024)	(0.023)	(0.021)	(0.020)	(0.022)	(0.022)	(0.024)	(0.024)	(0.021)	(0.018)	(0.028)	(0.021)	(0.028)	(0.031)	(0.027)	(0.027)
	DB5	0.525	0.631	0.561	0.584	0.566	0.594	0.501	0.634	0.556	0.598	0.541	0.572	0.472	0.606	0.501	0.522	0.553	0.586
		(0.027)	(0.021)	(0.024)	(0.023)	(0.021)	(0.020)	(0.022)	(0.022)	(0.024)	(0.024)	(0.021)	(0.018)	(0.028)	(0.021)	(0.028)	(0.031)	(0.027)	(0.027)
	DB7	0.502	0.648	0.571	0.57	0.557	0.571	0.477	0.628	0.582	0.557	0.542	0.566	0.494	0.682	0.539	0.556	0.593	0.617
		(0.026)	(0.021)	(0.023)	(0.022)	(0.020)	(0.020)	(0.021)	(0.021)	(0.023)	(0.023)	(0.020)	(0.018)	(0.027)	(0.020)	(0.027)	(0.030)	(0.026)	(0.025)
	DB9	0.481	0.626	0.559	0.553	0.570	0.597	0.518	0.640	0.586	0.572	0.596	0.619	0.494	0.622	0.567	0.540	0.542	0.565
		(0.026)	(0.021)	(0.023)	(0.022)	(0.020)	(0.020)	(0.021)	(0.021)	(0.023)	(0.023)	(0.020)	(0.018)	(0.027)	(0.020)	(0.027)	(0.030)	(0.026)	(0.025)
Alpha	CONT	0.246	0.252	0.286	0.263	0.238	0.242	0.243	0.254	0.272	0.258	0.249	0.243	0.214	0.245	0.274	0.272	0.238	0.233
		(0.011)	(0.011)	(0.012)	(0.011)	(0.009)	(0.009)	(0.015)	(0.013)	(0.013)	(0.013)	(0.011)	(0.012)	(0.016)	(0.012)	(0.020)	(0.019)	(0.013)	(0.015)
	DB5	0.234	0.230	0.269	0.260	0.241	0.217	0.239	0.228	0.282	0.249	0.241	0.229	0.258	0.261	0.333	0.308	0.267	0.252
		(0.011)	(0.011)	(0.012)	(0.011)	(0.009)	(0.009)	(0.015)	(0.013)	(0.013)	(0.013)	(0.011)	(0.012)	(0.016)	(0.012)	(0.020)	(0.019)	(0.013)	(0.015)
	DB7	0.257	0.234	0.270	0.266	0.249	0.238	0.253	0.243	0.273	0.276	0.241	0.250	0.240	0.210	0.297	0.286	0.238	0.236
		(0.010)	(0.011)	(0.012)	(0.011)	(0.009)	(0.009)	(0.015)	(0.012)	(0.012)	(0.013)	(0.011)	(0.011)	(0.016)	(0.012)	(0.019)	(0.018)	(0.013)	(0.015)
	DB9	0.252	0.233	0.273	0.258	0.251	0.241	0.235	0.229	0.259	0.254	0.237	0.240	0.236	0.247	0.287	0.293	0.258	0.266
		(0.010)	(0.011)	(0.012)	(0.011)	(0.009)	(0.009)	(0.015)	(0.012)	(0.012)	(0.013)	(0.011)	(0.011)	(0.016)	(0.012)	(0.019)	(0.018)	(0.013)	(0.015)
Beta	CONT	0.397	0.259	0.284	0.291	0.306	0.292	0.436	0.27	0.294	0.313	0.335	0.296	0.458	0.265	0.299	0.317	0.325	0.315
		(0.028)	(0.016)	(0.018)	(0.017)	(0.019)	(0.018)	(0.024)	(0.016)	(0.017)	(0.016)	(0.017)	(0.015)	(0.028)	(0.015)	(0.018)	(0.021)	(0.023)	(0.020)
	DB5	0.326	0.225	0.262	0.246	0.279	0.271	0.346	0.230	0.259	0.245	0.308	0.287	0.358	0.224	0.264	0.267	0.271	0.252
		(0.028)	(0.016)	(0.018)	(0.017)	(0.019)	(0.018)	(0.024)	(0.016)	(0.017)	(0.016)	(0.017)	(0.015)	(0.028)	(0.015)	(0.018)	(0.021)	(0.023)	(0.020)
	DB7	0.346	0.215	0.267	0.273	0.294	0.289	0.364	0.223	0.249	0.270	0.309	0.282	0.358	0.194	0.275	0.263	0.264	0.240
		(0.027)	(0.016)	(0.017)	(0.016)	(0.019)	(0.017)	(0.023)	(0.016)	(0.016)	(0.015)	(0.016)	(0.014)	(0.027)	(0.015)	(0.017)	(0.020)	(0.022)	(0.019)
	DB9	0.368	0.232	0.274	0.288	0.277	0.256	0.342	0.222	0.255	0.271	0.261	0.238	0.359	0.225	0.247	0.268	0.294	0.266
		(0.027)	(0.016)	(0.017)	(0.016)	(0.019)	(0.017)	(0.023)	(0.016)	(0.016)	(0.015)	(0.016)	(0.014)	(0.027)	(0.015)	(0.017)	(0.020)	(0.022)	(0.019)

INT – During deep breathing session; R2 – immediately after deep breathing; R3 – follow-up session; CONT – control group; DB5 – deep breathing for 5 min; DB7 – deep breathing for 7 min; DB9 – deep breathing for 9 min; LTem – left temporal; RTem – right temporal.

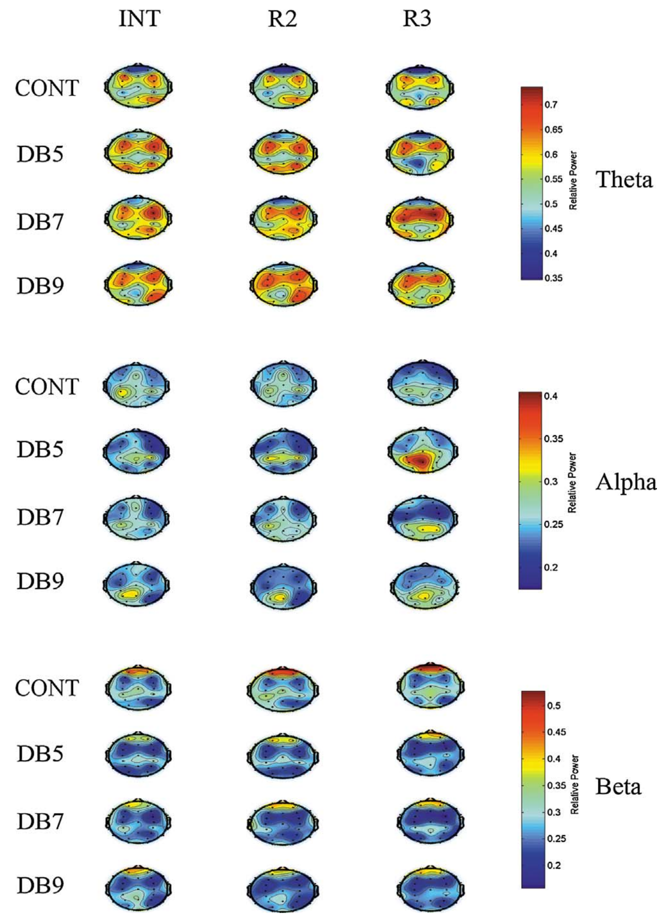

Fig. 4. The topography of the relative theta, alpha, and beta for each 4 groups (CONT, DB5, DB7, and DB9) during each time sections (INT, R2, and R3).

3.3. Beta band

There was a significant Location main effect ($F(2.281, 104.936) = 30.891$, $p < 0.001$, $\eta_p^2 = 0.402$). Post-hoc analysis with Bonferroni correction revealed that the relative beta power at the frontal location was significantly larger than the other five locations (all $p < 0.001$) while the power at central location was significantly smaller than the rest (all $p < 0.001$). Another significant difference occurred between the left temporal and parietal, occipital, and right temporal locations, with the beta power at left temporal being larger than the other three locations ($p = 0.008$, $p = 0.025$, and $p = 0.022$, respectively). Lastly, there was a significant Group main effect ($F(3, 40) = 3.412$, $p = 0.026$, $\eta_p^2 = 0.204$), showing that the relative beta power of CONT was larger than that of DB5 ($p = 0.033$), DB7 ($p = 0.045$), and DB9 ($p = 0.033$).

4. Discussion

One of the major findings in this study was the significantly larger frontal theta power in the DB5 and DB9 groups as compared to CONT ($p = 0.027$ and $p = 0.006$, respectively) whereas there was no difference in the frontal theta power between DB7 and CONT ($p > 0.05$), as shown in Fig. 4. The larger frontal theta power was not present after 7 days of consecutive practice (Table 2). Since deep breathing forms an elemental part in the majority of mindfulness meditations (Brown and Gerbarg, 2005) the increase in frontal theta could be interpreted as a greater focused attention (Aftanas and Golocheikine, 2001; Nakashima and Sato, 1993; Park et al., 2002). The result of increased theta power in the various literature on the EEG study of deep breathing and meditation practices is recreated here (Bušek and Kemlink, 2005; Chan et al., 2011; Henz and Schollhorn, 2017; Lagopoulos et al., 2009; Park and Park, 2012). Furthermore, the frontal theta power is inversely correlated to anxiety such that a greater frontal theta power indicates a lower anxiety (Inanaga, 1998). Collectively, the video-guided deep breathing is able to act as a meditation technique for achieving the state of ‘focused yet not anxious' that is common in most mindfulness meditations (Tomasino et al., 2014). However, one interesting point to note here is that only DB5 and DB9, but not DB7, had achieved a statistically larger frontal relative mean theta power as compared to the control group. The reason for this non-significant result for the DB7 group is unknown, but one possibility is the relatively small sample size in each group which may lead to a reduction in the statistical power.

Another novel finding in this study was the different topographical distribution of the relative theta power of the DB groups compared to the control group (Table 2 and Fig. 4). Focusing on the DB7 and DB9 groups, the distribution of the theta power across the scalp at all three time points (INT, R2, and R3) was mainly focused at the central location such that the theta power at the central location was larger than the majority of the other locations, hence showing a central-largest topographical distribution as compared to DB5 and CONT. In a study by Tang et al. (2009), the theta power from the Fz, FCz and Cz locations had a positive correlation with the high frequency heart rate variability power, which indexes the parasympathetic nervous system activity (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). Following this, the central dominance of the theta power obtained in this result can be interpreted as a shift from the sympathetic to the parasympathetic nervous system. The latter gives a state of feed-and-breed, whereas the former gives a state of fight-or-flight (McCorry, 2007). Hence, the greater activation of the parasympathetic nervous system caused the participants to be less anxious and led them to a state of relaxation (Pavlenko et al., 2009). The result observed here is consistent with the greater frontal theta and also, later in the beta band. From Table 2, the central-largest topographical distribution of the relative theta power was only observed in DB7 and DB9. This is suggestive of a time factor in play for the shifting of the autonomic nervous system such that a 5 min deep breathing duration was not sufficient in shifting towards the parasympathetic side. However, the lack of difference between DB7 and DB9 suggests that there the parasympathetic activation would not be different when the breathing duration further increases as the topographies of the theta power are relatively similar.

As for the beta power, there was a reduction in the overall relative beta power during deep breathing (INT), immediately after (R2) and also, after a 7-day follow-up in the DB groups (R3), as shown in Fig. 4. This reduction of beta power is interpreted as a decrease in anxiety (Pavlenko et al., 2009) and again, this is consistent with the shifting towards to the parasympathetic nervous system during deep breathing, which reduces anxiety (Miu et al., 2009). Even though there are relatively fewer studies on the beta power, current literature has produced mixed results. In an earlier study by Stancak et al. (1993) using a within-subject experimental design, the effect of paced breathing with the eyes staying closed at frequencies of 0.25, 0.20, 0.14, 0.10, and 0.06 Hz for 3 min on the EEG power was investigated. Their results showed that only for 0.25 and 0.20 Hz, a significant difference in the beta power was observed when compared to resting spontaneous breathing. At 0.10 Hz or 6 breaths per minute as employed in this current study, there was no pronounced difference in the beta band. A similar null result on the beta power was recreated by Gaurav et al. (2016) with the breathing rate at 6 breaths per minute and a breathing duration of 3 min as well. However, Prinsloo et al. (2013) had shown in their study on a 10 min single session of heart rate variability (HRV) biofeedback induced deep breathing had caused the relative beta power to decrease during the biofeedback intervention and also, during the post intervention period. It may seem that the HRV biofeedback is methodologically different but in reality, it shares many similarities with the video-guided deep breathing used in the current study; for

Table 2
Post-hoc test of the different brain regions for different time sections (INT, R2, and R3) from all 4 groups (CONT, DB5, DB7, and DB9) for the relative mean theta power. The table is interpreted starting from the column location and then the row location. For example, the first ' < ***' for the CONT group during INT can be interpreted as 'the mean relative theta power of the frontal location is smaller than that of the central location with $p < 0.001$'.

INT

Group		Frontal	Central	Parietal	Occipital	LTem	RTem
CONT	Frontal						
	Central	< ***					
	Parietal	< ***	> *				
	Occipital	< ***					
	LTem	< ***					
	RTem	< ***					
DB5	Frontal						
	Central	< ***					
	Parietal		> ***				
	Occipital						
	LTem		> ***				
	RTem	< *					
DB7	Frontal						
	Central	< ***					
	Parietal	< **	> ***				
	Occipital	< *	> ***				
	LTem	< *	> ***				
	RTem	< **	> ***				
DB9	Frontal						
	Central	< ***					
	Parietal	< **	> ***				
	Occipital	< **	> ***				
	LTem	< ***	> **				
	RTem	< ***					

R2

Group		Frontal	Central	Parietal	Occipital	LTem	RTem
CONT	Frontal						
	Central	< ***					
	Parietal	< ***					
	Occipital	< ***					
	LTem	< ***	> **				
	RTem	< ***					
DB5	Frontal						
	Central	< ***					
	Parietal		> ***				
	Occipital	< ***					
	LTem		> ***		> *		
	RTem	< **					
DB7	Frontal						
	Central	< ***					
	Parietal	< ***	> *				
	Occipital	< ***	> **				
	LTem	< **	> ***				
	RTem	< ***	> *				
DB9	Frontal						
	Central	< ***					
	Parietal	< **	> *				
	Occipital	< *	> **				
	LTem	< ***	> *				
	RTem	< ***					

R3

Group		Frontal	Central	Parietal	Occipital	LTem	RTem
CONT	Frontal						
	Central	< ***					
	Parietal	< ***					
	Occipital	< ***					
	LTem	< ***					
	RTem	< ***					
DB5	Frontal						
	Central	< ***					
	Parietal		> ***				
	Occipital						
	LTem	< *		< *			
	RTem	< ***					
DB7	Frontal						
	Central	< ***					
	Parietal		> ***				
	Occipital		> ***				
	LTem	< **	> *				
	RTem	< ***		< *			
DB9	Frontal						
	Central	< ***					
	Parietal						
	Occipital		> *				
	LTem		> *				
	RTem	< *					

LTem – Left temporal; RTem – right temporal; < – smaller than; > – larger than; * – $p < 0.05$; ** – $p < 0.01$; *** $p < 0.001$.

example, the HRV monitors the changes of heart rate variations associated with respiration across a range of frequencies. The biofeedback is done by controlling the breathing rate such that a resonant effect between the heart rate and the respiration is maximized, and this rate normally lies between 4.5–6.5 breaths per minute (Vaschillo et al., 2006). From these discussions, there are two possibilities to explain the varying results. The first explanation is that the beta power is modulated by the opening or closing of the eyes, much like the theta power (Aftanas and Golocheikine, 2001; Henz and Schollhorn, 2017). The second possibility lies in the duration of deep breathing. It seems only when the deep breathing duration is up to 5 min as was done in this study that there will be an effect on the beta power, and this trend stays the same up until 10 min of practice.

Analysis on the relative alpha power showed that there was no group difference between the control and the deep breathing groups during INT, R2, and R3. In terms of the topography, a shift of power spectrum from the central location towards the occipital location was evident in the DB groups but not in the CONT group (Table 3). The lack of difference between two groups for the relative alpha power magnitude contrasts markedly with literature reporting a heightened alpha power after deep breathing (Arambula et al., 2001; Fumoto et al., 2004; Park and Park, 2012; Sherlin et al., 2010; Yu et al., 2011) that is normally interpreted as an induction of a relaxation state. This discrepancy can be explained by the fact that the control participants are not shown any video during the deep breathing period, unlike the DB groups that followed the video guide. The visual stimulant perceived by the DB participants is greater than the control group and the presence of a greater visual stimulation could result in a reduction of the alpha power (Barry et al., 2009). Another possibility for the absence of the relaxed alpha wave could be due to the act of focusing on the video and also, on the breath. The alpha wave has an inverse relationship with the cortical activation of the brain (Alexander et al., 1996) and is modulated by the attention (Connell et al., 2008; Klimesch et al., 1998; Ray and Cole, 1985) such that the suppression of the alpha oscillation is evident with the engagement of attention. The act of focusing on the video and the breath caused a heightened brain activity needed for the extra active focusing instead of passively watching the video. Thus, the guidance for deep breathing via a video and the active focusing on the video may have leveled the relative alpha power and caused the power to be the same between the control and deep breathing groups.

From the above discussion, the known neurophysiological changes of deep breathing and its associated benefits have been recreated in this study. However, these replications were only observed for some particular deep breathing durations, and this is an indication that the mean power and topographical distribution of the different EEG frequency bands are modulated by the deep breathing duration. Combining the three bands' result, it seems that the notion of 'the longer the better' is supported such that for 9 min of deep breathing all of the benefits were obtained. The results presented here may serve as a guide in determining how long it is necessary for practicing deep breathing as an intervention to bring focus, increasing the parasympathetic activity, and to reduce anxiety.

One of the limitations of this study is the relatively small sample size in each group. Without a doubt, a greater sample size would lead to a more accurate result and a better understanding of the effects of the deep breathing durations on the neurophysiology of the brain. The maximum breathing duration in this study was limited to 9 min to prevent the possibility of hyperventilation in the participants. A greater duration can be investigated but precautionary steps need to be taken and some include having a prior training session, using different breathing techniques such as capnometry-assisted breathing (Meuret et al., 2008) or pursued lips breathing (Fregonezi et al., 2004), or separating the one long duration into several shorter durations. These precautions reduce the risk of hyperventilation. Alternatively, another

Table 3
Post-hoc test of the different brain regions collapsed across the time sections (INT, R2, and R3) from all 4 groups (CONT, DB5, DB7, and DB9) for the relative mean alpha power. The table is interpreted starting from the column location and then the row location. For example, the first ' < ***' for the CONT group during can be interpreted as 'the mean relative alpha power of the frontal location is smaller than that of the parietal location with $p < 0.001$'.

		Location					
		Frontal	Central	Parietal	Occipital	LTem	RTem
	Frontal						
	Central						
CONT	Parietal	< ***	< *				
	Occipital	< ***					
	LTem			> **			
	RTem			> **			
		Frontal	Central	Parietal	Occipital	LTem	RTem
	Frontal						
	Central						
DB5	Parietal	< ***	< ***				
	Occipital	< *	< **				
	LTem			> ***			
	RTem			> ***	> *	> *	
		Frontal	Central	Parietal	Occipital	LTem	RTem
	Frontal						
	Central						
DB7	Parietal	< *	< ***				
	Occipital	< *	< ***	> ***			
	LTem			> ***	> **		
	RTem				> **		
		Frontal	Central	Parietal	Occipital	LTem	RTem
	Frontal						
	Central						
DB9	Parietal	< **	< ***				
	Occipital	< *	< **				
	LTem			> *			
	RTem						

LTem – Left temporal; RTem – right temporal; < – smaller than; > – larger than; * – $p < 0.05$; ** – $p < 0.01$; *** $p < 0.001$.

improvement can be achieved by analyzing the EEG data separately for males and females. Due to the different hormonal activity in the genders, the final EEG data could be modulated by the hormonal processes (Becker et al., 1982; Carrier et al., 2001; Martinović et al., 1998). In our study, the female participants' sample size was not big enough to make a statistically viable comparison.

5. Conclusion

The effects of three different deep breathing durations on the EEG mean power and the topography of the theta, alpha, and beta band were investigated using a parallel group randomized controlled trial design. It was found that the frontal theta power of the DB5 and DB9 groups were significantly larger than that of CONT immediately after the deep breathing session but not for DB7. As for the theta power topography, deep breathing produced a central-largest topography consistent with the greater activation of the parasympathetic nervous system for DB7 and DB9. As for the beta band, the mean power was smaller in all three DB groups than the CONT group, showing that deep breathing led to a reduction of anxiety which was reported from prior research. There was no group difference in terms of the alpha power. This study showed that the duration of deep breathing may play a role in modulating the theta and beta power and the topography. The result here can serve as a guide in determining the efficiency of different deep breathing intervention durations, suggesting that at least a minimum of 9 min of deep breathing is needed to obtain the known neurophysiological changes and its associated benefits.

Conflict of interest

There are no conflicts of interest, or financial disclosures.

Acknowledgements

This work was funded by a research fund from University Tunku Abdul Rahman (UTAR) under the vote account number 6200/LB1, Malaysia. We thank all the participants who participated in this study and ICaterpillar Sdn Bhd for sponsoring the honorarium to the participants.

References

Aftanas, L.I., Golocheikine, S.A., 2001. Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: high-resolution EEG investigation of meditation. Neurosci. Lett. 310, 57–60. http://dx.doi.org/10.1016/S0304-3940(01)02094-8.

Ahani, A., Wahbeh, H., Nezamfar, H., Miller, M., Erdogmus, D., Oken, B., 2014. Quantitative change of EEG and respiration signals during mindfulness meditation. J. Neuroeng. Rehabil. 11, 87. http://dx.doi.org/10.1186/1743-0003-11-87.

Alexander, J.E., O'Boyle, M.W., Benbow, C.P., 1996. Developmentally advanced EEG alpha power in gifted male and female adolescents. Int. J. Psychophysiol. 23, 25–31. http://dx.doi.org/10.1016/0167-8760(96)00031-1.

Arambula, P., Peper, E., Kawakami, M., Gibney, K.H., 2001. The physiological correlates of Kundalini Yoga meditation: a study of a Yoga master. Appl. Psychophysiol. Biofeedback 26, 147–153. http://dx.doi.org/10.1023/A:1011343307783.

Barry, R.J., Clarke, A.R., Johnstone, S.J., Brown, C.R., 2009. EEG differences in children between eyes-closed and eyes-open resting conditions. Clin. Neurophysiol. 120, 1806–1811. http://dx.doi.org/10.1016/j.clinph.2009.08.006.

Becker, D., Creutzfeldt, O.D., Schwibbe, M., Wuttke, W., Fabberg, A., 1982. Changes in physiological, EEG and psychollogical parameters in women during the spontaneous menstrual cycle and following oral contraceptives. Psychoneuroendocrinology 7, 75–90. http://dx.doi.org/10.1016/0306-4530(82)90057-9.

Bindu, C., Dharwadkar, A., Dharwadkar, A., 2013. Comparative study of the immediate effects of deep breathing exercise coupled with breath holding up to the breaking point, on respiratory rate, heart rate, mean arterial blood pressure and peak expiratory flow rate in young adults. Med. Sci. 1, 33–38.

Bloch, S., Lemeignan, M., Aguilera-T, N., 1991. Specific respiratory patterns distinguish among human basic emotions. Int. J. Psychophysiol. 11, 141–154. http://dx.doi.org/10.1016/0167-8760(91)90006-J.

Brown, R.P., Gerbarg, P.L., 2005. Sudarshan Kriya Yogic Breathing in the treatment of stress, anxiety, and depression: part II – clinical applications and guidelines. J. Altern. Complement. Med. 11, 711–717. http://dx.doi.org/10.1089/acm.2005.11.711.

Bušek, P., Kemlink, D., 2005. The influence of the respiratory cycle on the EEG. Physiol. Res. 54, 327–333.

Busch, V., Magerl, W., Kern, U., Haas, J., Hajak, G., Eichhammer, P., 2012. The effect of deep and slow breathing on pain perception, autonomic activity, and mood processing: an experimental study. Pain Med. 13, 215–228. http://dx.doi.org/10.1111/j.1526-4637.2011.01243.x.

Carrier, J., Land, S., Buysse, D.J., Kupfer, D.J., Monk, T.H., 2001. The effects of age and gender on sleep EEG power spectral density in the middle years of life (ages 20–60 years old). Psychophysiology 38, 232–242. http://dx.doi.org/10.1111/1469-8986.3820232.

Chan, A.S., Cheung, M.C., Sze, S.L., Leung, W.W.M., Shi, D., 2011. Shaolin Dan Tian breathing fosters relaxed and attentive mind: a randomized controlled neuro-electrophysiological study. Evid. Complement. Altern. Med. 2011, 180704. http://dx.doi.org/10.1155/2011/180704.

Cheng, K.S., Chang, Y.F., Han, R.P.S., Lee, P.F., 2017. Enhanced conflict monitoring via a short-duration, video-assisted deep breathing in healthy young adults: an event-related potential approach through the Go/NoGo paradigm. PeerJ 5, e3857. http://dx.doi.org/10.7717/peerj.3857.

Chung, L.-J., Tsai, P.-S., Liu, B.-Y., Chou, K.-R., Lin, W.-H., Shyu, Y.-K., Wang, M.-Y., 2010. Home-based deep breathing for depression in patients with coronary heart disease: a randomised controlled trial. Int. J. Nurs. Stud. 47, 1346–1353. http://dx.doi.org/10.1016/j.ijnurstu.2010.03.007.

Connell, R.G.O., Dockree, P.M., Bellgrove, M.A., Turin, A., Ward, S., Foxe, J.J., Robertson, I.H., 2008. Two types of action error: electrophysiological evidence for separable inhibitory and sustained attention neural mechanisms producing error on Go/No-go tasks. J. Cogn. Neurosci. 21, 93–104.

Fregonezi, G., Federal, U., Grande, R., Regiane, V., Universidade, R., Grande, R., Fregonezi, G., 2004. Pursed lips breathing. Arch. Bronoconeumol. 40, 279–282.

Fumoto, M., Sato-Suzuki, I., Seki, Y., Mohri, Y., Arita, H., 2004. Appearance of high-frequency alpha band with disappearance of low-frequency alpha band in EEG is produced during voluntary abdominal breathing in an eyes-closed condition. Neurosci. Res. 50, 307–317. http://dx.doi.org/10.1016/j.neures.2004.08.005.

Gaurav, S., Meenakshi, S., Jayshri, G., Ramanjan, S., 2016. Effect of alterations in breathing patterns on EEG activity in normal human subjects. Int. J. Curr. Res. Med. Sci. 2, 38–45.

Heck, D.H., McAfee, S.S., Liu, Y., Babajani-Feremi, A., Rezaie, R., Freeman, W.J., Wheless, J.W., Papanicolaou, A.C., Ruszinkó, M., Sokolov, Y., Kozma, R., 2017. Breathing as a fundamental rhythm of brain function. Front. Neural Circuits 10, 1–8. http://dx.doi.org/10.3389/fncir.2016.00115.

Henz, D., Schollhorn, W.I., 2017. EEG brain activity in dynamic health Qigong training: same effects for mental practice and physical training? Front. Psychol. 8, 1–11. http://dx.doi.org/10.3389/fpsyg.2017.00154.

Homma, I., Masaoka, Y., 2008. Breathing rhythms and emotions. Exp. Physiol. 93, 1011–1021. http://dx.doi.org/10.1113/expphysiol.2008.042424.

Inanaga, K., 1998. Frontal midline theta rhythm and mental activity. Psychiatry Clin. Neurosci. 52, 555–566. http://dx.doi.org/10.1046/j.1440-1819.1998.00452.x.

Kan, D.P.X., Lee, P.F., 2015. Decrease alpha waves in depression: an electro-encephalogram(EEG) study. 2015 Int. Conf. BioSignal Anal. Process. Syst. ICBAPS 156–161. http://dx.doi.org/10.1109/ICBAPS.2015.7292237.

Kennedy, P.M., Zarbock, C.M., Burke, B.A., Diamond, S.G., 2011. Effect of deep breathing on extracted oxygen and cerebral hemoglobin levels. Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS 1021–1024. http://dx.doi.org/10.1109/IEMBS.2011.6090237.

Kimura, H., Nagao, F., Tanaka, Y., Sakai, S., Ohnishi, T., Okumura, K., 2005. Beneficial effects of the Nishino breathing method on immune activity and stress level. J. Altern. Complement. Med. 11, 285–291.

Klimesch, W., Doppelmayr, M., Russegger, H., Pachinger, T., Schwaiger, J., 1998. Induced alpha band power changes in the human EEG and attention. Neurosci. Lett. 244, 73–76. http://dx.doi.org/10.1016/S0304-3940(98)00122-0.

Krasnikov, G.V., Tyurina, M.Y., Tankanag, A.V., Piskunova, G.M., Chemeris, N.K., 2013. Analysis of heart rate variability and skin blood flow oscillations under deep controlled breathing. Respir. Physiol. Neurobiol. 185, 562–570. http://dx.doi.org/10.1016/j.resp.2012.11.007.

Lagopoulos, J., Xu, J., Rasmussen, I., Vik, A., Malhi, G.S., Eliassen, C.F., Arntsen, I.E., Sæther, J.G., Hollup, S., Holen, A., Davanger, S., Ellingsen, Ø., 2009. Increased theta and alpha EEG activity during nondirective meditation. J. Altern. Complement. Med. 15, 1187–1192. http://dx.doi.org/10.1089/acm.2009.0113.

Lin, I.M., Tai, L.Y., Fan, S.Y., 2014. Breathing at a rate of 5.5breaths per minute with equal inhalation-to-exhalation ratio increases heart rate variability. Int. J. Psychophysiol. 91, 206–211. http://dx.doi.org/10.1016/j.ijpsycho.2013.12.006.

Lopez-Calderon, J., Luck, S.J., 2014. ERPLAB: an open-source toolbox for the analysis of event-related potentials. Front. Hum. Neurosci. 8, 213. http://dx.doi.org/10.3389/fnhum.2014.00213.

Martinović, Z., Jovanović, V., Ristanović, D., 1998. EEG power spectra of normal pre-adolescent twins. Gender differences of quantitative EEG maturation. Neurophysiol. Clin. 28, 231–248. http://dx.doi.org/10.1016/S0987-7053(98)80114-7.

McCorry, L., 2007. Physiology of the autonomic nervous system. Am. J. Pharm. Educ. 71, 17–20. http://dx.doi.org/10.1111/j.1399-6576.1964. tb00252.x.

Meuret, A.E., Wilhelm, F.H., Ritz, T., Roth, W.T., 2008. Feedback of end-tidal pCO2 as a therapeutic approach for panic disorder. J. Psychiatr. Res. 42, 560–568. http://dx.doi.org/10.1016/j.jpsychires.2007.06.005.

Mills, E.J., Kelly, S., Wu, P., Guyatt, G.H., 2007. Epidemiology and reporting of randomized trials employing re-randomization of patient groups: a systematic survey. Contemp. Clin. Trials 28, 268–275. http://dx.doi.org/10.1016/j.cct.2006.09.002.

Miu, A.C., Heilman, R.M., Miclea, M., 2009. Reduced heart rate variability and vagal tone in anxiety: trait versus state, and the effects of autogenic training. Auton. Neurosci. Basic Clin. 145, 99–103. http://dx.doi.org/10.1016/j.autneu.2008.11.010.

Mori, H., Yamamoto, H., Kuwashima, M., Saito, S., Ukai, H., Hirao, K., Yamauchi, M., Umemura, S., 2005. How does deep breathing affect office blood pressure and pulse rate? Hypertens. Res. 28, 499–504. http://dx.doi.org/10.1291/hypres.28.499.

Nakashima, K., Sato, H., 1993. Relationship between frontal midline theta activity in EEG and concentration. J. Hum. Ergol. (Tokyo) 22, 63–67.

Nolan, H., Whelan, R., Reilly, R.B., 2010. FASTER: fully automated statistical thresholding for EEG artifact rejection. J. Neurosci. Methods 192, 152–162. http://dx.doi.org/10.1016/j.jneumeth.2010.07.015.

Park, Y.J., Park, Y.B., 2012. Clinical utility of paced breathing as a concentration meditation practice. Complement. Ther. Med. 20, 393–399. http://dx.doi.org/10.1016/j.ctim.2012.07.008.

Park, J.R., Yagyu, T., Saito, N., Kinoshita, T., Hirai, T., 2002. Dynamics of brain electric field during recall of Salpuri dance performance. Percept. Mot. Skills 95, 955–962. http://dx.doi.org/10.2466/pms.2002.95.3.955.

Paul, G., Elam, B., Verhulst, S.J., 2007. A longitudinal study of students' perceptions of using deep breathing meditation to reduce testing stresses. Teach. Learn. Med. 19, 287–292. http://dx.doi.org/10.1080/10401330701366754.

Pavlenko, V.B., Chernyi, S.V., Goubkina, D.G., 2009. EEG correlates of anxiety and emotional stability in adult healthy subjects. Neurophysiology 41, 337–345. http://dx.doi.org/10.1007/s11062-010-9111-2.

Pramanik, T., Sharma, H.O., Mishra, S., Mishra, A., Prajapati, R., Singh, S., 2009. Immediate effect of slow pace *Bhastrika pranayama* on blood pressure and heart rate. J. Altern. Complement. Med. 15, 293–295. http://dx.doi.org/10.1089/acm.2008.0440.

Prinsloo, G.E., Rauch, H.G.L., Karpul, D., Derman, W.E., 2013. The effect of a single session of short duration heart rate variability biofeedback on EEG: a pilot study. Appl. Psychophysiol. Biofeedback 38, 45–56. http://dx.doi.org/10.1007/s10484-012-9207-0.

Ray, W.J., Cole, H.W., 1985. EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. Science 228, 750–752. http://dx.doi.org/10.1126/science.3992243.

Sherlin, L., Muench, F., Wyckoff, S., 2010. Respiratory sinus arrhythmia feedback in a stressed population exposed to a brief stressor demonstrated by quantitative EEG and sLORETA. Appl. Psychophysiol. Biofeedback 35, 219–228. http://dx.doi.org/10.1007/s10484-010-9132-z.

Simpson, D.D., Nelson, A.E., 1974. Attention training through breathing control to modify hyperactivity. J. Learn. Disabil. 7, 274–283. http://dx.doi.org/10.1177/002221947400700502.

Song, H.-S.H., Lehrer, P.M.P., 2003. The effects of specific respiratory rates on heart rate and heart rate variability. Appl. Psychophysiol. Biofeedback 28, 2003. http://dx.doi.org/10.1023/A:1022312815649.

Stancak, A., Pfeffer, D., Hrudova, L., Sovka, P., Dostalek, C., 1993. Electroencephalographic correlates of paced breathing. Cogn. Neurosci. Neuropsychol. 4, 723–726.

Stedman, M.R., Curtin, F., Elbourne, D.R., Kesselheim, A.S., Brookhart, M.A., 2011. Meta-analyses involving cross-over trials: methodological issues. Int. J. Epidemiol. 40, 1732–1734. http://dx.doi.org/10.1093/ije/dyp345.

Tang, Y.-Y., Ma, Y., Fan, Y., Feng, H., Wang, J., Feng, S., Lu, Q., Hu, B., Lin, Y., Li, J., Zhang, Y., Wang, Y., Zhou, L., Fan, M., 2009. Central and autonomic nervous system interaction is altered by short-term meditation. Proc. Natl. Acad. Sci. 106, 8865–8870. http://dx.doi.org/10.1073/pnas.0904031106.

Task Force of The European Society of Cardiology, The North American Society of Pacing, A., Electrophysiology, A., 1996. Heart rate variability: standards of measurement, physiological interpretation, and clinical use. Eur. Heart J. 17, 354–381. http://dx.doi.org/10.1161/01.CIR.93.5.1043.

Telles, S., Raghuraj, P., Arankalle, D., Naveen, K., 2008. Immediate effect of high-frequency yoga breathing on attention. Indian J. Med. Sci. 62, 20–22. http://dx.doi.org/10.4103/0019-5359.38919.

Teplan, M., 2002. Fundamentals of EEG measurement. Meas. Sci. Rev. 2, 1–11. http://dx.doi.org/10.1021/pr070350l.

Tharion, E., Samuel, P., Rajalakshmi, R., Gnanasenthil, G., Subramanian, R.K., 2012. Influence of deep breathing exercise on spontaneous respiratory rate and heart rate variability: a randomised controlled trial in healthy subjects. Indian J. Physiol. Pharmacol. 56, 80–87.

Tomasino, B., Chiesa, A., Fabbro, F., 2014. Disentangling the neural mechanisms involved in Hinduism- and Buddhism-related meditations. Brain Cogn. 90, 32–40. http://dx.doi.org/10.1016/j.bandc.2014.03.013.

Vaschillo, E.G., Vaschillo, B., Lehrer, P.M., 2006. Characteristics of resonance in heart rate variability stimulated by biofeedback. Appl. Psychophysiol. Biofeedback 31, 129–142. http://dx.doi.org/10.1007/s10484-006-9009-3.

Wang, S.-Z., Li, S., Xu, X.-Y., Lin, G.-P., Shao, L., Zhao, Y., Wang, T.H., 2010. Effect of slow abdominal breathing combined with biofeedback on blood pressure and heart rate variability in prehypertension. J. Altern. Complement. Med. 16, 1039–1045. http://dx.doi.org/10.1089/acm.2009.0577.

Yadav, G., Mutha, P.K., 2016. Deep breathing practice facilitates retention of newly learned motor skills. Sci. Rep. 6, 37069. http://dx.doi.org/10.1038/srep37069.

Yu, X., Fumoto, M., Nakatani, Y., Sekiyama, T., Kikuchi, H., Seki, Y., Sato-Suzuki, I., Arita, H., 2011. Activation of the anterior prefrontal cortex and serotonergic system is associated with improvements in mood and EEG changes induced by Zen meditation practice in novices. Int. J. Psychophysiol. 80, 103–111. http://dx.doi.org/10.1016/j.ijpsycho.2011.02.004.

Zautra, A.J., Fasman, R., Davis, M.C., Craig (Bud), A.D., 2010. The effects of slow breathing on affective responses to pain stimuli: an experimental study. Pain 149, 12–18. http://dx.doi.org/10.1016/j.pain.2009.10.001.