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Powering Up Attentional Focus

Validating a school-based deep breathing intervention with mobile EEG—a pilot exploration

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***Abstract*—Electrophysiological and neuroimaging data are important sources of information for validating the efficacy or effects of interventions. Many interventions for children are carried out in the schools especially if they are educationally relevant. However, factors such as high costs and physical constraints have typically limited the use of electrophysiological and neuroimaging tools to laboratory settings. Despite their reduced capabilities, the appearance of low-cost, quick-to-set-up mobile equipment in recent years have renewed the possibility of applying such techniques to monitor effects in school-based interventions. The current study explores the utility of a low-cost, mobile electroencephalography (EEG) headset system in detecting neurophysiological effects of a school-based deep breathing intervention, found in a previous behavioral study to be efficacious in reducing self-reported state anxiety and enhancing test performance in children. As part of a larger pilot study, EEG, respiration, and behavioral data were collected from a group of right-handed 11-year-olds as they performed a flanker task of attentional focus twice, once with a deep breathing intervention and once without. Results from power spectral analyses suggest that the low-cost, low-resolution, mobile EEG system is able to detect power spectra differences associated with flanker interference and intervention effects.**

Keywords-attention; interference; breathing; EEG; intervention; children

I. Introduction

Test anxiety is a non-trivial issue in schools, especially in settings with high stakes examinations. It has been estimated that 10–40% of students, as young as age 7, may suffer from test anxiety [1, 2]. Children who are test anxious tend to exhibit maladaptive affective, cognitive, and behavioral responses – such as nervousness, worry and avoidance behaviors – during exams or similar stressful evaluative situations [3].

Test anxiety can adversely impact psychological well-being and performance. Linked to negative outcomes ranging from poor academic achievement to depression and suicide ideation [4, 5], schools are increasingly recognizing the need to equip their students with skills to ameliorate the adverse effects of test anxiety. One technique that has been found to help children with test anxiety is deep breathing. In a previous experimental study, it was found that teaching children to take deep breaths before a timed math test reduced their feelings of anxiety and enhanced their test performance [6]. However, although it was hypothesized that deep breathing might enhance performance by increasing attentional focus, the authors found no significant effects of the deep breathing intervention on reducing behavioral measures of interference on a flanker task [7], commonly used to index inhibitory control of attention to distractors.

On the other hand, interventions, such as attention training, have at times been found to enhance brain functioning at the neurophysiological level without necessarily manifesting as improvements in direct behavioral performance. For instance, an attention training study with preschool children found EEG indicators of a more efficient executive attention network following training, despite the lack of significant behavioral effects during an attention task [8].

Thus, the deep breathing intervention might have enhanced attentional focus at a neurofunctional level, even if no evidence was found at the behavioral level. The enhanced attentional focus, at the level of brain functioning, may then translate into better performance on the math test, even if it was not reflected in behavioral measures of attention. However, collecting neurophysiological data such as EEG from children during school-based tasks or interventions is difficult due to the costs and physical constraints of conventional equipment. High-resolution, medical/research-grade EEG systems tend to be very expensive, cumbersome and take a long time to set up, and can be uncomfortable for the child. This can deter children from participating in EEG studies, as well as limit the possibilities of collecting data for large-scale, school-based interventions. The recent development of low cost, lightweight, wireless, mobile EEG headsets that are quick

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and easy to set up and reasonably comfortable for children to wear, brings new possibilities to collect ecologically-valid EEG data in situ, during large-scale, school-based interventions.

The current paper presents data from a larger study that pilots the utility of the Emotiv EPOC+ wireless EEG headset system (Emotiv Systems Inc., San Francisco, CA, USA) to collect research-grade data. Though operating at a lower resolution than conventional research systems, the Emotiv EPOC+ system has been used in some previous studies to collect EEG data of sufficient quality to generate ERP and power spectra measures [9-11]. Specifically in this study, we examine whether the system is able to detect effects of a school-based deep breathing intervention for children on a flanker attention task, on the level of brain electrical activity.

II. Method

A. Participants

Right-handed Primary Five (~Grade 5) students ($N = 22$; $M_{age} = 10.96$; $SD = .29$; 10 boys) from five local schools participated as part of a larger study. All children had normal or corrected to normal vision, and no known neurological or developmental disorders. Usable EEG data was available from 15 participants (after excluding data from 7 students due to extreme noise or recording errors). Within this final dataset, behavioral data was available from 13 participants. Respiratory data was available from 4 participants.

B. Materials

A computerized modified flanker task [7, 12] was written with E-Prime and administered. On each trial, participants viewed a centrally presented arrowhead flanked by two arrowheads on either side. In the congruent condition, the flanking arrowheads pointed in the same direction as the central arrowhead (e.g., "< < < < <"). In the incongruent condition, the flanking arrowheads pointed in the opposite direction as the central arrowhead (e.g., "> > < > >"). Participants were asked to focus their attention on the central arrowhead and to indicate the direction it is pointing towards, by pressing a left or right response key. Participants were instructed to respond as fast as they accurately can.

All stimuli were presented in white text on a black background, at 32-point Arial font. Each stimulus presentation was preceded by a fixation cross of 500ms. The stimulus was presented on screen until a response was received or for a maximum duration of 1500ms, followed by an inter-stimulus interval (ISI) of either 1100ms, 1300ms, or 1500ms. The task comprised 150 trials each of congruent and incongruent trials, presented in 6 blocks of 50 intermixed trials.

Reaction time and accuracy measures were collected. Flanker interference is typically reflected by the difference in performance between congruent and incongruent trials, with poorer performance in the incongruent trials (requiring inhibitory control of attentional focus).

C. Procedure

Participants were tested individually in a quiet room within their respective schools, away from potential sources of major electrical interference such as elevators. Participants were seated in a chair in front of a 13" notebook (1366 x 768 pixels). At the start of the session, participants were fitted with an Emotiv EPOC+ wireless headset. Eyes-open resting state EEG data was recorded for the duration of 4 minutes. Participants were then fitted with a respiration belt. The flanker task was explained and participants completed a practice block before being administered the actual task. All participants completed the flanker task twice, once with deep breathing (breathing condition) and once without (control condition), with task order counterbalanced across participants. In the breathing condition, the experimenter taught the participants to take deep, gentle belly breaths: placing their palms on their lower abdomens, focusing on directing air into their bellies and watching/feeling the rise-and-fall with each inhalation/exhalation. Participants were observed as they engaged in a brief practice. After establishing that the technique was properly executed, a one-minute deep breathing practice ensued, before the flanker task was administered. Respiratory and EEG activity were recorded throughout the session. In the control condition, a one-minute-rest segment without deep breathing practice was recorded prior to the administration of the flanker task. Participants performed 6 blocks of 50 mixed congruent and incongruent trials, with 1-minute rest breaks between each block. Participants performed the deep breathing practice during all rest breaks in the breathing condition. A 10-minute rest break followed before the task was administered again under the second condition (breathing/control).

D. Respiratory recording and data processing

A Thought Technology respiration sensor belt (Thought Technology, Ltd., Quebec, Canada) was used to measure abdomen movement during the flanker task. The first and last minute of recording were discarded. Two measures were derived to reflect the participants' breathing patterns: average rate of respiration per minute and average respiratory amplitude per minute.

E. EEG recording and data processing

The EEG data was collected using the Emotiv EPOC+ wireless EEG headset system (Emotiv Systems Inc., San Francisco, CA, USA). Sensors on the 14-channel headset were configured based on the international 10–20 system at AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4, referenced to the mastoids. Acquired data was digitized with the embedded 16-bit ADC at a sampling frequency of 128 Hz and wirelessly sent to the computer. The electrodes are moistened with a saline solution prior to fitting on the participants' heads. Sensor contact quality was monitored with the Emotiv inbuilt program.

EEG data processing was performed offline using MATLAB (version R2017a, The MathWorks, Inc., Natick, MA, USA). Continuous EEG collected during the flanker task was bandpass filtered between 1-30 Hz using zerophase FIR filter with a Hamming window function. Single-trial data was then extracted from 0.5s pre-stimulus to 1s post-stimulus (-0.5s to 1 s), and noisy trials were identified and discarded using FASTER toolbox [13]. The remaining data was scanned for artefactual channels using PREP toolbox [14] and bad channels identified were interpolated using spherical interpolation. Next, the data was referenced to the common average referencing and Independent Component Analysis (ICA) was used to remove eye blink and muscle-related artifacts. The artefactual components were detected and removed using ADJUST toolbox [15].

Power spectral analysis was performed by calculating the power spectral density (PSD) using Welch's periodogram which provides robust PSD estimation by statistical methods. The PSD was computed using the non-baseline corrected 0-1s single trial data and PSD from successful congruent and incongruent trials was averaged separately to obtain the trial averaged PSD. These averaged PSD estimates were summed across 1.00-4.00Hz, 4.01-7.50Hz, 7.51-12.50Hz, and 12.51-30.00Hz bands to obtain absolute band power in the classical delta (δ), theta (θ), alpha (α) , and beta (β) power bands respectively. Relative band power at each channel was calculated by dividing the absolute band power in each power band with the total power in 1-30Hz. Using averaged PSD, measures of interhemispheric power asymmetry were also calculated for each frequency band at seven homologous channel pairs (AF3-AF4, F7-F8, F3-F4, FC5-FC6, T7-T8, P7-P8, O1-O2). The power asymmetry was calculated between the right (R) and left (L) hemisphere with the formula [(R-L)/(R+L)].

F. Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 24 (IBM Corp., Armonk, NY, USA). Behavioral data was examined by conducting Condition (deep breathing vs. control) × Congruency (congruent vs. incongruent) fully within repeated measures analyses of variance ANOVAs on mean reaction time (RT) and accuracy. Incorrect/inaccurate trials were excluded from the calculation of RT. Respiratory data was examined with a repeated measures ANOVA of Condition on rate of respiration and average respiratory amplitude. The EEG data from correct/accurate trials was examined by conducting separate three-way, fully within repeated measures ANOVAs with the factors of Condition (deep breathing vs. control), Congruency (congruent vs. incongruent), and Electrode sites, on the absolute power and relative power from each frequency band, and the inter-hemispheric asymmetry indices. The Greenhouse-Geiser epsilon correction was used when assumptions of sphericity were violated. Significant effects were probed by examining Bonferroni-corrected pairwise comparisons. Missing data was excluded in a pairwise fashion. Unless otherwise stated, statistical significance was evaluated at $\alpha = 0.05$. Given the small sample size, we also reported marginally significant results ($\alpha < 0.10$).

III. Results

A. Behavioral Measures

The typical Flanker interference effect was observed with a significant main effect of Congruency on RT [$F_{1, 12}$= 109.57, $p = 0.000$, $\eta\rho^2 = 0.90$] and accuracy [$F_{1, 12}$= 41.87, $p = 0.000$, $\eta\rho^2 = 0.69$] with significantly faster RTs and higher accuracy for congruent trials than incongruent trials, for both deep breathing and control conditions. However, no significant effect of the breathing intervention was observed on RT or accuracy: the main effect of Condition and Condition × Congruency interaction were not significant (Table 1). The participants were not faster or more accurate (generally, on the overall task) in the breathing compared to control condition. They also did not show smaller behavioural interference in the breathing compared to control condition.

TABLE I. Behavioral Measures of Flanker Task Performance

	Control		Breathing	
	Congruent Mean (SD)	***Incongruent Mean (SD)***	***Congruent Mean (SD)***	***Incongruent Mean (SD)***
RT (ms)	609.68 (50.80)	788.22 (114.94)	583.41 (56.46)	785.84 (116.49)
Acc (%)	96.67 (3.57)	86.05 (9.27)	96.36 (3.27)	85.54 (9.59)

B. Respiratory Measures

No significant main effect of Condition was observed with the respiratory measures. The average rate of respiration was not lower, and the average respiratory amplitude was not higher, in the breathing compared to control condition.

C. EEG Measures

In the interest of space, we focus on reporting significant effects of interest. For absolute power, the three-way ANOVAs did not show significant main or interaction effects.

For relative power, the Condition × Congruency × Electrode ANOVAs showed significant Condition × Congruency interaction effects only for the alpha band [$F_{1, 14}$= 6.92, $p = 0.020$, $\eta\rho^2 = 0.33$], with significantly higher power for incongruent compared to congruent trials only during the breathing condition (Fig. 1). The main effect of Congruency was marginally significant for the beta [$F_{1, 14}$= 3.11, $p = 0.099$, $\eta\rho^2 = 0.18$] and delta bands [$F_{1, 14}$= 4.56, $p = 0.051$, $\eta\rho^2 = 0.25$]. Relative beta power was higher for incongruent compared to congruent trials, while relative delta power was higher for congruent compared to incongruent trials.

A significant main effect of Electrode was observed for the alpha [$F_{1, 13}$= 10.70, $p = 0.000$, $\eta\rho^2 = 0.43$], delta [$F_{1, 13}$=4.14, $p = 0.001$, $\eta\rho^2 = 0.23$], and theta bands [$F_{1, 13}$= 3.74, $p = 0.003$, $\eta\rho^2 = 0.21$]. Most of the significant relative power differences between electrodes were observed in the alpha

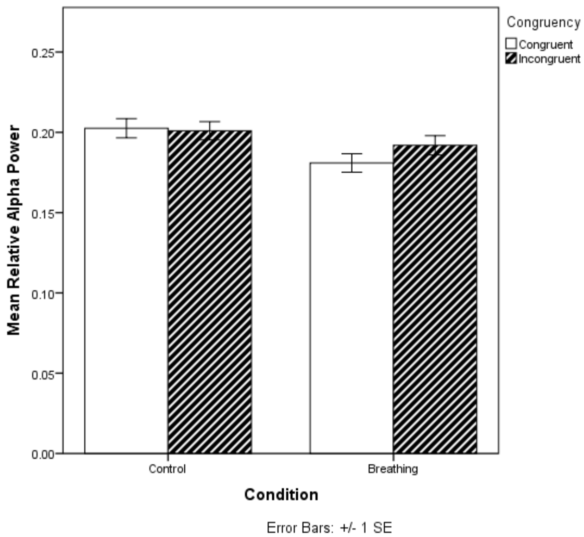

Figure 1. Relative alpha power significantly higher during incongruent compared to congruent trials only in the deep breathing condition.

band, with generally larger posterior to anterior power, especially in the occipital region (particularly right occipital). Specifically, significantly larger relative alpha power was recorded over O2 than over AF3, AF4, F7, F8, FC5, P7, P8, T7, and T8, and also over O1 than over F7, and over F4 and P8 than over AF3. Theta power appeared to be generally larger in the (right) frontal area, with significantly larger power over F4 than over FC5, FC6, and T7. Delta power was significantly stronger over the (left) anterior frontal (AF3) than over the right occipital (O2). The topological maps of group-averaged relative power in each frequency band for each condition and congruency type are presented in Fig. 2.

Although the interaction effects involving Electrode were not statistically significant for any frequency band, inspection of the topological maps in Fig. 2 suggested some possible trends. For instance, theta and delta power seemed to be higher in the breathing compared to control condition over certain regions. Considering the small sample size (and the large number of electrodes) in the current pilot, we proceeded with exploring the pairwise comparisons despite the non-significant three-way interactions. For relative alpha power, significant differences between congruent and incongruent trials were observed at a few sites during the breathing condition only. Specifically, relative alpha power was higher during incongruent compared to congruent trials

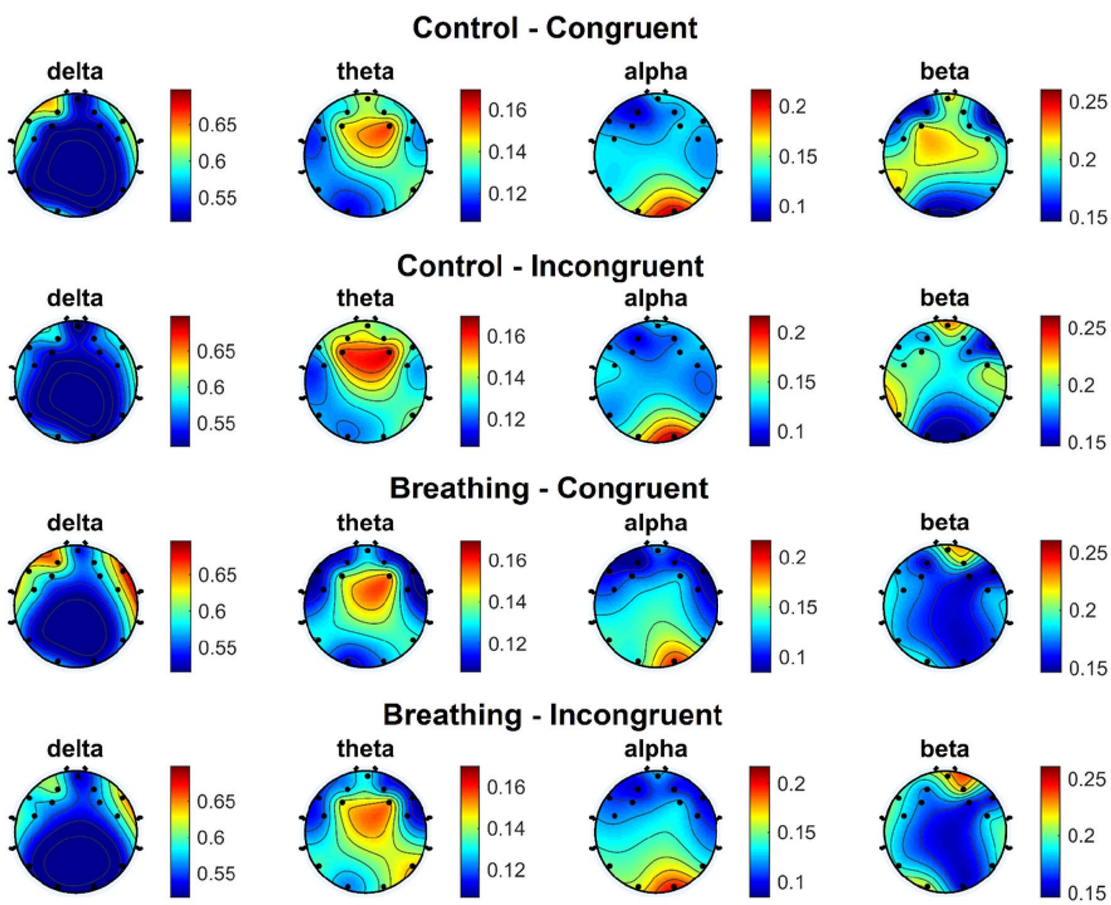

Figure 2. Topological maps of relative power.

at AF3, F7, F8, FC5, FC6, and O1. Relative theta power was also higher during incongruent compared to congruent trials during the breathing condition at P8, and at F3 during the control condition. Relative delta power was higher for congruent compared to incongruent trials at AF3 & F7 during both the control and breathing conditions, and at F8, O1, & P8 during the breathing condition.

For inter-hemispheric asymmetry, the three-way ANOVAs showed only main effects of Electrode-pair, which was significant for the theta band [$F_{6, 84}$= 2.22, p = 0.049, $\eta\rho^2$ = 0.14] and marginally significant for the delta band [$F_{6, 84}$= 2.09, p = 0.062, $\eta\rho^2$ = 0.13]. In both cases, lateralization was significantly different between the anterior frontal (AF3-AF4; more left) and the parietal (P7-P8; more right) pairs (Fig. 3).

IV. DISCUSSION

As per the previous behavioral study [6], the effects of the deep breathing intervention were not observable in behavioral performance on the flanker attention task. Effects were also not observed in terms of reducing the average rate of respiration (i.e., slowing down breathing) or increasing the average respiratory amplitude (larger volume of air intake)—though it should be noted that respiratory data was available only from four participants.

On the other hand, we found some evidence of the intervention having an effect on a neurofunctional level: relative alpha power was significantly higher during correct incongruent compared to correct congruent trials only during the breathing condition. Increased alpha during incongruent flankers has been argued to reflect an increase in top-down cognitive control, based on the view that alpha oscillations play an active inhibitory role [16, 17]. This suggests that the deep breathing intervention may have increased attentional focus in the face of distractors, by powering up alpha.

Consistent with the literature, we found alpha to be generally strongest over the occipital areas, and theta and delta in the frontal areas [16, 18]. Results of the Condition × Congruency pairwise comparisons paneled by Electrode suggest that the breathing intervention effects on relative alpha power are most likely to be observed over the left anterior frontal, bilateral frontal/ fronto-central, and left occipital sites. Although this last set of results followed a Condition × Congruency × Electrode interaction that failed to reach statistical significance, it should be noted that this might have been due to the limited power in the current study to detect significant effects with the small sample size, coupled with the number of sites examined. The overall interaction effect may emerge significant with a larger sample. Hence, though this set of results should be interpreted with caution, they provide some insights for future reference or validation.

The same set of (speculative) analyses also suggested that intervention effects may be observable in the theta frequency band, over the P8 site. Proposed to govern executive control during conflict processing, theta oscillations have been shown to be present across various interference paradigms, including the flanker attention task [19]. Variations in theta power have been proposed to reflect the adaptive allocation of cognitive resources to attentional control, according to task processing demands. Although top-down cognitive control processes are commonly attributed to the prefrontal cortex, it has been observed across types of interference tasks that where theta power differences are most strongly observed may vary with the brain region interfering information is processed in [19].

Interestingly, in the same set of analyses, relative delta power was found to be higher for congruent compared to incongruent trials during the breathing condition at F8, O1, & P8, and for both breathing and control conditions over left frontal/anterior-frontal regions. Findings from previous studies have suggested a more general action-monitoring

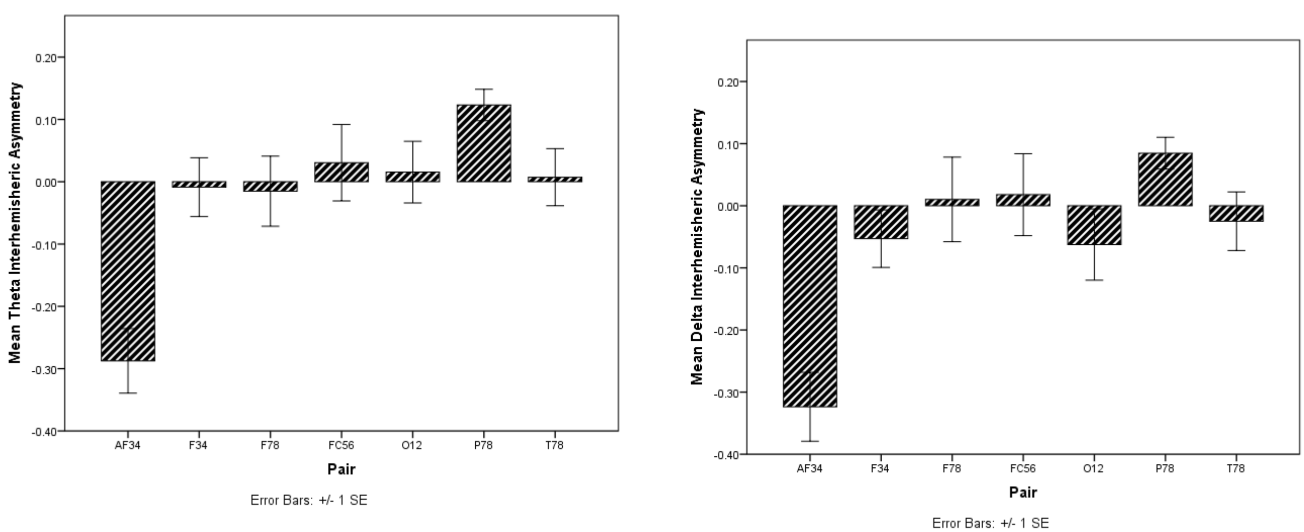

Figure 3. Theta and delta inter-hemispheric asymmetry, significantly different between AF3-AF4 and P7-P8 pairs.

role of delta—especially lower delta (1–2 Hz)—activity in the flanker task, towards the prevention of errors and more accurate task performance [20]. The higher accuracy rate on the congruent trials is consistent with this account.

It has been suggested that neural activity at different frequency bands may be involved at different phases/stages of interference processing and response [20, 21], in tasks such as the flanker. Başar and colleagues proposed that oscillations in each frequency range may serve multiple functions; complex and integrative brain functions are effected by specific configurations of multiple oscillations across various frequency bands in selectively distributed networks [22, 23].

Findings from the current study are broadly consistent with the literature on the role of top-down executive functions or cognitive control in the flanker task. Our finding of a marked left lateralization in the anterior-frontal channels during the flanker task is also consistent with the common view that the left prefrontal cortex is particularly important for executive control functions [24, 25]. The right lateralization observed in the posterior parietal channels is consistent with previous studies that have ascribed an important role to the right posterior parietal cortex in maintaining spatial attention [26].

Although the main effect of congruency was only marginally significant, the results suggest that EEG power differences between congruent and incongruent flankers—that is, flanker interference—may be detected on the Emotiv EPOC+ system. Though not the main focus of the current study, this may be of interest for the system's capacities for future studies.

The finding that congruency effects were observed in the beta and delta frequency bands while congruency differences specific to the breathing intervention were mainly observed in the alpha band suggests that effects specific to the deep breathing intervention may be particularly observed in the alpha frequency. Previous studies examining how the rate of respiration affects EEG spectral power has found slow paced breathing to increase power across almost all regions of the brain, in the alpha, beta, and theta bands [27]. Alpha activity in the human brain has in general been associated with concentration or attentional focus. Current findings thus suggest that the breathing intervention, at least to some extent, increased attentional focus during flanker interference.

It should be noted though, that the concentration of effects observed predominantly in the alpha frequency may also be in part due to alpha being the frequency band with the strongest signal that is most easily picked up on EEG. Hence, it is possible that intervention effects in the other frequency bands were too weak to be picked up by the Emotiv system, which are expectedly less powerful than research-grade systems. Nevertheless, the current results suggest that the system is capable of at least detecting large effects that may be reflected in the alpha frequency.

Taken together, and consistent with previous studies using the Emotiv system, the current findings suggest that the low cost, mobile Emotiv EPOC+ EEG headsets may provide some useful data during large scale, school-based interventions.

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