Espiral. Cuadernos del Profesorado
Vol. 18, Num. 37
March 2025
ISSN 1988-7701

How to reference this article:

Muñoz-Parreño, J. A., Belando-Pedreño, N., Merino-Barrero, J. A., & Valero-Valenzuela, A. (2025). Neurophysiological effects of active breaks in school children. *Espiral. Cuadernos del Profesorado, 18*(37), 15-31. https://doi.org/10.25115/ecp.v18i37.10099

Published on-line: 11 of February of 2025

Neurophysiological effects of active breaks in school children

Efectos neurofisiológicos de los descansos activos en escolares

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Abstract

Objective: The present study aimed to analyse and compare the acute effects of an active break (AB) on brain frequencies of children in Primary Education. **Method**: Twenty-four children (16 boys and 8 girls) between 9 and 11 years old (*M* = 10.79; *SD* = .59) from two Spanish primary schools were randomly selected. The sample was organised into an experimental group (EG) (*N* = 12; 4 girls and 8 boys) and a control group (CG) (*N* = 12; 4 girls and 8 boys). In both groups, an electroencephalogram was performed to analyse the brain waves that originate in response to an AB, in the case of the EG, in parallel with the CG, in which an AB was not performed. **Results**: The results reported variations of Alpha and Beta frequencies in frontal and prefrontal regions of the brain in the EG. In addition, significant Alpha data were obtained in the sum of all brain regions analyzed. **Conclusions:** these results contribute to the advancement of neuroscience, providing evidence that the application of AB in the classroom could be a useful strategy to improve the cognitive efficiency related to the teaching-learning processes in Primary Education children analyzed in this study.

Keywords: Electroencephalography, Active Break, Physical Activity, Cognitive Processes, Educational Processes, Health.

Resumen

Objetivo: El presente estudio tuvo como objetivo analizar y comparar los efectos agudos de un descanso activo (DA) sobre las frecuencias cerebrales de niños y niñas en Educación Primaria. **Método**: Se seleccionaron aleatoriamente 24 niños (16 niños y 8 niñas) de entre 9 y 11 años (*M* = 10,79; *DT* = .59) de dos colegios españoles de Educación Infalntil y Primaria. La muestra se organizó en un grupo experimental (GE) (*N* = 12; 4 niñas y 8 niños) y un grupo control (GC) (*N* = 12; 4 niñas y 8 niños). En ambos grupos se recogieron muestras mediante electroencefalograma para analizar las ondas cerebrales que se originaron en respuesta a la aplicación de un DA, en el caso del GE, en paralelo con el GC, en el que no se realizó un DA. **Resultados**: Los resultados reportaron variaciones de las frecuencias Alfa y Beta en regiones frontales y prefrontales del cerebro en el GE. Además, se obtuvieron datos Alfa significativos en la suma de todas las regiones cerebrales analizadas. **Conclusiones**: Estos resultados contribuyen al avance de la neurociencia, aportando evidencias de que la aplicación del DA en el aula podría ser una estrategia útil para mejorar la eficiencia cognitiva relacionada con los procesos de enseñanza-aprendizaje en los niños de Educación Primaria analizados en este estudio.

Palabras clave: Electroencefalografía, Descansos Activos, Actividad Física, Procesos Cognitivos, Procesos Educativos, Salud.

Received: September 6, 2024
Accepted: January 17, 2025

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Introduction

The maintenance of comprehensive health and the acquisition of more active lifestyle habits in schoolchildren has become one of the most important challenges for public health and the education system, in order to reduce physical inactivity and thus mitigate the appearance of cardiometabolic pathologies (hypertension, high cholesterol, diabetes, obesity) and mental health disorders (depression, anxiety, attempted self-harm), among others (Piercy et al., 2018) in schoolchildren and adolescents. In this regard, the curricular programming at the primary education stage is based on long periods of sedentary activity (between 6 and 7 hours a day) with only 3 Physical Education (PE) sessions of less than 60 minutes (Bedard et al., 2019). This reality has contributed to lifestyle modification, distancing them from options that allow them to be physically active (Pastor-Vicedo et al., 2021). Therefore, optimising physical activity (PA) time and reducing sedentary time are important goals for the cognitive, emotional and physical health of young people (Burns et al., 2020; Huang et al., 2018).

Scientific evidence shows that the application of PA at an early age can improve cognitive ability, as assessed by resting EEG (Srinivas et al., 2021). It is observed that children with better physical conditions (better oxygen consumption, strength-endurance, speed, agility, etc.) have greater attentional control than those with lower physical performance, as observed through EEG (Huang et al., 2015). In addition, acute physical exercise in this age range has been shown to normalise hyperactivity-derived arousal and improve their attentional state (Huang et al., 2018). In the same vein, recent studies in schoolchildren without obvious pathologies have shown that those with higher levels of PA have better executive performance (working memory) than others with lower levels (Hsieh et al., 2018).

Consequently, the educational context is considered an ideal environment for providing the appropriate dose of Health Physical Activity (HPA) for all schoolchildren (Donnelly et al., 2016). To increase the practice of PA in the educational context, strategies have been employed that integrate movement into the classroom by introducing PA intervals of varying intensity (cardiovascular effort) and peer interaction in some curricular classes (language, mathematics, languages, etc.) (Institute of Medicine, 2013). These "active breaks" (ABs) aim to increase PA and/or reduce physical sedentarism among children and adolescents. In this regard, ABs, considered as independent activities designed as short PA breaks to refresh the brain, either during academic classes or between transitions (Méndez-Giménez, 2020), can include curricular content (Schmidt et al., 2016). ABs are shown to be a form of physical exercise of variable intensity lasting between 5 and 15 minutes (Howie et al., 2015), linked to the curricular content of each subject to break physical sedentarism and the monotony of expository classes. ABs can also be combined with other types of cooperative and emotional activities for the development and improvement of executive functions (Muñoz-Parreño et al., 2021; Pastor-Vicedo et al., 2021), among other behaviours associated with social development.

In this regard, ABs could be used as an alternative formative and pedagogical intervention to increase PA among schoolchildren and adolescents, while also addressing the need to analyse its cognitive and behavioural consequences (Muñoz-Parreño et al., 2022). As a theoretical foundation for this intervention proposal, the postulates of cognitive neuroscience facilitate a better understanding within the educational community (especially for teachers) of the mental processes involved in learning. This science, focused on the analysis of neural processes, provides a holistic view and knowledge of the biological, cognitive, and socio-emotional needs of young students (Irisarri & Villegas-Paredes, 2021). However, more scientific evidence is currently needed to delve into the behavioural consequences, specifically in the analysis of brain oscillations and their potential cognitive consequences in school-aged children (Donnelly et al., 2016). Such consequences are represented in higher attentional levels (Ma et al., 2014) or in the adequate development of fine motor skills (Biino et al., 2021). Children enrich their teaching-learning process when exposed to various sensory inputs (channels of information and experimentation) of auditory, visual, olfactory, and motor nature (Irisarri & Villegas-Paredes, 2021). Review studies such as those by Masini et al. (2020) found positive results on PA levels and classroom behaviour with the application of ABs.

To contrast the cognitive effects of ABs, a precise measurement system of neural oscillations is needed to link theory, physiology, and cognition mechanisms. Neural oscillation research must be adequately interpreted and ultimately developed into mechanistic theories (Donoghue et al., 2021). The electroencephalogram (EEG) is one of the most used instruments to evaluate cognitive efficiency, understood as the ability to perform cognitive operations in the best possible way to achieve higher performance, maximising available resources (Rypma et al., 2006). Numerous studies in children in the clinical field have used EEG for the analysis of developmental disorders, such as attention deficit hyperactivity disorder (Chiarenza, 2021).

Currently, in education, authors like Xu and Zhong (2018) use portable EEG devices to measure electrical potentials recorded on the scalp, providing estimates of large-scale neuronal activity in relation to behaviour and cognition. Generally, four brain waves are recorded, indicating different frequency ranges, ordered from lowest to highest frequency (Hz): (a) Delta, (b) Theta, (c) Alfa y (d) Beta. Delta waves are primarily stimulated during deep sleep. Theta waves usually appear in moments of decreased consciousness before drowsiness, creative inspiration, and meditative states. Alpha arises in relaxed awareness situations and is related to cognitive control (Janssens et al., 2018), increased working memory processes (Sato et al., 2018), increased semantic memory (Klimesch, 1997), increased alertness and expectation, and increased attentional demand (Hogan et al., 2013). Beta is related to attention, thinking, and wakefulness (Sanei & Chambers, 2007).

Various studies focused on PA and the improvements caused on brain frequencies have reported increases in Alpha frequency (Hatfield & Kerick, 2007; Kubitz & Pothakos, 1997; Nan et al., 2014), associated with increased cognitive efficiency (Chang et al., 2015), although other studies report increases across the entire frequency range after PA, not just Alpha frequency (Ciria et al., 2017). However, it is important to clarify which elements could be determinant in the relationship between PA and the improvement of cognitive processes, such as the type, amount, intensity, frequency, and timing of PA (Donnelly et al., 2016). In this regard, studies like those by Tabata (2019) should be considered to determine the intensity of ABs in relation to the involvement of energy systems (aerobic and anaerobic pathways) compared to other conventional aerobic and anaerobic exercises used in “HIIT” (high-intensity interval training) exercise protocols.

According to what has been exposed and based on the reviewed bibliography, the present study aims to analyse and compare the effects of the application of ABs with curricular academic content on different types of brain frequencies (Alpha, Beta, Delta, or Theta) as indicators of cognitive functioning in primary education students. For this purpose, it is hypothesised that the acute application of ABs with curricular academic content produces an increase in brain frequencies (Alpha and Beta) and in the brain regions associated with greater cognitive efficiency in the students analysed. On the other hand, schoolchildren in the control group (CG) (not receiving active rest) are expected to show no significant brain oscillations of Alpha and Beta waves.

Method

Studio Design

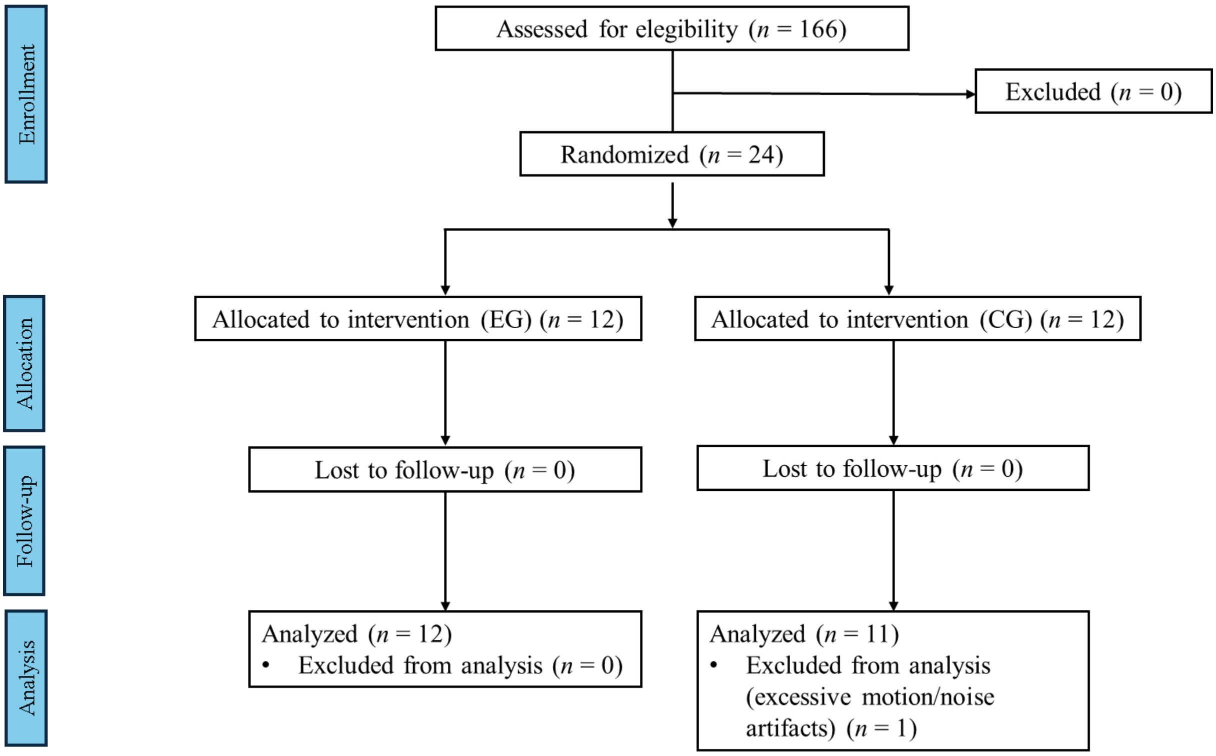
A quasi-experimental randomised study was designed in the group condition and in the students belonging to the groups (Luna, et al., 2020). In conducting this research, the recommendations of the CONSORT 2010 statement were followed (Cobos-Carbo & Augustovski, 2011). The intervention protocol was approved by the Ethics Committee of the University of Murcia (ID: 2036/2018) and was authorised by the directors of the educational centres and participating teachers.

Participants

Out of 166 students (92 boys and 74 girls) between 9 and 12 years of age (M = 10.90; SD = .70) belonging to the 5th and 6th grade levels of primary education from two educational centres with similar sociodemographic and economic characteristics in the Autonomous Community of Castilla-La Mancha (Spain), chosen for accessibility and convenience. One participant was excluded due to excessive motion/noise artifacts (Muller et al., 2021). Initially, in both levels, the condition of the research group was randomised in each of the educational levels (classes already established by the educational centre) by means of a computer programme, with the CG configured by four groups (two groups of 5th graders and two groups of 6th graders) and the EG by four groups (two groups of 5th graders and two groups of 6th graders). In a second phase, in each of the groups, the selection of 3 students per class was randomised by means of a computer application in both the CG (4 girls and 8 boys) and EG (4 girls and 8 boys), each constituted by 12 participants. The inclusion criteria (*n* = 166) were to have the informed consent of the parents (or legal guardian). The criteria for exclusion (*n* = 0) were a) physical limitation that prevented the practice from taking place, b) specific learning difficulty referred by dyscalculia and/or dyslexia and c) other cognitive problems such as attention deficit hyperactivity disorder or autism spectrum disorder. None of the participants had previously participated in an AB intervention. This presented an EEG data set of *N* = 24 participants (16 boys and 8 girls; *M* = 10.79; *SD* = .59) belonging to the 5th grade of primary school (4 classes, *n* = 83) and 6th grade of primary school (4 classes, *n* = 83) in two phases (see Figure 1).

Figure 1

Diagram of Participants



Instruments

The commercial brain-computer interface Emotiv Epoc+ Model 1.1 (San Francisco, CA, USA) was used because this instrument is suitable for taking measurements in an environment such as the school classroom and is one of the most widely used in these fields (Xu & Zhong, 2018). On the other hand, this instrument appears to be capable of detecting power spectral differences associated with intervention effects in children (Khng & Mane, 2020). This electrical neuro-signal detection system, like other EEGs, captures and amplifies brain waves that originate in response to some mental action. It is configured in 14 channels or sensors for the reception of brain waves and two reference channels, supported by the international system of location of electrodes 10-20, specifically in the locations AF3, AF4, F3, F4, F7, F8, FC5, FC6, T7, T8, P7, P8, O1, O2, CMS (P3), and DRL (P4) as references (Sareen et al., 2020). The processing speed was selected at 256 Hz and 16 bits per second to load the maximum resolution (Williams et al., 2020). The device sends the signals to the computer (Windows 10, intel CORE i7, 16 Gb RAM) via a Bluetooth 5.0 wireless system, by means of an antenna inserted into the computer via a USB connection. The process information displayed on the computer screen and the data recording were carried out using the Emotiv Xavier Test BenchTM software, version 3.1.19 (San

Francisco, CA, USA), created by the EEG manufacturer. This panel makes it possible to check the quality of the signal collected by each sensor, display the brain's electrical signals in real time, modify the signal acquisition parameters, etc. For this work, the frequency bands proposed by Michel et al. (1992) from EEG were taken as references -1.0-3.5 Hz (Delta), 4.0-7.5 Hz (Theta), 8.0-12.0 Hz (Alpha)- except the Beta frequency, which was grouped with an amplitude of 12.5-30.0 Hz (Costa et al., 2024).

Procedure

Initially, a pilot study was conducted with a 6th grade Primary School class five months before collecting the data for this study. This first study was used to adjust the duration and type of PA, recovery time, characteristics of the images with academic content, etc. In addition, it served to experiment with the use of the portable EEG, its installation, data collection and processing, and whether the 4 minutes of recording was a time that the participants could withstand. On the other hand, it was possible to record videos to show to the teachers in order to sensitise them to the intervention that would be carried out in their classes.

Each group had a different teacher who was not related to the other research groups. The curricular contents taught by both the EG and the CG were the same for each educational level, since identical printed materials and didactic programmes were used. The areas in which AB were applied were mathematics and Spanish language and literature. The academic content for 5th graders was fractions and signs of comparison in mathematics and personal pronouns in Spanish language. For 6th graders, content related to fractions and simple or compound verbal forms was taught for mathematics and Spanish language and literature, respectively.

The study of neurophysiological responses with EEG was carried out in the usual classes of each group of students, where the teacher focused on the development of concepts, leaving critical thinking, reflection, and confrontation of ideas on social aspects aside. Teachers focused on developing the scientific aspect of each subject, becoming the centre of the learning process and the decision-making agent. Data collection covered three teaching sessions lasting 45 minutes each, starting at 9:00 a.m. in all cases and ending at 11:15 a.m. (8 days in total).

Phase 1: preparing the instrument. After the selection of the test participants, the class began as usual. During this period, the EEG sensors were moistened with a saline preparation, so they were ready to be installed on the children's scalps. The placement was carried out 8 minutes after the start of the session to establish a proper link between the EEG and the computer. To do this, the direct connection of the sensors to the scalp and the connection quality of each sensor were checked using the Emotiv Xavier Test BenchTM software (v.3.1.19) and the coherence of the brain waves recorded.

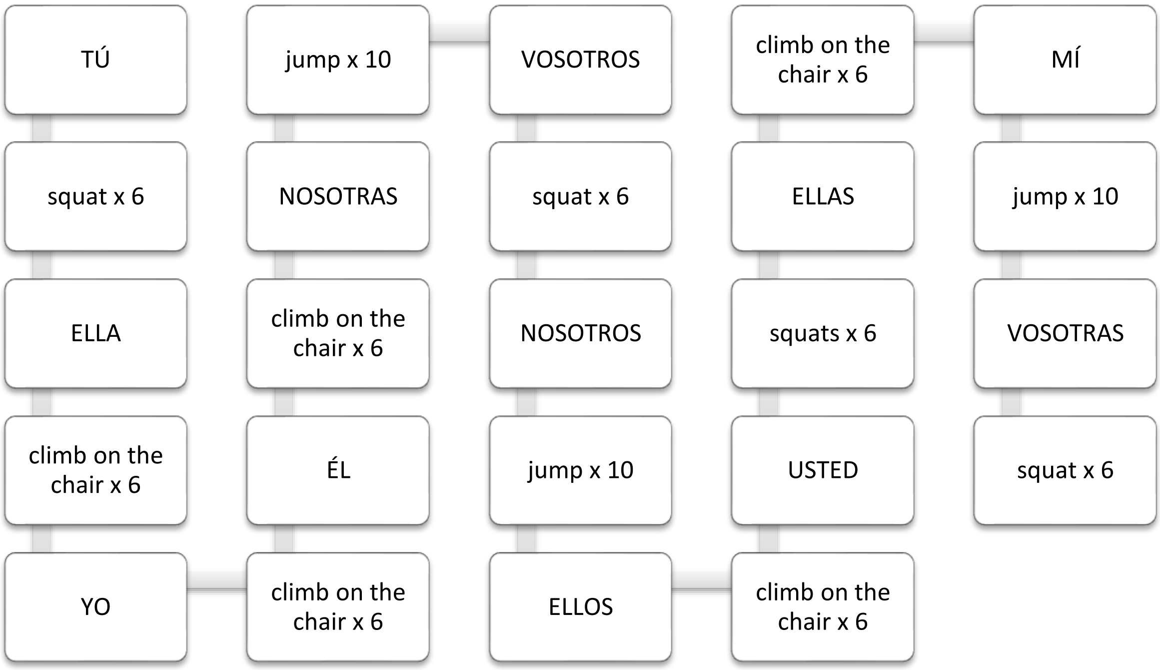
Phase 2: pre-test recording. After 10-12 minutes of class, the first pre-test recording of 4 minutes and 30 seconds was made.

Phase 3: apply AB or normal sedentary class. Once it was finished, the EEG was withdrawn and the children continued with the development of the session in the case of the CG, or they performed a adaptation Tabata-type AB (High-Intensity Interval Training) of approximately 10 minutes in the case of the EG. The adaptation consisted of increasing the length of the recovery time by 5 seconds (the original Tabata method proposes 10 seconds of recovery and 20 seconds of PA) so that the students had more time to solve the problems presented to them on the digital whiteboard, which were related to the academic content. This decision was taken because during the pilot test we observed that only 10 seconds of exposure to the academic content was not enough for the students to process it and give an adequate response. In the EG, PA plus academic content was applied. The PA consisted of 20 seconds of physical exercises (e.g., squats, jumping jacks, arm backgrounds, jumps, burpees, tricep backgrounds, etc.) with a recovery between these intervals of 15 seconds of active recovery with soft jogging in place while presenting a cognitive challenge corresponding to the academic content worked on in class (e.g., solving a fraction in mathematics and identifying which syllable carried the accent in Spanish language and literature). During this phase, the researcher proceeded to wet the electrodes again to obtain a quality signal from the EEG.

Figure 2 shows an example of the application of an AB for the 5th grade of Primary Education, consisting of the application of PA together with academic content in the area of Language and Literature (personal pronouns in Spanish language).

Figure 2

Example of AB applied in this study: "personal pronouns" (in Spanish)



Note. Instructions: Then the different personal pronouns will appear. Students will do the following will: first person pronouns: jump x 10; second person pronouns: squat x 6; third person pronouns: we climb on the chair x 6 (3 each with alternating right-left leg). Jogging gently on the spot throughout the exercise.

Phase 4: post-test recording. Once this period had elapsed (10 minutes of the usual session in the CG or the performance of the AB in the EG), the post-test was recorded with a similar duration of 4'30" of neurophysiological signal (see Figure 3).

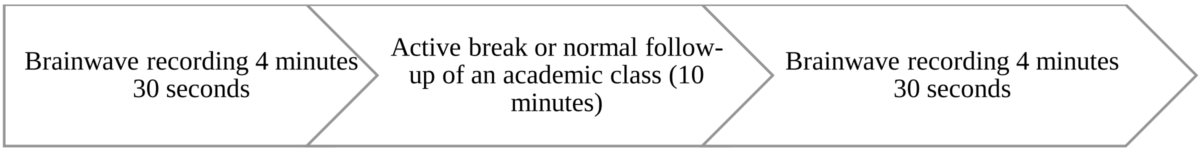
Figure 3

General protocol for EEG data collection

For the proper performance of the EEG data collection, the children were placed in the front of their classrooms, sitting on chairs with arms to support them during the recording and to be in a comfortable position. The instructions to the children were to follow the session in a normal way and to be as static as possible during the recording (no body movements, turning of the neck, etc.) The process was carried out with their eyes open, with the intention that the students would follow the session under normal conditions (see Figure 4).

Figure 4

Recording protocol used for EEG data collection



Data Analysis

First, the sample was characterised by means of descriptive statistics of frequency and percentage. For the normality test, the Shapiro-Wilk statistic was used, as it was the most powerful test for detecting non-normality for samples of fewer than 50 participants (Afifah et al., 2022), which revealed a non-normal distribution for some of the data (pre and post Alpha and pre Beta frecuencies, Table 1). In this case, non-parametric tests were used to compare the CG and the EG before and after the test in the Alpha, Beta, Theta and Delta frequency bands as well as the location of each of the sensors individually. The Wilcoxon signed range test was used to compare the pre- and post-test variables. The Mann-Whitney test was used to compare the variables between the CG and EG. These comparisons were made in the pre- and post-test. The effect size was calculated to quantify the magnitude of the difference between two means in postest and for each separate group between the pretest and postest. Cohen (1988) suggested that d = .02 represents a "small" effect size, d = .05 a "medium" effect size and d = .08 a "large" effect size. Eventually, statistical power was calculated using a post hoc analysis, Wilcoxon signed-rank test (matched pairs) and Wilcoxon-Mann-Whitney test (two groups), and a sensible default power level of .80 was considered following Ellis (2010).

Table 1

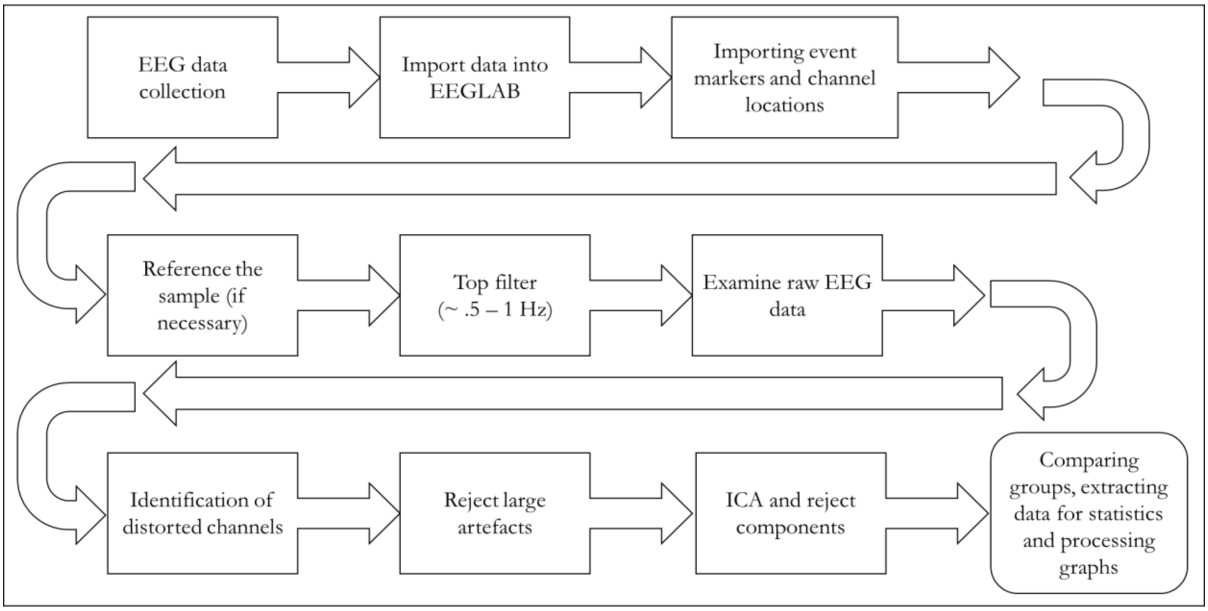
Shapiro-Wilk normality test for samples of fewer than 50 participants

	Pre-test		Post-test	
Fz	***W***	***p***	***W***	***p***
Alpha	.902	.024	.855	.003
Beta	.908	.047	.953	.314
Delta	.980	.893	.965	.554
Theta	.974	.775	.967	.587

All analyses were executed with the IBM SPSS v. 25.0 statistical package for Windows (IBM corp., Armonk, NY, USA) and G*Power v3.1 (Düsseldoft, Germany) (Erdfelder et al., 1996). The free EEGLAB application for MATLAB v14.1.2 (San Diego, CA, USA) (Delorme & Makeig, 2004) was used for the analysis of data from the neurobiological test (EEG). Following the recommendations of the creators of this software, the process of pre-processing the data proposed by them was used, as well as the statistical analysis of the comparison of the EG and CG to obtain the graphs (they will be explained in the section on results) (see Figure 5).

Figure 5

EGG data processing protocol



Note. EEG: electroencephalogram; ICA: Independent Component Analysis of EEG data.

Once the data had been collected from each participant, they were imported into the EEGLAB software using an .edf file. Once the files were uploaded, the EEG channels used were scaled according to the international 10-20 system (Emotiv Epoc+). In the next step, a filtering at 0.5 Hz was applied. Afterwards, the artefacts that could occur during the recording of the data were examined and the bad channels were automatically eliminated by selecting the frequency threshold option at 15 dB. The next step was the application of the run ICA command to remove artefacts produced by blinking, eye movements, muscle movements, etc., during data acquisition without removing the affected part of the data (Delorme, 2023; Gafoor & Uppunda, 2023).

With the processed data, the study was created with all participants, both EG and CG, to extract the power spectrum figures for the frequency bands selected for this research, using the Bonferroni statistic with a p-value of .05.

Results

Pre-test Analysis

The comparation of the variables in the pre-test for the CG and EG through Mann-Whitney's U analysis did not show significant differences (p > .05) in the sum of the total data for each frequency band analysed (Table 1) nor for each of the sensor locations.

Post-test Analysis

For the comparation of the variables in the post-test between the CG and EG, the Mann–Whitney analysis was carried out again, which did not reveal significant differences in the band frequency, except for the sum of the Alpha frequencies (p = .01), which was in favour of the EG. It was also possible to observe higher values for the EG in the Beta frequency (p = .07), although, in this case, without reaching 5% of significance level (Table 2). Regarding the effect size, we show a medium effect size in Delta and Theta frequencies and a large effect size in Alpha and Beta one. Alpha frequency reaches the expected statistical power (β = .10), while Beta (β = .39), Delta and Theta (β = .65) one remain below what is conventionally accepted (Ellis, 2010).

Table 2

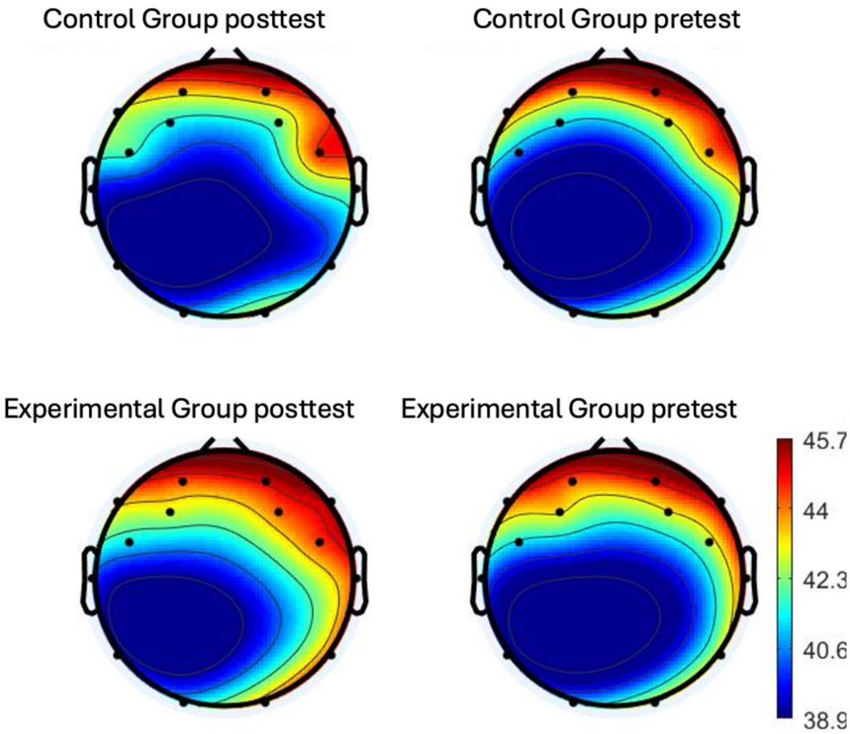
Means and standard deviations of pre- and post-test according to the group results (statistical and p-value) of the test of the Wilcoxon signed ranges for the pre- and post-test comparison and the Mann-Whitney test for comparison between

		Pre-test				Post-test					Pre–post differences		
Fz		Mean	Standard deviation	Mann–Whitney *U*	*p*	Mean	Standard deviation	Mann-Whitney *U*	*p*	Cohen's d	Wilcoxon Z	*p*	Cohen's d
Alpha	Control	2106.05	673.10	59.00	.45	1913.33	513.03	30.00	.02*	-1.26	-1.10	.27	.32
	Experimental	2063.29	1014.88			3084.01	1212.54				-3.06	.00**	-.56
Beta	Control	3296.52	1176.63	70.00	.91	2824.12	848.87	41.00	.07	-.83	-1.26	.21	-.70
	Experimental	3240.00	971.39			3678.34	1173.67				-1.41	.16	-.41
Delta	Control	2253.00	888.47	72.00	1.00	2290.28	1355.56	51.00	.23	-.54	-.63	.53	-.03
	Experimental	2207.50	653.27			2996.73	1275.73				-1.80	.07	-.78
Theta	Control	4444.65	1547.28	69.00	.86	4090.11	1628.58	49.00	.18	-.54	-1.26	.21	.22
	Experimental	4315.14	941.4			4952.11	1555.21				-1.57	.18	-.50

Regarding the differentiated analysis of each location of the sensors in the post-test, significant differences between CG and EG were obtained in Alpha AF3, Alpha AF4, Alpha F3, Alpha F4, Alpha F7, Alpha F8, Alpha P8, Alpha T8, Alpha O2, Beta AF3, Beta AF4, Beta F3, Beta F4, Beta F8, Beta T8, and Theta F4 in favor of the EG (Figure 6, 7, 8 and 9).

Figure 6

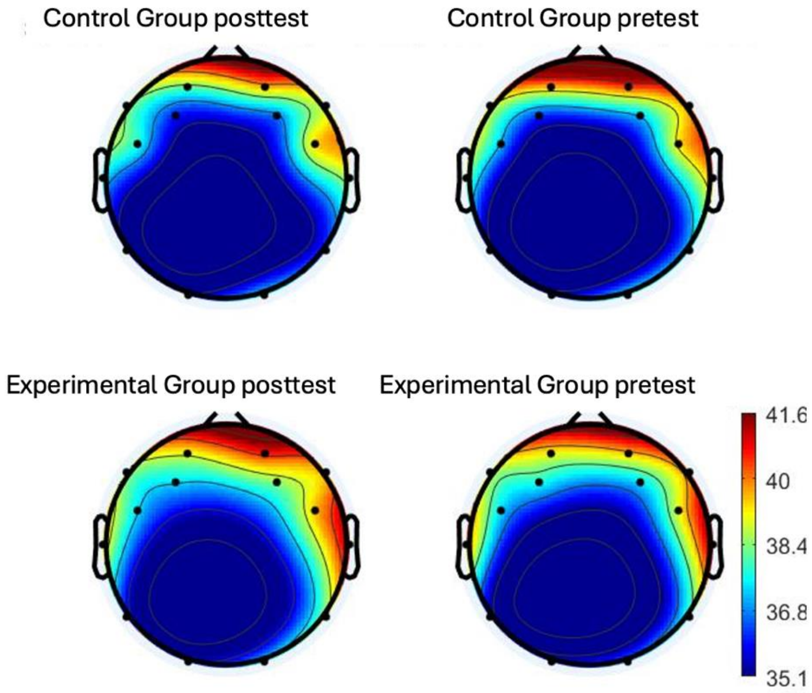
Alpha frequency (8.0-12.0 Hz)



Note. Top part CG, bottom part EG; right figure pretest data, left figure posttest data.

Figure 7

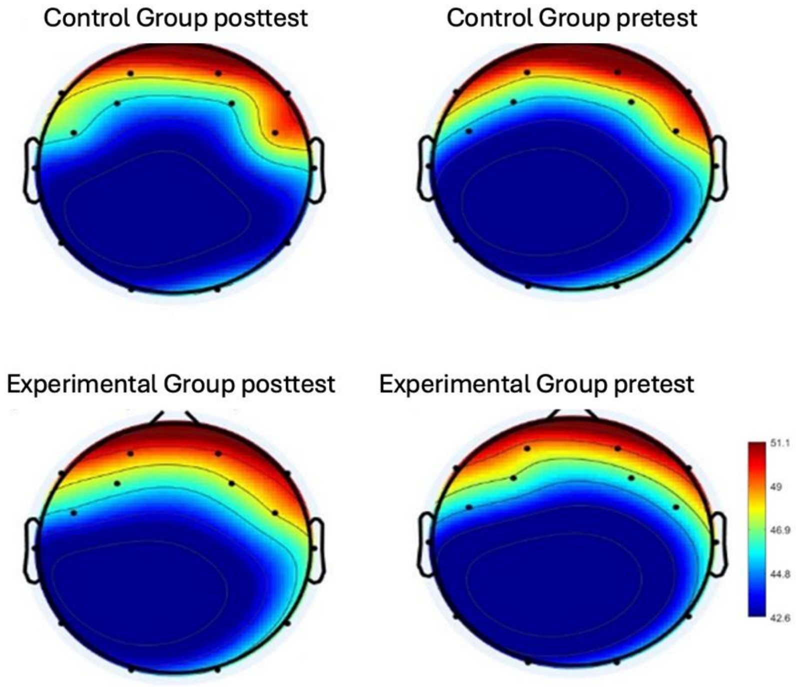
Beta frequency (12.5-30 Hz)



Note. Top part CG, bottom part EG; right figure pretest data, left figure posttest data.

Figure 8

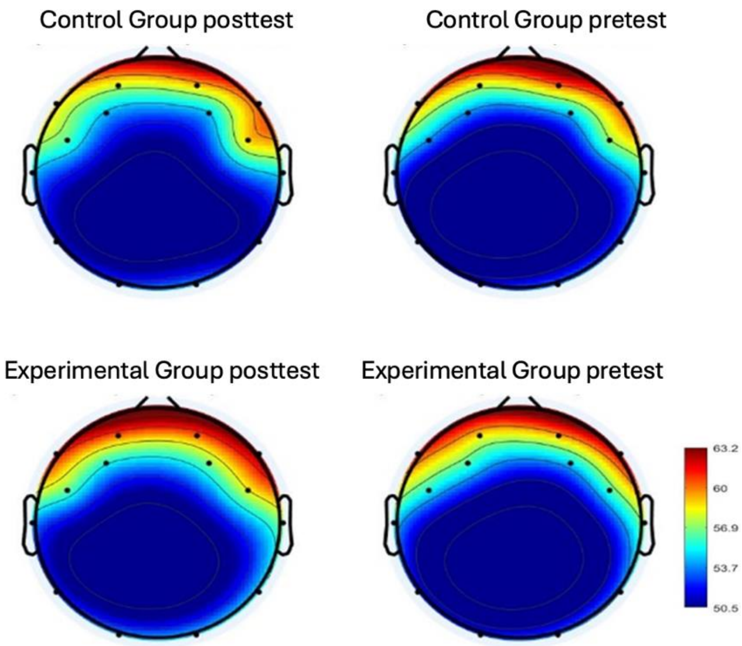
Theta frequency (4.0-7.5 Hz)



Note. Top part CG, bottom part EG; right figure pretest data, left figure posttest data.

Figure 9

Delta frequency (1.0-3.5 Hz)



Note. Top part CG, bottom part EG; right figure pretest data, left figure posttest data.

Effects over Time

For the differences over time (inter-group), significant values were obtained only for the EG in the sum of Alpha band frequencies (p = .002) (Table 2). According to the effect size we observe in CG small effect size in all variables except Beta frequency. In the EG we show small effect size in Beta and Theta frequencies and medium in Alpha and Delta. Finally, the statistical power for the frequencies both groups are below what is conventionally accepted and show a high risk of incurring a type II error.

Discussion

The present study aimed to analyse and compare the effects of the acute application of AB with academic curricular content on different types of brain frequencies (Alpha, Beta, Delta, or Theta) and their locations in the cerebral cortex as indicators of cognitive functioning in 5th- and 6th-grade students of primary education. In general, of the four frequencies identified previously and reviewed in the present work, the results showed statistically significant differences in favour of the EG only in the Alpha frequency (both intra- and inter-group). However, statistical significance was not obtained in the Beta, Delta, and Theta frequencies. Therefore, the proposed hypothesis was partially confirmed.

The results obtained are in line with those obtained by several studies have addressed the implementation of programmes based on AB in the classroom and their effects on variables such as attention, concentration and academic performance (Carlson et al., 2017; Howie et al., 2015) and increase PA levels and provide academic benefits (Norris et al., 2020). Similarly, the results would provide empirical evidence of the benefit of PA on cognitive performance, an aspect that was not found in the studies conducted by Donnelly et al. (2016) and Masini et al. (2020). Therefore, the implementation carried out shows that the acute intervention based on PA could produce changes in the type of brain waves emitted so that the waves registered after said intervention favour the cognitive performance of the evaluated students.

Regarding the Alpha frequency, individualising by locations, there was greater activation in the frontal and prefrontal brain regions of both hemispheres, right temporal areas, right parietals, and right occipitals (as shown in Figure 3). These results are consistent with those obtained in other studies, such as the study carried out by Kubitz and Pothakos (1997) in participants who, after performing a 15-minute aerobic training, showed a significant increase in Alpha waves in frontal areas of the brain. In keeping with this logic and concerning the greater activation of right temporal regions, this may be an indicator of mobilisation of visual and motor resources (Hatfield & Kerick, 2007). Furthermore, the Alpha increase in occipital regions of the brain suggests that rapid cognitive control occurs, inhibiting attentional processes towards visual information that interrupts other main goal-oriented actions that, at that time, are considered relevant (Janssens et al., 2018). Likewise, other studies indicate that the correlation between the Alpha frequency and the occipital areas may indicate an improvement in peripheral vision (Nan et al., 2014). This relates to the AB proposal of the present study, where PA and academic content presented on the digital board through images were integrated. Therefore, this evidence would justify the findings of this test, where participants are subjected to physical efforts with visual content to which students must pay attention, inhibiting other kinds of inconsequential stimuli.

Moreover, the reported results may indicate an increase in working memory processes, since they are related to the findings of Sato et al. (2018), who analysed this executive ability in children through a visual memorisation task, finding Alpha frequency increases in frontotemporal regions, which suggests an activation of working memory to maintain visual stimuli. Previous research shows that Alpha brain waves have been linked to attentional demands, alertness, and expectation (Klimesch et al., 1998). In their study in adolescents, Hogan et al. (2013) highlight that, after vigorous acute exercise, cognitive processes can be improved by increasing the efficiency of the attentional system demonstrated by higher levels of Alpha frequency. Current studies in the field of cognitive neuroscience, such as that of López-Vicente et al. (2021), whose main objective is to analyse cognitive and behavioural developmental changes in dynamic functional connectivity through magnetic resonance imaging in children and adolescents, show a general increase in the temporal variability of connections between intrinsic connectivity networks with increasing age (age-associated intrinsic neuronal maturation).

Related to the increase in Alpha on AB and, therefore, in its positive relationship with school learning. Murat et al. (2015) carried out an intervention based on training called the Motion Technology System. Their results show that this type of PA improves the Alpha brain state, associated with concentration and improvement in the learning processes demonstrated in the test results. This evidence is related to a better predisposition of the participants to an increase in attentional processes and semantic memory (search, access, and retrieval of information in long-term memory stores) associated with the increase in Alpha power (Klimesch, 1997). Regarding the Beta frequency, as well as the rest of the frequencies analysed, the results did not show significant inter-group or intra-group differences. This fact is shown in contrast to other studies that show the benefit of increasing the Beta frequency on attentional processes and concentration states (Park et al., 2016). There is strong research evidence of a strong connection between motor and psychomotor experimentation in the classroom with positive consequences for learning such as: gross motor and fine motor skills (Biino et al., 2021), increased attention levels in a particular activity (Ma et al., 2014), improved working memory and the consolidation of a varied vocabulary (Macedonia & Mueller, 2016).

Finally, it is necessary to specify that exercise causes oscillatory brain activity (Ciria et al., 2018), proved in this research by the changes in the increases or decreases of the different frequencies analysed. Therefore, there is a complex pattern of brain activity during physical exercise while attending to other relevant aspects (Ciria et al., 2019), such as the stimuli that were presented to the participants related to academic content.

Several limitations are recognised in the present study. Firstly, despite the randomisation carried out in both the group condition and the students within the groups themselves, the number of participants evaluated ($N = 24$) is considered limited, not providing adequate statistical robustness for the application of multivariate statistical analyses (Seljebotn et al., 2019). Secondly, the results refer to 5th- and 6th-grade primary school students, requiring more studies for greater generalisability of the findings to students throughout the educational stage. The activities performed and the teacher that taught them in each grade were different, and this could be a source of differences that could be affecting the current date, so the grade should be taking into account in the statistical analysis in future projects. Thirdly, a commercial EEG was used (although endorsed for research) and a procedure for taking samples in a variable environment, where polluting variables may exist (different teachers, ways of leading the class, distribution of students, etc.). Fourthly, the impact of cognitively validated tasks could have been recorded and controlled during the performance of the AB, providing more information to assess a cognitive gain in the EG, considering this gain as a variable dependent on the application of the AB. Finally, the ecological reality of the study, carried out in natural and usual teaching conditions, did not allow the EEG to be applied to all participants, an aspect that we tried to control with a pure randomisation process. This fact also limited the possibility of making comparisons by gender or educational level.

Conversely, we interpret strength to control for all of the above conditions by pure randomisation of participants. To ensure greater reliability in measurements of brain oscillations associated with cognitive processes, attention must be paid to the fact that some aspects of intelligence can only be explained by time-varying functional connectivity. The finding that time-varying functional connectivity has a unique relationship to population behavioural variability suggests that it may reflect transient neural communication that fluctuates around a stable neural network (Vidaurre et al., 2021).

Finally, and for future research, it is thus advisable to use a larger sample size, an age range with students belonging to various educational levels, and EEG with more spatial resolution, a greater number of sensors, and/or channels that allow to deepen the study of the frequencies identified in the present work. In addition, inter-subject quasi-experimental studies could be carried out to test the behavioural consequences of the application of training and pedagogical intervention programmes on young students for their overall health.

Conclusions

In line with the results obtained and the scientific evidence provided, the acute application of ABs with academic curricular content produced an increase in Alpha brain frequencies as well as the temporal lobe cortex associated with greater cognitive efficiency in the participants. It seems that AB could become an ideal practice to apply in classroom because they do not interfere in stressful processes that can cause distortions in learning. Similarly, a continuous programme in AB could lead to cognitive effects and transfer to other situations and contexts, benefiting the adjustment of children to daily life. Finally, including cognitively validated tasks together with the application of AB could help in the interpretation of cognitive change associated with brain pattern modifications.

Practical Applications

It is essential to design an adequate design of AB that consists of the implementation of AB of 5 to 10 minutes, guided by teachers during the normal course of the class and that can be implemented in any school context, as it does not require a space, material or specialized personnel. This would allow further evidence of the behavioural consequences of PA integrated into the teaching-learning process, using cognitive neuroscience tools such as the EG, among other means of functional magnetic resonance imaging. These practices could lead to an improvement in the development of executive, emotional and social skills in students (Carlson et al., 2017).

Contribution of each Author: Conceptualization, J.A.M.P., N.B.P. and A.V.V.; methodology, J.A.M.P., J.A.M.B. and A.V.V.; validation, N.B.P. and A.V.V.; J.A.M.P., J.A.M.B. and A.V.V.; manuscript writing, J.A.M.P., N.B.P. and A.V.V.; writing, revision and editing, J.A.M.P., N.B.P., J.A.M.B. and A.V.V.; supervision, A.V.V. and N.B.P.

Funding: This research did not receive any external funding.

Conflict of Interest: The authors declare that they have no conflict of interest.

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