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Comparison of children's inhibitory control, attention and working memory in three different throwing games: EEG exploratory study
Comparación del control inhibitorio, la atención y la memoria de trabajo de los niños en tres juegos de lanzamiento diferentes: Estudio exploratorio de EEG

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Abstract: in this study we explore inhibitory control, attention and working memory differences, through EEG biomarkers, in three types of throwing games (simple throwing, throwing at a goal, and simultaneous throwing with another player). Encephalographic recordings were collected from 8 children aged 7-8 years during the performance of three throwing games. Theta (4-7Hz), alpha (7-13Hz) and low beta (13-20Hz) frequency spectra of different biomarkers associated with inhibitory control, attention and working memory were compared. Results of this exploratory study show that small modifications in playing conditions lead to significant demands on inhibitory control, attention and working memory. Action against an opponent attempting to disrupt the throw would require greater inhibitory control, as well as better focus of attention and greater use of working memory. On the other hand, simultaneous action against an opponent who has the same target might involve greater arousal and approach towards the target. The results show significant differences between the different games, with greater demands of inhibitory control in the games of throwing to goal (opposition with different roles) over the games without opposition or with opposition but with the same role (simultaneous throwing). These results show a new area of study and indicate the interest of analysing the characteristics of each game.
Keywords: Executive Functions, Children Physical Game, Electroencephalography.

Resumen: en este estudio exploramos las diferencias en el control inhibitorio, la atención y la memoria de trabajo, a través de biomarcadores EEG, en tres tipos de juegos de lanzamiento (lanzamiento simple, lanzamiento a portería y lanzamiento simultáneo con otro jugador). Se recogieron registros encefalográficos de 8 niños de 7-8 años durante la realización de tres juegos de lanzamiento. Se compararon los espectros de frecuencia theta (4-7Hz), alfa (7-13Hz) y low beta (13-20Hz) de diferentes biomarcadores asociados al control inhibitorio, la atención y la memoria de trabajo. Los resultados de este estudio exploratorio muestran que pequeñas modificaciones en las condiciones de juego conducen a demandas significativas en el control inhibitorio, la atención y la memoria de trabajo. La acción contra un oponente que intenta interrumpir el lanzamiento requeriría un mayor control inhibitorio, así como una mejor concentración de la atención y un mayor uso de la memoria de trabajo. Por otro lado, la acción simultánea contra un oponente que tiene el mismo objetivo podría implicar una mayor excitación y acercamiento hacia el objetivo. Los resultados muestran diferencias significativas entre los distintos juegos, con mayores demandas de control inhibitorio en los juegos de lanzamiento a portería (oposición con distintos roles) sobre los juegos sin oposición o con oposición pero con el mismo rol (lanzamiento simultáneo). Estos resultados muestran un nuevo campo de estudio e indican el interés de analizar las características de cada juego.
Palabras clave: Funciones ejecutivas, juego físico infantil, electroencefalografía.

Introduction

Throwing is a fundamental movement skill that demands different neuromotor competences (Wickstrom, 1990). There are many traditional games that involve this skill. Each throwing game structure will request different cognitive, emotional or motor requirements (Lagardera and Lavega, 2004; Parlebas, 1988). These implications have been well studied through different observational and psychometric methods (e.g. Lavega et al. 2014; Pic et al, 2018; Pic et al., 2019), however, the conditions of the action itself have, until recently, hindered investigating the brain processes involved in these games (Park et al., 2015, Wang et al., 2019). Moreover, although studies on brain activity during throwing activities are beginning to be conducted outside the laboratory, these studies are focused on sports and adults (e.g. Baumeister et al., 2008; Christie et al., 2017; Chuang et al., 2013; Deeny et al.; 2003; Gallicchio et al., 2017; Janelle et al., 2008) with little work focusing on children's games (e.g. García-Monge et al., 2020). Similarly, executive

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functions have been studied during the performance of different sport activities with adult populations (e.g. Cheron et al., 2016; Reinecke et al., 2011), but not in the case of children's games. With this study we aim to examine differences in brain activity between three throwing games, more specifically between electroencephalographic (EEG) biomarkers associated with the demands of, inhibitory control, attention and working memory.

Since Luria (1973) put forward his theory of the III Functional Units pointing out the role of the third unit (which he placed in the prefrontal cortex) in the processes of programming, regulation, and verification of conscious mental and behavioural activity (which Lezak, 1982, would call executive functions), there have been many theories and organisations given to executive functions (EF) (for a historical review see Ardila and Ostrosky-Solís, 2008)). Processes such as planning, mental flexibility, attention shifting, working memory, response inhibition, monitoring, attention, emotional control, impulse control, or social adjustment of behavior have been considered as processes of regulation and «supervision» necessary in the functioning of cognitive processes that Goldberg (2001) summarizes in his metaphor of «conducting an orchestra». Authors such as Diamond (2013) or Lehto et al. (2003) point to inhibition (self-control-resisting temptations and resisting acting impulsively) and interference control (selective attention and cognitive inhibition); working memory; and cognitive flexibility as the core of EFs. Welsh, Friedman and Spieker (2006, 180) would give the following «working definition»:

Executive function involves the process of integrating and combining separate, but collaborative, cognitive abilities in service of a future goal. [...] *This construct includes several core cognitive processes, including, but not limited to: attention, working memory, inhibition, and self-monitoring.*

EF are fundamental in school (Blair and Razza, 2007; Borella et al., 2010; Morrison et al. 2010), work (Bailey, 2007) or social development (Denson et al. 2011; Moffitt et al., 2011). Many programs have therefore sought to develop different EFs (For review see Diamond, 2012 or Shaheen, 2014). Some of these programs have been based on situations of games and sports (Alesi et al. 2014; Alesi et al. 2016; Alesi et al. 2020; Bryant et al. 2020; Davis et al., 2011; Ishihara et al., 2017; Wang et al., 2020). Games provide varied scenarios close to children's interests in which different EFs are demanded (Healey and Halperin, 2015; Jiao et al., 2020; Rosas et al.; 2019; Savina, 2014; Shaheen, 2014; Veraksa et al. 2020). Play as a mediator that enables cognitive development was well studied by Vygotsky (2016) or disciples such as Elkonin (1985). In general, games establish frameworks of freely assumed obligations and allow for experimentation in a friendly environment (Bruner, Jolly and Sylva, 2017). Games demand different cognitive abilities and requires the inhibition of the children's desire to 'push' their agendas, and, as a result, promotes self-regulation skills (Savina, 2014, 1695); and by requiring observance of the rules, it provides the necessary conditions for the development of executive functions (Veraksa et al., 2020). In play children learn to plan, self-monitor and evaluate their own actions (Veraksa et al., 2020). The different challenges of each game require to a greater or lesser extent the control of impulsivity, attention to the actions of opponents and to the changing conditions of the interaction, the planning of one's own action, the response to new situations that appear in the course of the game, or the adjustment of the response to the demands of the moment.

Given that executive functions are conditioned by the contexts in which the action takes place (Fishbein et al., 2019), it is to be assumed that small changes in the conditions of the activity to be developed will also entail modifications in the demands of the different executive functions. Each game is a special microsystem, and small modifications in its structure will lead to different cognitive, emotional or motor processes (Lavega et al. 2014; Pic et al., 2018; Pic et al., 2019). As noted, the aim of this study is to examine differences in brain activity between three pitching games, more specifically between electroencephalographic (EEG) biomarkers associated with inhibitory control, attention and working memory demands. From among the EFs, these have been chosen given the central role that some authors assign to them (Welsh et al. 2006) and the possibility of accessing some electroencephalographic biomarkers that identify them. Although the EFs are not confined to discrete regions of the cerebral cortex, different biomarkers have been identified that make it possible to identify their greater or lesser demand.

Inhibitory control is a complex function (Diamond, 2013) that has been associated with different brain regions, including subthalamic nucleus (Mosher et al., 2021) or the right inferior frontal cortex (Aron et al. 2004; Aron, Robbins and Poldrack, 2014)). As Diamond (2013) points out, inhibitory control involves being able to control one's attention, behavior, thoughts, and/or emotions to override a strong internal predisposition or external lure, and instead do what's more appropriate or needed. Several EEG signatures have been stablished as neural markers of the response inhibition process. Wagner et al., 2018 or Jha et al. 2015 associate this process with modulations in the right frontal beta rhythms (13-20Hz). Beltran et al. (2019) and Huster et al. (2013) describe the increment in power in fronto-central theta band (4–7 Hz) rhythms as EEG signature of inhibitory control. Increased alpha amplitude (7-13Hz) at motor cortex has been linked to voluntary motor inhibition (Hummel et al., 2002; Sauseng et al., 2013). In general, as Wöstmann et al. (2019, 9798) point out: *because lower alpha power correlates with increased neural responses to the target and enhanced behavioral measures of target detection, low alpha power is considered a signature of enhanced neural excitability to support target selection. At the same time, alpha power does increase in brain regions that process distracting stimuli. Although high alpha power is considered a brain state of inhibited neural processing.*

Furthermore, the frontal alpha asymmetry (FAA), is considered as neural index of the approach or withdrawal motivational system and behavioral inhibition/activation system (for revision see Harmon-Jones and Gable, 2018) greater relative left frontal activity is associated with approach-related tendencies, and greater relative right activity is associated with withdrawal-related and behavioral inhibition tendencies.

Attention is linked to inhibitory control (Klimesh, 2012) and to working memory (Diamond, 2013) with which it shares neural basis (e.g. Gazzaley and Nobre, 2012; Mayer et al., 2007). Some authors propose as an indicator of attention the power alpha and beta bands in left prefrontal cortex (Rodriguez et al. 2013 , Molina-Cantero, 2017).The work of Gola et al., 2013) highlights the relationship of occipital beta waves in attention. Worden et al., 2000 focus their work on the increase of occipital alpha waves as indicators of visuospatial attention. Gordon et al. (2018) or Shestyuk et al. (2019) used fronto-central alpha decreases and concomitant theta increases as attention markers. Benedek et al. (2014) identified alpha power increases in right parietal cortex during focused internal attention process. Klimesch (2012) notes that alpha waves reflect inhibition of task-irrelevant networks and synchronisation within task-relevant networks, supporting the processes to which attention is directed and inhibiting all other processes.

Working memory requires sustained attention (Sauseng et al., 2010) and supports inhibitory control (Diamond, 2013). Different brain regions are involved in the working memory process. O'Reilly and Frank (2006) proposed that subcortical structures in the midbrain, basal ganglia, and amygdala are a gate that allows working memory representations in prefrontal cortex. Some works (e.g. Dieber et al., 2007; Griesmayr et al., 2010; Julie et al. (2005) showed that the frontal midline theta power increased as the memory load increased. Likewise, the work of Itthipuripat et al. (2013) exposed that theta power is increased over frontal cortex during working memory tasks. This frontal theta signal of the working memory can decrease under stress conditions (Gärtner et al., 2014). The work of Jensen and Tesche (2002) shows increases in frontal 7-8.5Hz oscillations with memory load in a working memory task. Spitzer and Haegens, 2017 associate beta frequencies with various cognitive functions, such as working memory and decision making. Sauseng et al. (2010) or Reinecke et al. (2011) identified in their studies a fronto-parietal network for the working memory, analyzing theta frequency band for frontal electrode positions and alpha-2 frequency band for parietal electrode positions. Works like Gordon et al. (2018) o Vecchiato et al. (2011) measured working memory in EEG using theta wave activity in the brain by frontal electrodes 3.5-7.5 Hz.

In this study, some of these biomarkers will be used to compare inhibitory control, attention and working memory differences, in three types of throwing games.

Material and Methods

Participants

A total of eight children volunteers (four males and four females, mean age 7.20 years ± 0.19) participated in the experiment. All the participants were right-handed and healthy. All participants and their families gave written informed consent. The study was performed in accordance with the Declaration of Helsinki and was approved by Ethic Committee of Valladolid University. The experiment was accompanied by an educational activity for participants on the functioning of the brain and the recording of brain signals. The participants and their families have been receiving reports on the results obtained from the different analyses of the data.

Procedure

The room that was set up for the sessions was isolated in order to avoid any kind of distraction or noise. Participants sat in a comfortable chair with their arms resting on the launch table.

Three throwing games were proposed to the participants:

• First condition: «Throwing.» Participant had to throw tennis balls at 10 wooden pieces from 2.5m. In preliminary tests we had seen that it was an easy challenge for children of this age.

• Second condition: «Goal.» Participant had to throw, from a distance of 2.5m, tennis balls to a goal (of 80cm) defended by a dummy handled by a friend of the participant. This challenge increased the complexity of the throw as the target became changeable and a relational variable was introduced into the game.

• Third condition: «Simultaneous.» This consisted of a throw to 10 wooden blocks located 2.5 m away, simultaneously to another opponent who threw to the same targets. This challenge introduces a time factor (knocking down the blocks before the opponent) and therefore could increase the arousal.

A. "throwing" condition B. "goal" condition C. "simultaneous" condition

Figure 1. Simulation of three experimental conditions ("Throwing," "Goal," and "Simultaneous").

«Throwing» was proposed as the first activity to serve as a throwing test. The «simultaneous» throwing challenge was left for the end since it was assumed that it would generate the highest excitement and it was intended that this possible state would not influence a later challenge. The experiments were carried out between 5 and 6 pm. In each game they were able to perform 15 throws. We did not leave more attempts to avoid disinterest in the task and because in experiments with children it is recommended to use an electrode application time under 30 minutes (Brooker et al., 2020).

After a brief explanation of the procedure and instructions to minimize movement and speech during the recording, the EEG recording system was put in place. An Emotiv EPOC headset with 16 electrodes, 14 EEG recording channels (AF3, AF4, F3, F4, F7, F8, FC5, FC6, P7, P8,T7,T8, O1, and O2) and 2 reference electrodes (P3 and P4), positioned according to the International System 10–20, was used. The electrodes of this system are contact and saline type. The Emotiv Control Panel software provides visual monitoring of the electrode impedance lower than 5 kÙ (kilo-ohmios) in order to obtain a good quality signal. The recorded EEG signal, with a sampling frequency of 128 Hz, is sent wirelessly to a Bluetooth receiver placed on the computer. The Emotiv EPOC has an artifact cancelation system on its reference electrodes and a filter for the frequencies 50 (notch filter) and 60 Hz. Emotiv-epoc has been widely used in studies on executive functions (e.g. Jirayucharoensak et al., 2019; Lulé et al., 2018; Mondéjar et al., 2015, Zhao, 2020).

Signal Pre-processing

For a first inspection of the data the Emotiv Brain Activity Map (v3.3.3) and Emotiv TestBench (v1.5.0.3) (Emotiv, San Francisco, USA) applications were used. The Emotiv Brain Activity Map shows brain power activity maps at different frequencies obtained through a spectral analysis (Fast FourierTransform—FFT) of each channel signal. The Emotiv TestBench displays the spectrum of the signals through a FFT (in decibels –dB-). In this first inspection, brain maps were compared with the spectrum and video images of each participant's actions in order to identify events.

Data pre-processing and analyses were carried out using EEGLAB toolbox (v.2019.1)(Swartz Center for Computational Neuroscience, La Jolla, USA) for Matlab (MathWorks, Natick, USA). Baseline of the EEG signal for each channel was removed. A spatial filtering of Common Average Reference (CAR) was applied. For frequential filtering, data were high-pass filtered at 0.5Hz to remove slow drifts. Artefacts were visually identified and rejected from the channels data.

Data were decomposed by Independent Component Analysis (ICA). Components that did not account for brain were visually identified and removed. For this purpose, ICALabel tool (an electroencephalographic independent component classifier) was used. This is a plugin that, among other things, shows us the probability that the component picks up brain activity or other artefacts (muscles, blinking, heart, etc.).

Analysis

The frequency domain analysis was performed using the Fast Fourier Transform (FFT) algorithm (with the resolution of 0.125 Hz) to calculate absolute ($\mu V^2/Hz$) power spectral density within theta (4–7 Hz), alpha (7–13 Hz), and low beta (13–20 Hz) bands (this is a power-based logarithmic transform based on the microvolt (μV) measurement and the time, calculated for each frequency band). Channels and component measurements were pre-compute. Power spectral density metrics for each channel and condition were calculated.

The analyses focused on some biomarkers associated with inhibitory control, attention and working memory. Inhibitory control was analysed using alpha and beta frequency values collected in the right inferior prefrontal area (channels F8 and FC6) following the work of Jha et al. (2015) and Wagner et al.(2018), as well as analysing frontal alpha asymmetry (FAA) for channels F3 and F4, using the plugin designed for EEGLab (Tesar, 2016): FAA = mean(log(log(POW_R)-log(POW_L)). Alpha values for F4 (pre-motor cortex, Koessler, 2009) also were analysed.

To compare attention, spectral power data were taken in the alpha and beta bands in the right frontal (AF3) and occipital (O2 and O3) areas (Molina-Cantero, 2017; Rodríguez et al., 2013; Gola et al., 2013; Worden et al., 2000). In addition, mean alpha values at different points are an indicator of attention (Foxe et al., 2011, Gould et al., 2011).

Working memory was compared using the parameters suggested by Sauseng et al. (2010), Reinecke et al. (2011) or Gordon et al. (2018), analysing theta frequency band for frontal electrode positions (F3 and F4) and in AF3, AF4, FC5 and FC6 looking for possible effects of stress on working memory (Gärtner et al., 2014).

EEGLAB allows users to use either parametric or non-parametric statistics to compute and estimate the reliability of these differences across conditions («throwing,» «goal,» and «simultaneous»). The toolbox also allows the obtaining of different spectrum parameters such as the maximum and minimum, mean, medium, mode, standard deviation, and range. EEGLAB allows performing analysis of variance on power spectra. For mean power spectra, the p-values are computed at every frequency. In this case an analysis of variance (ANOVA) test was developed in order to detect statistical differences between the three conditions for the different neuro-markers using permutation statistics. The specific time-frequency point was considered significant at p d» 0.001. EEGLab designers recommend that while parametric statistics might be adequate for exploring data, it is better to use permutation-based statistics to plot final results.

Paired analyses of variance between the three games for the different neuro-markers were also performed.

Moreover, paired analyses of two-tailed Wilcoxon signed-rank test was used to analyze the statistical differences between the values obtained for the frontal alpha asymmetries. The significance level for the Wilcoxon rank test was set at 0.05.

Results

Some markers for inhibitory control point to significant differences between the three game situations.

Power spectral density values of low beta frequency band (13-20Hz, figure 2, B and D) for F8 location are significantly higher ($p < .001$) for the «goal» condition (M=44.51; sd=0.69) versus «throwing» condition (M=42.19; sd=0.97), but not so ($p=.0271$) versus «simultaneous» condition (M=44.01; sd=0.84). However, differences are significant ($p < .001$) between the three conditions in power spectral density values for FC6 area, with highest values for the «goal» condition (M=43.64; sd=0.7), followed by «simultaneous» (M=42.66; sd=0.82) and «throwing» (M=41.74; sd=0.97) (table 1).

Table 1. Mean, SD and range in different power spectrum different frequency bands (delta, theta, alpha and low beta) for diverse electrode sites for "throwing", "goal" and "simultaneous" conditions.

	delta Mean	delta std	delta range	theta Mean	theta std	theta range	alpha Mean	alpha std	alpha range	low beta Mean	low beta std	low beta range
ThrowF8	55.53	1.37	2.5	50.62	1.62	3.48	47.11	2.57	5.96	42.19	0.97	3.1
GoalF8	59.63	1.12	2.13	52.54	1.87	4.27	48.44	2.01	4.93	44.51	0.69	2.06
SimultF8	58.71	1.46	2.53	52.25	1.94	4.39	48.52	2.18	5.17	44.01	0.84	2.69
ThrowFC6	52.74	1.15	2.28	49.2	1.3	2.84	46.53	2.47	6.19	41.74	0.97	2.77
GoalFC6	56.42	0.47	0.91	50.74	1.63	3.65	47.41	1.79	4.44	43.64	0.7	2.11
SimultFC6	55.62	0.89	1.79	49.95	1.69	3.74	47.02	2.09	5.14	42.66	0.82	2.77
ThrowF4	52.33	0.73	1.36	49.48	1.15	2.61	46.59	2.42	6.04	42.02	0.98	2.49
GoalF4	55.45	0.63	1.18	50.21	1.43	3.21	46.77	1.86	4.57	42.92	0.66	1.97
SimultF4	54.91	0.83	1.66	49.66	1.58	3.52	46.46	2.15	5.34	41.79	0.95	2.83
ThrowF3	51.68	0.7	1.22	48.37	1.33	2.95	44.95	2.47	6.03	39.89	1.19	3.26
GoalF3	55.02	0.69	1.33	49.75	1.42	3.18	45.83	1.83	4.69	42.25	0.82	2.15
SimultF3	54.24	0.91	1.68	49.72	1.38	3.06	45.96	2.1	5.33	41.45	1.02	2.9
ThrowFC5	50.36	1.17	2.15	47.13	1.01	2.16	44.28	2.22	5.22	39.62	1.02	2.88
GoalFC5	54.38	1.25	2.36	48.33	1.67	3.79	44.97	1.5	3.53	42.09	0.47	1.36
SimultFC5	53.68	1.45	2.59	46.93	1.21	2.6	44.29	2.01	4.77	40.29	0.73	1.99
ThrowF7	55.34	2.15	4.15	49.41	1.23	2.71	45.71	2.59	6.25	40.68	1.04	2.96
GoalF7	59.55	1.76	3.07	53.36	1.73	3.85	49.2	2.03	5.08	45.29	0.69	1.99
SimultF7	58.6	2.15	4.12	52.25	1.55	3.43	48.39	2.27	5.5	43.94	1.08	2.92
ThrowAF3	52.46	0.47	0.91	49.6	0.89	1.98	46.14	2.63	6.56	41.11	1.18	3.16
GoalAF3	55.56	0.79	1.44	50.4	1.31	2.97	46.84	2.02	4.77	43.21	0.76	1.93
SimultAF3	55.01	0.73	1.39	49.42	1.35	2.94	45.96	2.39	5.53	41.59	0.92	2.6

Table 2.
p-value of paired ANOVA test for different areas and frequency bands.

Paired ANOVA	Theta p-value	alpha p-value	low beta p-value
throw/goal F8	< 0.001	0.122	< 0.001
throw/goal FC6	< 0.001	0.0203	<0.001
throw/goal F4	<0.001	<0.001	0.066
throw/simult F8	<0.001	0.0561	< 0.001
throw/simult FC6	<0.001	0.0404	<0.001
throw/simult F4	0.6301	0.1045	0.0245
goal/simult F8	0.257	0.1185	0.0271
goal/simult FC6	0.0541	0.1067	<0.001
goal/simult F4	<0.001	<0.001	<0.001

In alpha frequency band (7-13Hz), related to functional inhibition mechanisms (Foxe, 2011 ;Haegens, 2014), no significant differences appear between the three game conditions (figure 2, A and C). «Goal» condition reaches mean values in power spectral density of 48.44dB in F8 and 47.41 in FC6; «simultaneous» 48.52 in F8 and 47.02 in FC6; and «throwing» 47.11 in F8 and 46.53 in FC6. However, analysing the low alpha band (7-9Hz) in FC6 there are significant differences ($p < .001$) between the «goal» condition (M=48.33; sd=1.04) and the other two conditions («throwing» M=47.98, sd=0.88; «simultaneous» M=47.77, sd=0.71).

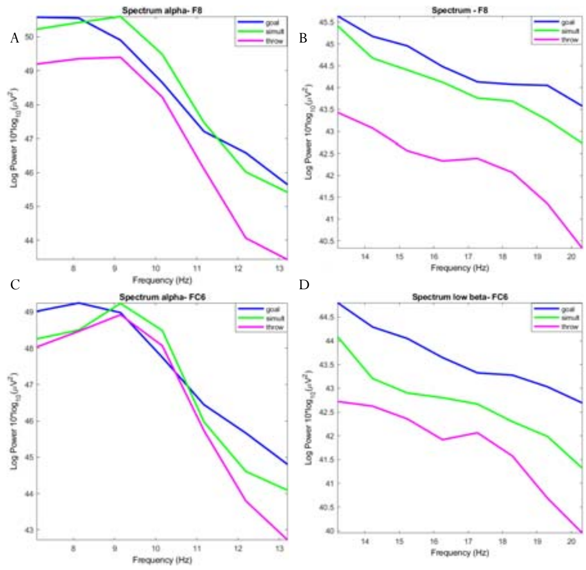

Figure 2. Alpha (7-13Hz) and low beta (13-20Hz) power spectrum for F8 and FC6 areas.

Signals collected in the right pre-motor cortex (figure 3, B) show significative differences (p< .001) in alpha power spectrum among «goal» condition (M=46.77, sd= 1.86, range=4.57), «simultaneous» (M=46.46, sd=2.15, range=5.34) and «throwing» (M=46.59, sd= 2.42, range=6.04), but they are not significative (p= .1045) between «simultaneous» and «throwing». In the left pre-motor cortex (figura 3, A) the significative differences (p< .001) are stablished between «throwing» (M= 44.95, sd=2.47, range= 6.03) and «simultaneous» (M= 45.96, sd= 2.1, range= 5.33).

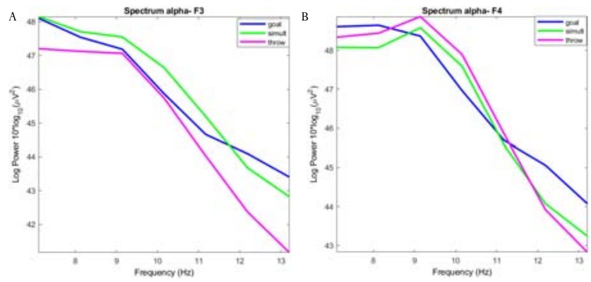

Figure 3. Alpha (7-13Hz) power spectrum for F3 and FC6 signals.

The frontal alpha asymmetry (FAA), considered as neural index of the approach or withdrawal motivational system and behavioral inhibition/activation system (Harmon-Jones and Gable, 2018), has higher average values (table 3) in «throwing» (M= 1.2914, sd=0.0785) condition, followed by «goal» (M=1.0634, sd=0.1372) and «simultaneous» (M=0.8105, sd=0.1021). The paired

Table 3
Mean FAA values for each participant and paired Wilcoxon rank test scores

FAA	Partic. 1	Partic. 2	Partic. 3	Partic. 4	Partic.5	Partic. 6	Partic. 7	Partic. 8	Mean	sd
Throw	1.2874	1.2796	1.1524	1.2994	1.3649	1.2122	1.3559	1.3798	1.2914	0.0785
Goal	1.117	0.9361	0.8361	1.156	0.9512	1.2282	1.1565	1.1321	1.0634	0.1372
Simult.	0.8326	0.9553	0.7471	0.6879	0.8246	0.7225	0.9578	0.7562	0.8105	0.1021

Paired Wilcoxon	W-value (critical value (p<.05): 3	Mean Difference	Z-value
Throw/Goal	1	0.36	-2.385
Throw/Simult	0	0.34	-2.5205
Goal/Simult.	1	0.13	-2.385

Wilcoxon rank test show significative differences among FAA (table 3).

Another feature to take into account is the alpha peak frequency (APF) in F4 alpha spectrum (maximal power value in the frequency spectrum) . «Goal» condition reaches its maximum value (49.25dB for APF) at 8.12Hz, while «simultaneous» (49.23dB for APF) and «throwing» (48.92 dB for APF) reach it at 9.14Hz.

Moreover, balance between excitation (E) and inhibition (I) can be estimated from the power law exponent (slope) of the power spectrum (Gao et al., 2017). The slope of the curve was calculated for the alpha frequency spectrum after its peak (*m* =Ä*y*/Ä*x* = *y*2 «*y*1/*x*2 «*x*1). As shown in figure 4, the steepest slope of the spectrum at the alpha frequency would be presented by the «throwing» condition (*m* =-1.532), followed by «simultaneous» (*m* =-1.379) and «goal» condition shows a lower slope (*m* =-1.057).

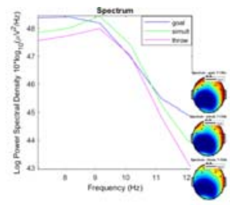

Figure 4. Spectrum plotting of the three conditions components ("throwing," "goal," "simultaneous"), with their plot averaged topography over frequency range, from 7 to 13 Hz (alpha).

Some markers for attention show significant differences between the three game situations. Power spectral density values of alpha frequency band (7-13Hz) in left frontal area (associated with attention, Molina-Cantero, 2017; Rodríguez et al., 2013) do not show significant differences between the three conditions (table 4, figure 5). However, when analysing the low alpha band (7-9Hz) significant differences (p< .001) appear between the three conditions with higher spectral power values for «goal» condition (M=48.33; std=1.04),

Table 4. Alpha (7-13Hz) and low beta (13-20Hz) frecuency band values in left frontal and occipital areas and p-values of paired ANOVA in alpha and low beta bands for in these areas.

	Mean	std	range	Paired ANOVA	p-value
Throw AF3 (7-13Hz)	46.14	2.63	6.56	Thrw/Goal AF3(7-13Hz)	0.024
Goal AF3 (7-13Hz)	46.84	2.02	4.77	Thrw/Simult. AF3 (7-13Hz)	0.103
Simult AF3 (7-13Hz)	45.96	2.39	5.53	Goal/Simult. AF3 (7-13Hz)	0.016
Throw AF3 (7-9Hz)	47.98	0.88	2.06	Thrw/Goal AF3(7-9Hz)	<0.001
Goal AF3 (7-9Hz)	48.33	1.04	2.25	Thrw/Simult. AF3 (7-9Hz)	<0.001
Simult AF3 (7-9Hz)	47.77	0.71	1.47	Goal/Simult. AF3 (7-9Hz)	<0.001
Throw AF3 (13-20Hz)	41.11	1.18	3.16	Thrw/Goal AF3 (13-20Hz)	<0.001
Goal AF3 (13-20Hz)	43.21	0.76	1.93	Thrw/Simult AF3 (13-20Hz)	0.064
Simult. AF3 (13-20Hz)	41.59	0.92	2.6	Goal/Simult AF3 (13-20Hz)	<0.001
Throw O2 (7-13Hz)	43.89	2.31	5.61	Thrw/Goal O2 (7-13Hz)	0.022
Goal O2 (7-13Hz)	44.94	1.63	4.02	Thrw/Simult. O2 (7-13Hz)	0.101
Simult. O2 (7-13Hz)	44.33	1.96	5.06	Goal/Simult. O2 (7-13Hz)	0.094
Throw O2 (13-20Hz)	39.81	0.7	2.17	Thrw/Goal O2 (13-20Hz)	<0.001
Goal O2 (13-20Hz)	42.29	0.22	0.72	Thrw/Simult O2 (13-20Hz)	0.018
Simult. O2 (13-20Hz)	40.99	0.31	1.08	Goal/Simult O2 (13-20Hz)	0.023
Throw. O1 (7-13Hz)	46.31	2.72	7.14	Thrw/Goal O1 (7-13Hz)	<0.001
Goal O1 (7-13Hz)	45.94	2.04	5.4	Thrw/Simult. O1 (7-13Hz)	0.263
Simult. O1 (7-13Hz)	46.2	2.69	7.09	Goal/Simult. O1 (7-13Hz)	<0.001
Throw O1 (13-20Hz)	40.14	1.19	3.55	Thrw/Goal O1 (13-20Hz)	<0.001
Goal O1 (13-20Hz)	41.58	0.7	2.03	Thrw/Simult O1 (13-20Hz)	0.084
Simult. O1 (13-20Hz)	40.64	0.91	2.76	Goal/Simult O1 (13-20Hz)	0.023

followed by «throwing» (M=47.98; std=0.88) and «simultaneous» condition (M=47.77; std=0.71).

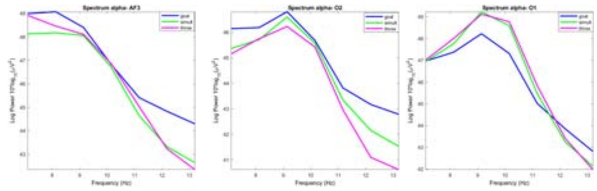

Figure 5. Spectrum plotting of the three conditions (“throwing”, “goal” and “simultaneous”) in right frontal and occipital areas for frequencies from 7 to 13Hz (alpha).

In occipital area values for alpha band differ greatly between the right and left areas. In the right area there are no significant differences; «goal» has the highest values (M=44.94, sd=1.63), followed by «simultaneous» (M=44.33, sd=1.96) and «throwing» (M=43.89, sd=2.31). In left occipital area there was a significant difference (p< .001) between «goal» condition and the other two conditions. «Throwing» and «simultaneous» show a pronounced alpha peak (49.26dB at 9.14Hz) compared to «goal» condition.

Power spectral density values of low beta frequency band (13-20Hz) in left frontal area show significant differences between «goal» and the other two conditions (table 4, figure 6, A) with high values for «goal» condition (M=43.21, sd=0.76). In the case of the occipital area, the frequency spectrum for low beta band shows significant differences (< .001) on the right side between the three conditions (table 4, figure 6, C) with high values for «goal» condition (M=42.29, sd=0.22), followed by «simultaneous» (M=40.99, sd=0.31). «Throwing» condition presents low values in low beta and a steeper slope (M=39.81, sd=0.7, range=2.17). In the left occipital area «goal» condition (M=41.58, sd=0.7) presents significant differences with «simultaneous» (M=40.64, sd=0.91) and «throwing» (M=40.14, sd=1.19) conditions.

A, Right Frontal B, Left occipital C, Right occipital

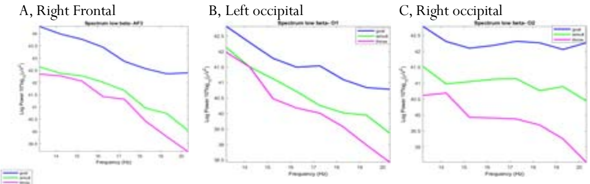
Figure 6. Spectrum plotting of the three conditions (“throwing”, “goal” and “simultaneous”) in right frontal (A) and occipital areas (B and C) for frequencies from 13 to 20Hz (beta).

Finally, to study the possible differences between the three conditions with respect to working memory demands, the values of the power spectral densities in the theta frequency band (4-7Hz) for the F3 and F4 channels were used as reference (Reinecke, 2011; Sauseng, 2005).

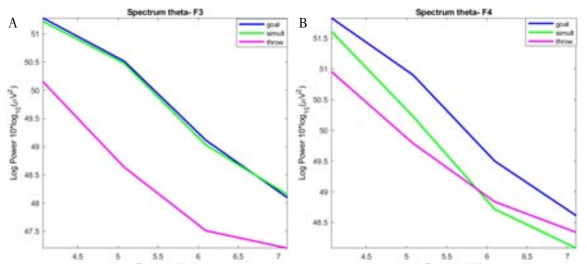

Figure 7. Spectrum plotting of the three conditions (“throwing”, “goal” and “simultaneous”) in F3 (A) and F4 (B) areas for frequencies from 4 to 7Hz (theta)..

In the left premotor area (figure 7, A) there are significant differences (p<.001) between «goal» and «throwing» conditions and between «simultaneous» and «throwing» condition. «Goal» (M= 49.75, sd=1.42) and «simultaneous» (M= 49.72, sd=1.38) have higher values than «throwing» (M= 48.37, sd=1.33).

In the right premotor area, the values are higher than in the left premotor area. «Goal» condition reaches the highest values in the spectrogram (M= 50.21,sd=1.43), followed by «simultaneous» (M= 49.66,sd=1.58) and «throwing» (M= 49.48,sd=1.15). Significant differences (p< .001) were only recorded between the «goal» and «throwing» conditions.

Looking for possible effects of stress on working memory (Gärtner et al., 2014), the positions AF3, AF4, FC5 and FC6 (figure 8) were analysed.

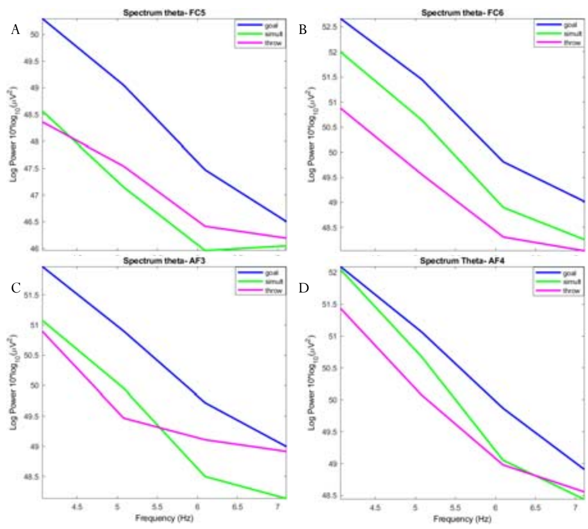

Figure 8. Spectrum plotting of the three conditions (“throwing”, “goal” and “simultaneous”) of FC5 (A) and FC6 (B), AF3 (C) and AF4 (D) for frequencies from 4 to 7Hz (theta).

A more pronounced depression in theta range spectrum of the «simultaneous» condition in left frontal areas (FC5: M=46.93, sd=1.21; AF3: M=49.6, sd=1.35) compared to the values for the right frontal areas.

Discussion

EEG signals have been widely used for studying different cognitive functions. In this study we explore inhibitory control, attention and working memory differences, through EEG biomarkers, in three types of throwing games (simple throwing, throwing at a goal, and simultaneous throwing with another player). The results show significant differences ($p < .001$) between the three game conditions in several parameters associated with inhibitory control, attention and working memory.

In terms of inhibitory control, the results point towards greater inhibitory control in the «goal» throwing game.

Based on work such as that of Jha et al., 2015 and Wanger et al, (2018), the high values for low beta frequency (13-20Hz) in the lower right frontal area could indicate a higher demand for inhibitory control in the «goal» condition compared to the other two games, something in line with the higher values of goal condition in the alpha frequency spectrum (related to functional inhibition mechanisms, Foxe, 2011 ;Haegens, 2014 , Jensen, 2012), especially in the low alpha range (7-9Hz) considered a signature of enhanced neural excitability to support target selection (Wöstmann et al. (2019, 9798) or attention (Klimesch, 1999). This enhanced inhibitory response in «goal» game would also be reflected in the right pre-motor cortex, which with higher values in alpha frequency, may be linked to voluntary motor inhibition (Deiber et al., 2020) of processes not involved in the main throwing movement. It could be interpreted that the greater control in the inhibition of responses in the game of throwing at goal compared to the other two games may be determined by the conditions imposed by the internal logic of the game (Parlebas, 2001). Simultaneous throws to an opponent are made without stopping, at a fast pace; however, throws to goal with a goalkeeper are made with more intentionality, adapting the shot to the possible response or position of the goalkeeper. This would require greater control of the timing of the shot, inhibiting more impulsive responses.

Higher alpha peak frequencies in the spectrum for the «goal» and «simultaneous» conditions could indicate higher level of arousal (Gutmann 2015) or increased investment and activation of cortical resources (Hülsdünker et al., 2015). It can also be interpreted as a better adjustment to task demands (Mierau et al., 2017).

If we take these higher levels of arousal for the «goal» and «simultaneous» conditions as valid, the frontal alpha asymmetry (FAA) results, following works such as Harmon-Jones and Gable, 2018 or Müller et al., 2018, can be interpreted as a higher approach to the target in the simultaneous throwing game and a behavioral inhibition in the individual throwing game. The intermediate FAA results for the throw-to-goal game might indicate a play between containment and approach to the target.

Moreover, the less pronounced alpha frequency spectral slope values in the right frontal areas of the «goal» and «simultaneous» conditions may indicate a greater neural balance between excitation and inhibition (e.g. Gao et al., 2017; Weber et al., 2020). As pointed out by Weber et al. (2020) the spectral slope is assumed to reflect the ratio between excitation and inhibition at the synaptic level with more negative slopes reflecting enhanced inhibition.

As for the significance of the results of the biomarkers used to assess differences in attention between the three games, we found that «goal» situations demand more attention. The significantly higher values of «goal» condition in the low alpha (7-9Hz) and low beta frequency band (13-20Hz) in left frontal area, would indicate greater attention (Klimesch, 2012; Wöstmann et al. (2019, 9798) compared to the other two game conditions. This would be corroborated by another indicator such as higher values of «goal» condition in the right and left occipital areas in the alpha and low beta frequencies related to attention (Gola et al., 2013; Worden et al., 2000). It can be inferred that the changing conditions of throwing in the «goal» throwing game (given that it is not a fixed target as in the other two games, but a target that depends on the goalkeeper's actions), may request a higher demand of attention and target selection.

Regarding working memory, following in our interpretation the work of Itthipuripat et al. (2013), the results show higher demands in the «goal» and «simultaneous» throwing games. If we analyse the demands of each game, it makes sense to think that the actions during the «goal» throw require some working memory handling data on the goalkeeper's actions and on the consequences of the actions of previous throws.

Furthermore, the low values in the theta frequency spectrum in the left frontal area for the «simultaneous» condition could be marking an effect of stress on working memory (Gärtner et al., 2014). Analysing the «simultaneous» throwing game situation, it is plausible to interpret that, given that the intervention rhythm is conditioned by the action of the other player, this could provoke a certain feeling of stress (García-Monge et al., 2020), which could be indicating the alpha peak frequency (Gutmann 2015).

Conclusions

The results of this exploratory study show that small modifications in game conditions lead to different demands on inhibitory control, attention and working memory. The modification of elements in the game structure such as individual or simultaneous intervention with another opponent, throwing at a fixed target or one with a goalkeeper, or facing an opponent with the same role (thrower) or with the opposite role (stopping the throw), condition the functioning of brain processes.

Action against an opponent trying to thwart the throw would require greater inhibitory control, as well as better attentional focus and greater use of working memory. On the other hand, simultaneous action against an opponent who has the same target might entail greater arousal and approach towards the target.

A limitation of the present study concerns the small sample size of the study. Although exploratory EEG studies of brain activity with small sample sizes are common, we are currently working to test these results with a larger sample of children of different ages and with other biomarkers for executive functions.

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