Frontal lobe executive dysfunction in short-term attentional control following a header in women's soccer

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Summary

Introduction: Football is currently the most popular and fastest growing sport in the world. Women's football players does not stop growing and currently arouses great interest, but most of the scientific recommendations for the female game have been based so far on research conducted in men. The increasing increase in the practice of women's football makes it necessary to include these types of studies.
Objective: To assess the executive functions of the frontal lobe in the control of short-term attention after having performed 6 heading shots with an intelligent ball, in non-professional adult football players.
Methodology: The study design was experimental of an intervention group with pre and post evaluation. The study consisted of two phases, in the first phase the collection of personal data, sports history, anthropometric measures was performed, and the Stroop Test was performed to evaluate the executive functions of the frontal lobe. In the second phase, 6 consecutive head shots were made from 28 meters and the Stroop test was carried out again. The sample consisted of 12 players, with an average age of 25.3 (SD = 6.5 years) and a range between 18 and 40 years. The average number of years they had been playing football in federated teams was 6.5 (SD = 2.35 years), practicing between 7 and 10 hours per week in football.
Results and conclusions: The repeated impacts when football heading, when the speed is higher than 62 km / h, produce significant and specific cognitive changes in female football players, immediately after the auction; indicating a disruption in voluntary brain functions, causing negative alterations in executive functions.

Key words:
Brain injuries. Head injuries. Football. Executive function. Prefrontal cortex. Stroop test.

Disfunciones ejecutivas del lóbulo frontal en el control de la atención a corto plazo tras el remate de cabeza en el fútbol femeninos

Resumen

Introducción: El fútbol es actualmente el deporte más popular y de más rápido crecimiento en todo el mundo. El fútbol femenino no para de crecer y despierta en la actualidad un gran interés, pero la mayoría de las recomendaciones científicas para el juego femenino se han basado hasta ahora en investigaciones realizadas en hombres. El aumento creciente de la práctica del fútbol femenino hace necesario incluir estos tipos de estudios.
Objetivo: Fue valorar las funciones ejecutivas del lóbulo frontal en el control de la atención a corto plazo después de haber realizado 6 remates de cabeza con un balón inteligente, en jugadoras de futbol adultas no profesionales.
Metodología: El diseño de estudio fue experimental de un grupo intervención con evaluación pre y post. El estudio constó de dos fases, en la primera fase se realizó la recogida de datos personales, la historia deportiva, las medidas antropométricas y se realizó el Test Stroop para evaluar las funciones ejecutivas del lóbulo frontal. En la segunda fase, se realizaron 6 remates de cabeza consecutivos desde una distancia de 28 metros y se volvió a realizar el test de Stroop. La muestra estuvo formada por 12 jugadoras, con una media de edad de 25,3 (DE=6,5 años) y un rango entre los 18 y 40 años. La media de años que llevaban jugando al futbol en equipos federados fue de 6,5 (DE=2,35 años), practicando entre 7 y 10 horas semanales al futbol.
Resultados y conclusiones: Los impactos repetidos al realizar los remates de cabeza con un balón de fútbol, cuando la velocidad es superior a los 62 km/h, producen cambios cognitivos significativos y específicos en jugadoras de fútbol femenino, inmediatamente después del remate; indicando una disrupción en las funciones cerebrales voluntarias, provocando alteraciones negativas en las funciones ejecutivas.

Palabras clave:
Lesiones cerebrales. Lesiones cabeza. Fútbol. Función ejecutiva. Corteza prefrontal. Test Stroop.

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Introduction

Soccer is currently the most popular and fastest growing sport in the world. In recent times, women's soccer has experienced exponential growth at all levels and is currently awakening considerable interest. According to the FIFA 2014 Survey, 30 million women are currently playing soccer worldwide[1]. The rollout of the FIFA Women's Soccer Strategy is a road map that aims to get 60 million women playing soccer by 2026[2]. In Spain, the number of registered women players increased from 11,300 in 2003[3] to 60,329 in 2017[4]. As is the case with many sports, soccer carries an inherent risk of injury, including cerebral concussion and subconcussion. However, soccer is unique in the use of headers, a defensive or offensive movement used to deliberately hit the ball and direct it during play. In matches, players may head the ball an average of 6-12 times, with the ball reaching high speeds of up to 80 km/hour or more. During training sessions, headers, often at low speed, can occur 30 times or more[5].

Although not all football headers produce concussion, these subconcussive impacts may impart acceleration, deceleration and rotational forces on the brain, leaving structural and functional deficits[6]. Poor attention, memory performance, and verbal learning results may occur after subconcussive impacts, and have been attributed to damage to the white matter in the brain and possible chronic neurodegenerative consequences[7-9]. These forces imparted on the midbrain, corpus callosum and fornix could be responsible for the symptoms of concussion, such as loss of consciousness, amnesia and cognitive impairment. Even in the less serious, subconcussive impacts, significant forces are transmitted to the deep structures of the midbrain and brain stem, also implying injuries[9,10].

Although there is growing concern with regard to sports-related brain injuries and possible long term consequences, there has been less emphasis on the cumulative effects of repetitive subconcussive impacts. Subconcussive impacts are defined as similar events to concussion or mild traumatic brain injury, but apparently they imply insufficient impact or acceleration forces to produce symptoms associated with concussion[7].

The cumulative effect of repetitive subconcussive impacts on the structural and functional integrity of the brain still remains largely unknown. Athletes in impact sports, such as soccer, experience a large number of impacts in just one playing season[7]. On the other hand, most of these header impacts are not considered to be a factor associated with potential injuries. As a result, few studies have been made of the long term consequences.

Most soccer studies have been conducted on male players. Therefore, up to now, most of the scientific recommendations for women's soccer are based on investigations made on men, which may not be appropriate[11]. The growing increase in women's soccer makes it necessary to include studies of this nature.

The following working hypothesis is put forward: the repeated impacts from headers during non-professional soccer in the adult female population cause executive dysfunctions of the frontal lobe in short-term attentional control.

The study aimed to assess the executive functions of the frontal lobe in short-term attentional control after performing headers with the ball, in non-professional women soccer players.

Material and method

Subjects

The study population comprised non-professional women soccer players. The players taking part in the study were selected by intentional sampling from among the women's senior team of CF Arenys de Mar (Barcelona) according to the following inclusion and exclusion criteria. Those who voluntarily agreed to participate in the study were included, while any players with head injuries, prior concussion, or acute or chronic disorders were excluded.

Firstly, the authorisation of the soccer club was requested and then the players were informed of the purpose of the study. They were asked to give their signed informed consent to voluntarily take part and under the data protection law, ensuring the anonymity and confidentiality of the data at all times.

Design and procedure

The study design was experimental on an intervention group with pre- and post-assessment. The study comprised two phases. The first phase consisted in the collection of sociodemographic variables and variables related to the practice of sports (athletic history, number of years registered as a soccer player, predominant position on the playing field, total number of hours per week playing soccer and frequency of headers during a match) and anthropometric measurements. The Stroop test was subsequently conducted, without interference (Stroop effect off) recording the number of errors and the speed of processing, and then with interference (Stroop effect on) recording the number of errors and the speed of processing.

In the second phase, 6 consecutive headers were performed from a distance of 28 metres. It was decided to do 6 headers as this is the average number of headers performed during a training session[12]. Furthermore, consecutive headers facilitate the appearance of subconcussion. All the shots were performed by the same person, trying, as far as possible, to achieve shots of a similar speed. The variables collected with the smart ball were the ball speed in km/h, the RPM rotation at the time of the header and the total time of the header. This was immediately followed by another Stroop Test, without and with interference, recording the number of errors and the processing speed.

Stroop test

The test was developed by Ridley Stroop13 to assess the processing speed of the inhibition component of the executive functions, the ability of the subject to inhibit an automatic response and to select a response based on arbitrary criteria[14]. Using the Stroop test to produce response inhibitions, frequently committed errors and the opportunity for subsequent behavioural correction, the different cortical areas associated with each of these specific executive processes were identified[15].

To measure the inhibition capacity, interference based actions were used. Numerous versions of the Stroop Test have been developed. This study used the EncephalApp-Stroop smartphone application based on the adaptation of the classical stest. It consists in a colour and word test in which the subject reads the names of randomly placed colours and must always select the colour of the sign that appears (green, blue and red). It has 2 different conditions: 1. With no interference (Stroop off effect). The colour sign # is shown with no significance, there is no interference. 2. Interference (Stroop on effect). The words green, blue and red appear randomly written with the three possible colours (Figure 1). The colour in which they are written must be selected, not the meaning of the written word. This causes an interference, in which the inhibitory component of the executive functions appears.

When the Stroop effect does not appear, it is more a reflex reaction towards the achievement of the goal. However, when the Stroop effect is on, this implies the inhibition of the reflex action towards the initial response, which then generates a new response implying a voluntary act, the colour-word interference effect[14].

The test is performed from 7 consecutive measurements. Any errors in the first two were not counted, being used to get the player familiar with the test and to reduce the learning effect that could be reflected in the post-test.

At the end of the test, the actual application calculates the time of each phase, the total speed of each condition and records the number of errors.

Smart ball

The Adidas Smart Ball miCoach is fitted with inner sensors that provide data on each shot, sending these data to an iOS device using Bluetooth 4.0 technology. This ball has the same weight and size as a standard soccer ball, with a weight of 450 g and a diameter of 68.6 cm. The study recorded the ball speed in km/h, the rotation in RPM and the path of the shot up to the impact on the player's forehead.

Figure 1. Stroop effect off (without interference) and Stroop effect on (with interference).

Statistical analysis

A statistical analysis was made of the data obtained. Initially the descriptive analysis was made: for the quantitative variables, the study used the indicators of mean, standard deviation, range and the confidence intervals were presented at 95% provided that the variable had a normal distribution. For the comparison of two means, the Student-Fisher T test for independent groups was used, given the normality of distributions. The General Linear Model (GLM) analysis was used to study the mean differences with repeated measures and a multivariable analysis was made from the means of the number of errors taken from the post-test. An alpha risk of 5% was assumed.

An analysis was made of the mean velocity differences and the errors drawn from the pre- and post-tests, taking account of the off and on Stroop effect. The speeds recorded in each of the post-test phases were also detailed, as well as the phase in which the errors were made. Finally correlations were established between the variables for the players making up the sample with the amount of errors drawn, as well as the correlation between the speed of the ball, km/h, with the post-test errors.

Results

The sample comprised 12 players with an average age of 25.3 (SD=6.5 years) and a range between 18 to 40 years. The average number of years in which the women had been playing soccer in registered teams was 6.5 (ST=2.35 years), playing soccer between 7 to 10 hours per week.

Characteristics on heading the ball

The results obtained from the smart ball were as follows: the average speed reached by the ball at the time of impact was 62.5 km/h (CI 95%: 57.8 - 67.7 km/h), the average number of revolutions per minute was 373 RPM (CI 95%: 286 - 446 RPM). The average time employed to perform 6 headers was 2.55 min (CI 95%: 2.03 - 3.38 min).

Stroop Test response speed

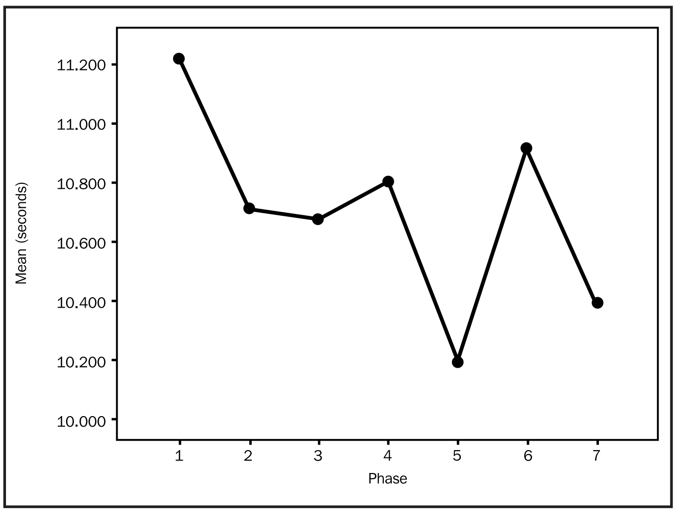
Comparing the speed in the average response time, expressed in seconds (s), of the test with the Stroop effect off (no interference) before the header was 10.8 s (CI 95%: 9.8 - 12.6 s) and after the header 10.7 s (CI 95%: 9.4 - 12.0 s), no statistically significant differences were observed (p = 0-737). Neither were any differences observed (p= 0.302) with the Stroop effect on (with interference), before the head it was 12.0 s (CI 95%: 9.5 - 13.3 s) and after the header 11.7 s (CI 95%: 9.9 - 13.2 s) (Table 1).

When analysing the response speed for each phase of the test after the header with the Stroop effect off (no interference), significant differences were observed between phases 1-2, 1-5, 1-7, 4-5 and 5-6 (F=7.39; gl=6.0; p=0.014) (Figure 2), which indicates that the Stroop effect response speed with no interference drops from one phase to another.

Table 1. Speed of response in the Stroop test with and without interference.

	Pre-test		Post-test		Difference
	Mean (s)	CI95%	Mean (s)	CI95%	T-test Student-Fischer
Stroop without interference	10.8	9.8 - 12.6	10.7	9.4 – 12.0	p= 0.737
Stroop with interference	12.0	9.5 – 13.3	11.7	9.9 – 13.2	p= 0.302

Figure 2. Response speed, in seconds, at each test phase after the header with the Stroop effect off.



The greatest drop in response time was between phase 1 (11.2 s) and phase 2 (10.7 s) (p=0.018).

With regard to the response speed with the Stroop effect on (interference) performance was extremely variable in each phase, with no statistically significant differences observed between phases (Figure 3). This indicates that the response speed during the Stroop effect with interference is independent of the time that has elapsed after the header.

Number of errors in the Stroop Test

With regard to the number of errors made before the header with the Stroop effect off (no interference) an average of 0.42 errors was obtained (CI 95%: 0-2 errors). After the header, the average number of errors was 0.75 (CI 95%: 0-2 errors). No significant differences were observed between both situations, before and after (p=0.220). With regard to the number of errors with the Stroop effect on (interference), the average before the header was 0.50 errors (CI 95%: 0-2 errors) and 1.5 errors (CI 95%: 0-3 errors) after the header, noting a statistically significant increase in the number of errors after the header (p=0.015) (Table 2).

Figure 3. Response speed, in seconds, at each test phase after the header with the Stroop effect on.

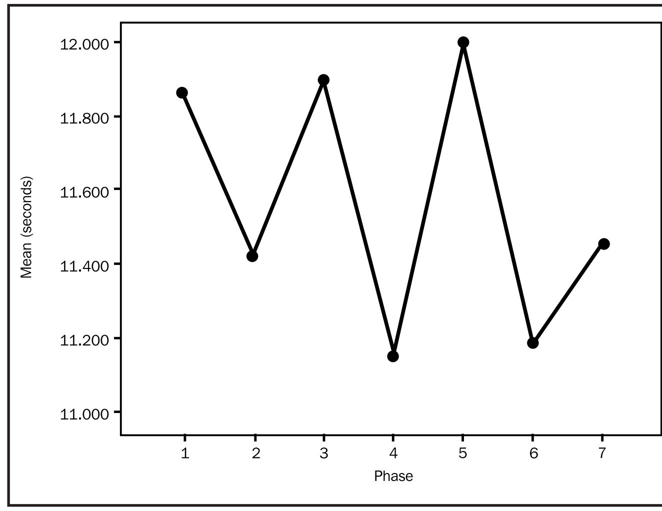


Table 2. Mean number of errors in the response in the Stroop test with and without interference.

	Pre-test		Post-test		Difference
	Mean errors	CI95%	Mean errors	CI95%	T-test Student-Fischer
Stroop without interference	0.42	0 - 2	0.75	0 - 2	p= 0.220
Stroop with interference	0.50	0 - 2	1.5	0 - 3	p= 0.015

When analysing the number of errors in the responses, based on the time or phases where such errors occurred with the Stroop effect with no interference, it was noted that phase 1 gave an average of 0.25 errors, phase 2 an average of 0.33 errors and phase 3 an average of 0.17 errors. From phase 4 to 7, no errors were made, noting statistically significant differences with regard to the number of errors in the phases (F=5.2; gl= 9.0; p=0.024). It is from phase 2 onwards where the greatest number of errors were located, significantly dropping (Figure 4).

When analysing the number of response errors based on the time or phase in which these occur with the Stroop effect with interference, significant differences are observed (F=8.75; gl= 7.0; p=0.007) between the following phases: in phase 1 the average was 0.36 errors, in phase 2 it was 0.27 errors, in phase 3 it was 0.45 errors, in phase 4 it was 0.27 errors and from phase 5 to 7 there were no errors. The most noteworthy differences were observed between phase 1 and phase 3, after which the number of errors dropped to reach 0 in phase 5 (Figure 5).

Figure 4. Average errors in each test phase after the header with the Stroop effect.

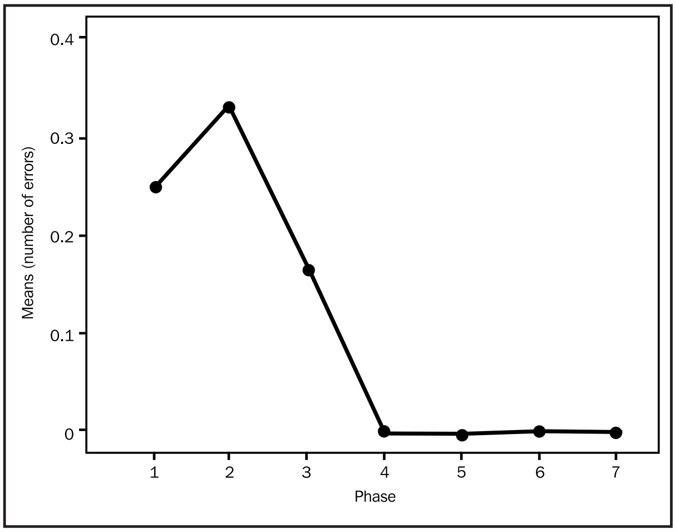


Figure 5. Average errors in each test phase after the header with the Stroop effect on.

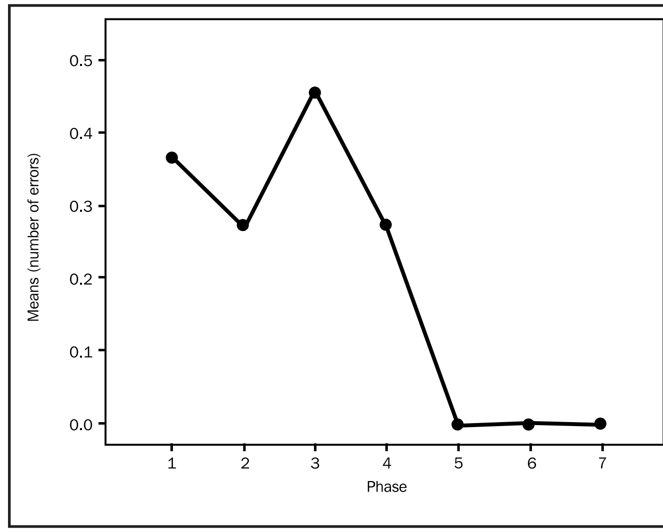


Table 3. Speed of response according to ball speed.

Speed ball	Test Stroop	Speed of response (s)	Difference (s)	CI 95% of the difference		T-test Student-Fisher
				Lower	Higher	
≤62 km/h	Without interference	10.58	-1.10	-1.69	-0.52	p=0.005
	With interference	11.68				
>62 km/h	Without interference	10.86	-0.78	-1.42	-0.15	p=0.025
	With interference	11.65				

Ball speed and number of errors

By correlating the ball speed during the header with the number of errors made with the Stroop effect on, a modest statistically significant association was observed (r=0.59; p=0.043). The greater the speed, the greater the number of errors made. On the other hand, with the Stroop effect off, no correlation was observed. By classifying the speed of the ball into two groups, over or under 62 km/h, it was observed that when the ball speed is more than 62 km/h this is significantly associated with a greater number of errors in the test (r=0.95; p=0.003). This relationship is not established for lower ball speeds.

Ball speed and response time

When relating the speed of the ball to the response speed in the Stroop test, off and on, no statistically significant association was observed.

When the analysis is made by classifying the ball speed into two group, over or under 2 km/h, then a comparison of the response speed in the on and off Stroop test shows statistically significant differences between the groups. The speed of response is faster with the Stroop effect off, with no interference, moreover it is independent of the ball speed (Table 3).

Number of revolutions per minute of the ball and response errors

The revolutions per minute (RPM) of the ball showed no correlation with the number of errors made (r=0.20; p=0.52), neither with the Stroop effect on (r=0.16; p = 0.62) nor with the effect off (r=0.06; p = 0.84).

Errors and speed of response

No statistical relationship was observed between the number of errors and the speed of response at each stage of the Stroop test, on and off. The number of errors was not associated with the speed of reaction. On analysing the relationship between the number of errors and the speed of response in the subsequent phase, with the Stroop test on and off, no statistical relationship was observed between both variables in any of the 7 phases. The reaction time for the execution of the following test was not related to previous errors made, with or without interference.

With regard to the time taken to execute all the headers, no correlation with the number of errors was observed (r=0.11; p = 0.74), either with the Stroop effect on (r=-0.07; p = 0.83) or with the effect off (r=-0.10; p = 0.76).

Finally, neither did age show any correlation with the number of errors (r=-0.26; p = 0.41), nor the number of years playing in a registered team ($F=1.17$; $p = 0.35$), nor the position on the field ($F=0.04$; $p = 0.96$) or the number of headers ($F=0.304$; $p = 0.59$).

Discussion

This study showed that the repetitive impacts of heading the soccer ball cause a disruption in the voluntary brain functions. Female soccer players experienced significant and specific changes in cognition immediately after the header, with ball speeds of more than 62 km/h. A negative alteration was observed in the processing of the inhibition component of the executive functions, the ability of the subject to inhibit the automatic tendency to select the habitual response and to generate behavioural correction in the response, implying a voluntary act (Stroop effect) and a response conflict.

Neuroimaging studies suggest that neurocognitive symptoms are due to the microstructural and metabolic alterations accumulated in the brain caused by repetitive head-impact exposure[16,17]. The force of the impact causes subconcussion in the cerebral cortex that may alter the neurometabolism and functional connectivity, as suggested by Svaldi DO[18], finding a decrease in the cerebrovascular reactivity in female soccer players, preceding the neurocognitive symptoms. Rodrigues AC[19] and Bigler ED[20] provided preliminary evidence of the relationship between head impact exposure and the structural and functional changes in the brain. Koerte IK[21] found differences in the white matter integrity in soccer players, suggesting a possible demyelination caused by neuroinflammation. The regions most affected are the right orbitofrontal white matter, the genu and anterior portions of the corpus callosum, the association fibres involving bilateral inferior fronto-occipital fasciculus, optic radiations, and right superior and bilateral anterior cingulum, as well as the corona radiata, the internal capsule and the superior frontal gyrus. The most persistent cerebral regions that present changes in cerebrovascular reactivity are the frontal dorsolateral[22] and frontotemporal18 regions. All these cerebral regions are responsible for processing the input signals and for the executive response functions. In a broad sample of young soccer players with a history of prior concussion, there was no evidence of negative effects on cognition and no evidence of differences between genders[23].

Male and female brains show anatomical, functional and biochemical differences in all stages of life[24,25]. In women's brains, the neurons are packed tightly together, so that certain layers of the cerebral cortex are more densely populated. Some women even have as many as 12 percent more neurons than men[26]. Although men have larger cerebral volumes than women, the ratio of grey to white matter is higher in the frontal, temporal, parietal, occipital lobes, cingulate gyrus and insula in women in relation to men.[25,27] These regional differences may be related to the distribution of the oestrogen and androgen receptors. Global cerebral blood flow is higher in women than in men, while global cerebral metabolism is equivalent[25]. The results suggest that the cortical functional unit has a different ratio of input and output components in men and women that could have implications for the gender differences in cognition and behaviour[26].

A noteworthy fact is the speed of the ball. Lewis ML *et al*[28] observed that players are exposed to a mean acceleration force of 49 G when heading the ball at a speed of 39.3 miles per hour (63 km/hour). Exposure to repetitive blows to the head entails the risk of microstructural and functional changes to the brain[17]. The study results suggest that ball impacts of more than 62 km/h cause subconcussion, altering the quality of the response and negatively affecting the test results.

These impacts may produce changes in the cerebral blood flow, neurometabolic changes and changes in the cortico-subcortical and subcortico-subcortical connectivity, causing a dissociation between the dorsolateral prefrontal cortex, involved in the response inhibition, and the anterior cingulate cortex that affects attention control, important role in regulative processing of perceptual conflict and in detecting response conflict.[29-31], hindering the response planning of the executive functions. Consequently, the errors of commission would be due to late activation instead of low activity in these same areas of response inhibition, as suggested by Garavan H, *et al*[15]. It was observed that the restoration of connectivity and the response reaction time improved from the second phase of the test onwards.

On the other hand, when there is no response conflict, it is more of a reflex action towards the achievement of the goal, not being affected by the speed of the ball. In the automation of the response, there is a learning process with regard to the appearance of the response conflict. For irrelevant tasks (Stroop effect off) when the involvement of inhibition is unnecessary, there is no interference with the execution of the task. This makes us suspect that there is no involvement of the dorsolateral prefrontal cortex.

With regard to the errors in the execution of the tests, no relationship was observed between the number of errors and the player's age, nor years of experience, position on the field or frequency of headers. However, the immediate acute negative effect on the executive functions is evident. The headers do not appear to cause any cumulative effects of subconcussions on the executive functions among the players taking part in the study. A history of cerebral concussion is associated with a greater risk of clinically diagnosed depression and depressive symptoms, however it is not clear whether these findings can be generalised beyond former professional male soccer players[32]. Soccer players have been reported to have a greater cortical thinning with age and early cognitive impairment as a result of the repetitive impact of the ball.[33]. To avoid the possibility of a cumulative chronic negative effect when heading the ball, a series of recommendations were proposed and the correct playing technique[34].

The results of our study suggest that the heavy impacts of heading the ball and successive headers should be avoided. There is a need to limit the accumulated load during the season, both in training sessions and matches alike. A period of rest after the competition season is also necessary in order to maintain a good brain health. Evidence of a negative effect on brain functionality must be taken into account when making recommendations for practising sports at school.

The conclusions obtained in this present investigation must be adopted with the necessary caution, given that the results come from a small sample of 12 subjects, which is a limitation to the study. Despite this, the results point in the same direction as other investigations and, in turn, suggest that there is a need to continue to investigate. For this reason, the number of subjects will be increased for subsequent investigations. There is also another limitation inherent in the study design, which is the non-randomisation in the selection of participants and the lack of a control group. Although both aspects were considered, it was not possible to implement them. Prospective studies are required, in order to assess the relationship of accumulated subconcussive impacts with the cognitive functions and mental health of soccer players, registered and amateurs alike. The lack of studies on players in the medium and long term means that it is not possible to identify the future consequences of headers and the neurocognitive symptoms caused by metabolic and microstructural damage accumulated in the brain.

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Conflict of interests

The authors have no conflict of interest at all.

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