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Executive functions, deliberate practice, and biological maturation are associated with soccer success

Funciones ejecutivas, práctica deliberada y maduración biológica están asociadas con éxito en fútbol

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Resumen

El objetivo de este estudio fue analizar qué variables fueron más importantes para la clasificación final de los equipos. Se consideraron la función ejecutiva, la práctica deliberada y la maduración biológica entre un equipo de mayor y menor ranking en el campeonato. Los 51 jugadores se dividieron en el equipo superior y el inferior. Los jugadores se sometieron a pruebas de señal de stop, fluidez en el diseño y fluidez verbal. La práctica deliberada se preguntó mediante un cuestionario y la maduración biológica se basó en la compensación de la madurez. Los análisis estadísticos se realizaron con análisis discriminante y comparación entre equipos. Los resultados mostraron un poder discriminatorio en las pruebas de maduración biológica, práctica deliberada y fluidez en el diseño. Los resultados de Stop-Signal muestran diferencias estadísticamente significativas a favor del mejor equipo (SSRT: p=0,006 / d=0,84 y MRT: p=0,016 / d=0,74). Además, los jugadores del equipo superior tuvieron más tiempo de práctica deliberado (p<0,000 / d=1,41), así como una maduración más avanzada (p<0,000 / d=1,62) que los jugadores del equipo inferior. Por lo tanto, la función ejecutiva, la práctica deliberada y la maduración biológica parecen ser esenciales para el éxito colectivo del fútbol y deben estimularse en las sesiones de entrenamiento.

Palabras claves: Básica, Educación Física, necesidades, psicología.

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Abstract

The aim of this study was to analyze which variables were most important for the teams' final rank. Executive function, deliberate practice, and biological maturation between a higher-ranked and a lower-ranked team in the championship were considered. The 51 players were divided into the top and bottom team. The players underwent stop-signal, design fluency, and verbal fluency tests. Deliberate practice was asked by questionnaire, and biological maturation was an isis maturity offset. The statistical analyses were performed with discriminant analysis and a comparison between teams. The results showed a discriminatory power in biological maturation, deliberate practice, and design fluency test. The Stop-Signal results show statistically significant differences in favor of the top team (SSRT: $p=0.006$ / $d=0.84$ and MRT: $p=0.016$ / $d=0.74$). Moreover, players in the top team had more deliberate practice time ($p<0.000$ / $d=1.41$), as well more advanced maturation ($p<0.000$ / $d=1.62$) than the players in the bottom team. Therefore, executive function, deliberate practice, and biological maturation seems to be essential for collective soccer success and should be stimulated in training sessions.

Keywords: Cognition, executive functions, soccer, biological maturation, deliberate practice.

Introduction

The literature has presented studies that analyze the final ranking of the teams and indicate some factors that influence a better final ranking in soccer competitions, such as physical and psychological teams' performance (Silva et al., 2019; Williams & Jackson, 2019; Clemente et al., 2019). According to the psychological aspect, there is an increase in studies on the relationship between executive functions and team sports performance (Carnevale et al., 2022; Kalén et al., 2021). This growing interest can be explained by the fact that in team sports, the players are in an unpredictable environment where they constantly must process information and make appropriate decisions (Ivarsson et al., 2019). In addition, to become a champion, teams must play with regular performance and be effective in game actions throughout the competition (Silva et al., 2019; Maleki et al., 2016).

In soccer, to be effective in-game actions, athletes need a high level of decision-making ability (Vestberg et al., 2012; Williams & Ericsson, 2005), and several factors are associated with decision-making ability, such as executive functions. Executive functions are numerous mental processes that regulate the processing of information from the environment, not allowing actions to be produced automatically or instinctively (Diamond, 2013). Inhibitory control and cognitive flexibility are soccer players' most investigated executive functions (Huijgen et al., 2015; Verburgh et al., 2014 & 2016; Vestberg et al., 2012, 2017 & 2020). Inhibitory control is inhibiting thoughts and emotions, such as interrupting a motor action already in the course (Barkley, 2001). Cognitive flexibility is the capacity to generate solutions for different problems and adapt to environmental changes (Diamond, 2013). Some studies compared executive functions between elite and non-elite players and demonstrated that elite players had better results in inhibitory control, cognitive flexibility, and attention tests (Vestberg et al., 2012; Huijgen et al., 2015; Verburgh et al., 2014; Sakamoto et al., 2018). Some other studies evaluated the executive functions of players belonging to the same division and showed a strong correlation between cognitive flexibility and the average of goals, number of assists, and tactical performance (Carnevale et al., 2022; Vestberg et al., 2017 & 2020).

The literature considers that executive functions are influenced by deliberate practice (weekly training hours over the years) and biological maturation (blood level testosterone) (Huijgen et al., 2015; Vanttinen et al., 2010). In addition to the relationships with executive functions, deliberate practice, and biological maturation are related to sports performance when practiced by young people. Some studies indicated that elite players have engaged in deliberate practice activities designed to improve their performances with benefits and specific goals as successive refinement through repetition and feedback (Ericsson, 2014). On the other hand, the timing of biological maturation was also associated with sports performance. In this context, some studies showed that early maturing players have advantages in soccer because of their height, weight, strength, and speed (Buchheit et al., 2014; Lloyd et al., 2015). These advantages allow the players to make more high intensity moves, have better tactical behavior, and influence faster development (Abarghoueinejad et al., 2021; Figueira et al., 2018).

No study has evaluated the average team performance in executive functions, with the players' average scores on the executive functions' tests. So, executive function measures are individualized, despite soccer being a collective game. The present study comes with a change of perspective in executive function evaluation. It may change the sports science and players' training perspectives because it is the first to use discriminant analysis to explain the final rank of elite young teams according to the game variables. Therefore, the present study aims to analyze which variables most influenced the teams' final position and compare inhibitory control, cognitive flexibility, deliberate practice, and biological maturation between higher-ranked and lower-ranked teams from a Brazilian elite young championship.

Methods

This was a descriptive and comparative cross-sectional study approved by the local ethics committee. All the players' parents or legal guardians signed a consent form authorizing them to participate in the study, and the players signed an assent form.

Participants

Data were analyzed using the G*Power 3.1.9.4® software to estimate the minimum sample size following the procedures described by Faul et al. (2007). An a priori power analysis deemed a sufficient sample size of 24 players in each category based on = 85% power ($1 - \beta$), an alpha (α) of 0.05, and large effect size (ES) ($d = 0.8$) (Faul et al., 2007). A total of 51 soccer players participated. They came from two U-15 male soccer teams that participated in the state championship organized by the Rio de Janeiro State Soccer Federation, disputed in two phases. In the first phase, 14 teams played against each other in two shifts, and teams classified in the first four positions were promoted to the playoffs (second phase). In this study, the teams were selected at the end of the first phase, and for better grouping the teams, all 14 teams were classified into four top teams (positions 1-4) and four bottom teams (positions 11 - 14). All eight teams from these two blocks were invited to participate in the study. However, only two teams, one from each block, responded positively (2nd and 11th places). All the players of these two teams agreed to participate in this study, which corresponded to 27 players included from the 2nd team ranked, and 24 from the 11th team ranked.

Anamnesis was applied to identify the players' eligibility, and the inclusion criteria were: 1) practicing systematically for at least six months; 2) regular registry in the Soccer Federation. The exclusion criteria were: 1) being injured or returning from an injury in the past two months before data collection; 2) using medication that acts upon the central nervous system.

Executive functions (inhibitory control and cognitive flexibility)

Stop-Signal Test: Stop-Signal is a psychological test used to evaluate motor inhibitory control (Logan & Cowan, 1984). The test was conducted on a portable computer (Lenovo - IdeaPad S400 Touch) following Verbruggen et al. (2008) protocol. It was executed with Inquisit 5 Lab, a platform for neuropsychological tests that is part of the Millisecond LLC software.

The test had four execution blocks, the familiarization containing 32 trials (8 with inhibition and 24 direct trials randomized) and three test blocks with 64 trials each (16 with inhibition and 48 direct trials randomized) and separated by an interval of 10 seconds. During the test, the participants were told to keep their eyes locked on a central fixation point. After a break of 2000 ms, arrows appeared in the center of the screen, pointing to the right or the left. After the response, the arrows would disappear, and a new fixation point would appear.

The test was to press the left response key (Z) if the arrow pointed to the left and the correct response key (/) if the arrow pointed to the right unless a sound appeared after the arrow appeared. In this case, the response had to be interrupted, and the participant was not supposed to press any key. The interval between the arrow apparition and the sound signal began at 250 ms, adjusted by the software up or down (50 ms) depending on the assertiveness displayed during the last response. Thus, the interval grew if the reaction to the previous stimulus was correct (up to 1150 ms) and shrunk if incorrect (down to 50 ms).

Performance on this test was evaluated through the Stop-Signal Reaction Time (SSRT), the inhibitory process latency estimate, and the estimative of how much time it takes the subject to identify the stimulus and process the motor response inhibition. Linked to this, it is possible to achieve the Mean Reaction Time (MRT), which is the average velocity of “Go condition” answers, and the Assertiveness of Inhibitory Responses, which is the correct “Stop condition” answers.

Design Fluency Test (DFT): The test belongs to the Delis-Kaplan Executive Function System (Swanson, 2005). The DFT measures the ability to draw as many designs (geometric figures) as possible in 60 seconds. Three conditions increase the level of difficulty and complexity of the test. Condition 1 provides a basic design fluency test, connecting all the black dots with four straight lines. Condition 2 measures design fluency and response inhibition, connecting all the white dots with the same rules. Condition 3 measures design fluency and cognitive flexibility, connecting all black-and-white dots with the same rules.

This test taps primary visual attention, motor speed, visual-perceptual, and constructional skills. The executive functions required include initiating problem-solving behavior, fluency in generating visual patterns, creativity in drawing new designs, simultaneous processing in drawing the designs while observing the rules and restrictions of the task, and inhibiting previously drawn responses. The variables collected with this test are the total drawings created, adding results from all three phases.

Verbal Fluency Test (VFT): The test belongs to the Delis-Kaplan Executive Function System (Swanson, 2005) and follows a categorical semantic model. The VFT measures the ability to generate words fluently in an effortful phonemic format from overlearned concepts (category fluency). VFT has been used in neuropsychology in both research studies and clinical practice. The sport psychologist can gain supplemental information about language skills and processing since the ability to generate words fluently.

The object of the test is that each subject should say as many different animals' names as possible in 60 seconds. The answers were recorded on a Samsung smartphone voice recorder. The repeated words were discarded, resulting in several different correct answers.

Deliberate practice / general background information

Anamnesis: It is an instrument for collecting players' data. In addition to the primary information such as name, date, and place of birth, extra information was also collected, like schooling, amount of training (training hours per week), and weekly games. One of the anamnesis topics was a deliberate practice which is the time during the entire life that the player practiced systematically. Thus, players spend the total time they were training at soccer clubs so that deliberate practice time can be verified. This topic, the players had to answer about when they are registered in soccer clubs. Other important information was collected as current injuries and data related to the inclusion and exclusion criteria of the sample. Finally, coaches were explicitly asked about their time of experience to avoid confounding variables.

Biological Maturation

Maturity Offset: Anthropometric measurements, age, stature, and body mass were necessary to calculate the maturity offset. Maturity Offset is a non-invasive protocol that verifies a player's biological maturation stage through the peak in their growth speed (Mirwald et al., 2002), following an equation:

$$-9.236 + [0.0002708 \times (LL \times TCH)] + [-0.001663 \times (CA \times LL)] + [0.007216 \times (CA \times TCH)] + [0.02292 \times (BM / S) \times 100]$$

In the equation, LL = leg length (cm); TCH = trunk-cephalic height (cm); CA = chronological age (years); BM = body mass (kg); and S = stature (cm) (Malina & Koziel, 2014). Maturity Offset has three classifications: pre-growth spurt if $MO < 0$, growth spurt if $MO = 0$, and post-growth spurt if $MO > 0$. This means that the higher the maturity offset result, the more biologically mature the player is.

Design and Procedures

All evaluations happened in the team training centers in an environment with controlled luminosity, comfort, and without noise. The data collection followed the counterbalanced order, as shown in figure 1, and the evaluation lasted for approximately one hour with a minimum rest period of 24 hours. It is essential to point out that the motivation, competition, and determination of the players with the tests applied had the collaboration of the entire technical committee, supervising and guiding the performance of the tests with the necessary commitment. In addition, clubs received reports on players' performance in all tests.

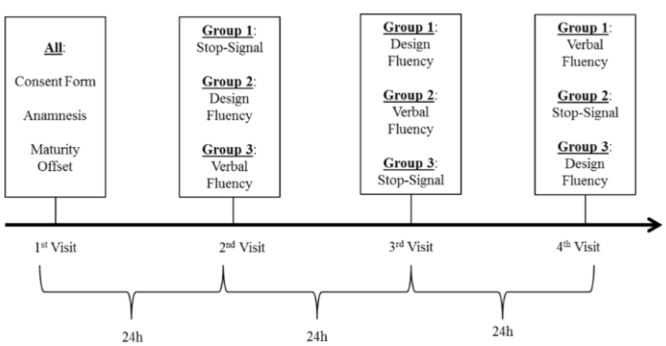

Figure 1. Experimental design of the executive functions, deliberate practice, and biological maturation.

Statistical Analysis

The Kolmogorov-Smirnov test was used to prove that the data follows a normal distribution, except for the DFT test variable. After that, a discriminant analysis was conducted to find the statistical team variables that discriminate among the two groups. The discriminant analysis allows a researcher to study the differences between two or more groups of objects concerning several variables simultaneously. Using structural coefficients (SC), we identified the variables better for discriminating top from bottom position teams. It was considered relevant for interpreting the linear vectors that the SC above 0.30 (Tabachnick & Fidell, 2007).

The variables (executive function, deliberate practice, and biological maturation) were compared in both teams using the t-test for independent samples and the Levene test to demonstrate equal variance. Mann-Whitney's U-test for independent samples was used for the DFT test variable. Cohen's d was used to calculate the effect size for all comparisons. The effect sizes were classified as d around .20 is considered small, d around .50 is considered moderate, and d around .80 is considered significant (Cohen, 1988). A significance of $p \leq 0.05$ was adopted for all tests. The IBM SPSS Statistics 23.0 statistical was the software.

Results

Table 1 shows the results of the teams' descriptive characteristics. There are no significant differences between all the variables, indicating that the sample was homogenous. Another variable that could bring about methodological differences in the teams' training was the coaches' academic background, but both coaches had soccer specialization courses.

Table 1.
Demographic and training characteristics of a top and bottom U15 soccer team

	The top team (n=27)	Bottom team (n=24)	Value of *P*
Age (years)	15.21 (0.30)	15.28 (0.26)	0.44
Schooling (years)	9.08 (0.65)	9.36 (0.59)	0.14
Practice (h/wk)	7.20 (2.28)	8.80 (3.03)	0.37
Game (g/wk)	1.00	1.00	NE
Coach's Xp (years)	3.00	4.00	NE

Notes: h/wk=hours/week; g/wk=games/week; Coach's Xp=Coach's experience; NE=Not Evaluated; (standard deviation).

Table 2 shows the variables that were included in the discriminant analysis model. The discriminant function obtained was significant ($p < 0.05$). In this discriminant function, the variables that had a higher discriminatory power were biological maturation, deliberate practice, and cognitive flexibility (DFT). The points of discriminant analysis validation were eigenvalue (0.934), Wilks´ Lambda (0.517), canonical correlation (0.695), chi-square (18.140), degrees of freedom (7), significance (0.011), and variance percentage (100%).

Table 2.
Standardized coefficients from the discriminant analysis of the variables between the top and bottom position teams.

	Function 1
Maturity Offset	0.668*
VFT	-0.102
DFT	0.517*
SSRT	-0.107
MRT	-0.035
Stop Condition	0.093
Deliberate Practice	0.585*

*Notes: *SC discriminant value ≥.30; VFT=Verbal Fluency Test; DFT=Design Fluency Test; SSRT=Stop Signal Reaction Time; MRT=Mean Reaction Time.*

The results of deliberate practice time (6.20±1.98 vs. 3.83±1.37 / p<0.000 / d=1.41) and maturity offset (1.41±0.41 vs. 0.92±0.43 / p<0.000 / d=1.62) showed that players in the top team had more deliberate practice time, as well more advanced maturation than the players in the bottom team (Fig. 2a). On the cognitive flexibility (Fig. 2b), DFT showed that the top team scored better (30.00±5.17 vs. 25.96±7.79 / p=0.049 / d=0.60) and VFT did not show significant differences between both teams (18.54±5.93 vs. 17.25±4.62 / p=0.399). In figure 2c, the inhibitory control (Stop-Signal) results show significant differences in favor of the top team (SSRT: 237.74±29.93 vs. 277.28±58.44 / p=0.006 / d=0.84 and MRT: 777.12±136.79 vs. 874.81±126.79 / p=0.016 / d=0.74).

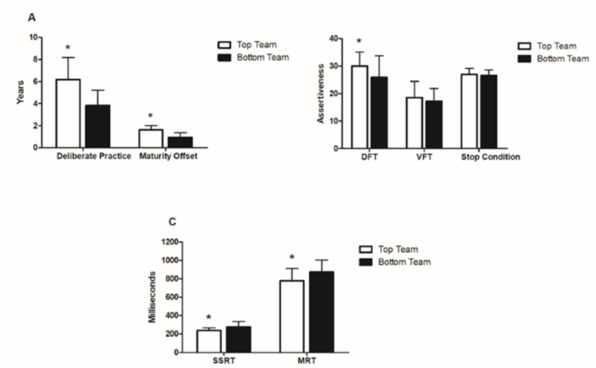

Figure 2. Results (average ± standard deviation) of the top and bottom teams in the deliberate practice and maturity offset (A); Stop Condition, DFT, and VFT (B); SSRT and MRT (C).

Notes: Key: * = significant difference between the top and bottom U-15 teams (p<0.05); DFT = Design Fluency Test; VFT = Verbal Fluency Test; SSRT = Stop Signal Reaction Time; MRT = Mean Reaction Time.

Discussion

The present study aimed to analyze which of the variables inhibitory control, cognitive flexibility, deliberate practice, and biological maturation most influenced the teams' final rank between higher and lower-ranked teams from a Brazilian elite young championship. The discriminant analysis showed that the performance in cognitive flexibility, deliberate practice and biological maturation were the most influential variables for the team to be better ranked at the end of the championship. The best-ranked team scored on average higher in inhibitory control and cognitive flexibility, in addition, they showed more deliberate practice time and were advanced in biological maturation.

Executive Functions

One result of executive functions was the appearance of cognitive flexibility at the Design Fluency Test on the discriminant analysis; it was the only executive function variable included in this analysis model. A characteristic of DFT that makes this test so complex is the greater demand for spatial dispersion processing, an aspect that is also important for the game's tactical variables, which may explain that appearance. In addition, both soccer and the Design Fluency Test require the ability to adapt to the game changes and mold different motor responses. During a soccer game, there is an activation of the neural circuits in the sensory, executive, and motor areas responsible for identifying, interpreting, choosing, and producing a tactical action to make the next moment of the game more favorable for the team (Faw, 2003).

Since player decisions depend heavily on ever-changing situations, elite players must be able to use their executive functions to process information and recognize situations, discover the most effective move among all possible choices in a short space of time under mental pressure, inhibiting intended actions, and making new decisions according to rapidly changing situations (Sakamoto et al., 2018; Vestberg et al., 2020). Thus, soccer players need to develop executive functions to have the ability to "read the game." More specifically, the importance of inhibitory control and cognitive flexibility for offensive and defensive tactical actions is evident (Carnevale et al., 2022). For example, the inhibitory control in response to a feint or the use of cognitive flexibility to perform different technical and tactical acts according to the opponent's behavior.

The executive functions results were compared between the top and bottom teams. The top team outscored the bottom team on the Stop Signal Test and Design Fluency Test, measuring both inhibitory control and cognitive flexibility. According to the literature, these executive functions aid soccer success because they are present in decision-making during a soccer game (Vestberg et al., 2012). The importance of understanding the executive functions of soccer players lies in the multifactorial variables of the player and game since the formation as a human seems to be essential for sporting success (Larsen et al., 2013). The game, like life, does not automatically present the players' solutions (Garganta & Oliveira, 1996). Thus, players must make decisions and interpret game information creatively and intelligently. The randomness and unpredictability of the game stimulate the players' creativity, which can be developed through many hours in soccer-specific play activities in childhood (Roca & Ford, 2021) or even through different types of small-sided and conditional games (Caso & Kamp, 2020).

The Verbal Fluency Test and the assertiveness of the inhibitory responses in the Stop Signal Test were not significantly different between the top and bottom teams. The Verbal Fluency Test uses neural language circuits, requiring semantic processing of speech and memory (Baldo et al., 2006), such as vocabulary storage. The Verbal Fluency Test might be less specific than other evaluations for soccer evaluations players. Regarding the assertiveness of the inhibitory responses, it is essential to point out that the Stop Signal Reaction Time and the Mean Reaction Time from the same test were significantly different, showing that the higher-ranked team's correct answers happened with a shorter reaction time. This result indicates that responding to stimuli is essential but responding correctly and quickly to the stop signal can be decisive. According to Vestberg et al. (2020), elite players often demonstrate creative decision-making with high accuracy at high speed, which is complementary to our findings.

Deliberate Practice and Biological Maturation

Another factor that was included in the discriminant analysis is deliberate practice. This can be explained based on recent studies in the literature that point to an association between deliberate practice time and the acquisition of creativity and tactical decision-making in young and adult professional players (Roca & Ford, 2021; Machado et al., 2020). According to that, it is important for intentional soccer practice for the sport's success. The top team conducted more deliberate practice time compared to the bottom team. In this sense, players may develop more outstanding expertise in recognizing different stimuli from the game in motor and cognitive areas with more deliberate practice time. This also leads to better emotional balance against the game's stress (Faw, 2003), leading to greater information processing speed and dynamism in decision-making (Nakamoto & Mori, 2012).

Regarding biological maturation, the top team had an early biological maturation compared to the bottom team. Biological maturation was also included in the final model of the discriminant analysis. It could be explained because the top teams have selected players who are early maturated (Figueiredo et al., 2010), and they are associated with more match participation in youth competitions (Eskandarifard et al., 2022). The early development may give the players advantages during U-15 games because the higher level of testosterone in the blood stimulates greater muscle potency, accelerating reaction time (Vanttinen et al., 2010) and increasing the density/volume of white cerebral mass (Paus, 2005), which is responsible for the transmission of information between different regions of the brain, thus improving the rate of decision-making reprogramming (Nakamoto & Mori, 2012). All these findings from the literature represent the game's biological complexity and are complementary to our results.

Another explanation for biological maturation influencing the final rank of the teams is that top teams recruited athletes who were early matured, and these players can acquire more game minutes (Bezuglov et al., 2019); because of that, they can display more tactical skills, and experience a more extensive arsenal of game actions in the field. Moreover, the literature showed that players who were advanced in their biological maturation scored better on tactical performance, more specifically, the offensive phase of the game, with a more significant number of width and length actions, progress actions with the ball, and more pass lines created than players who had not yet reached their maturational peak (Borges et al., 2017; Reis & Almeida, 2020).

Practical Application

According to the present study results and the complementary literature, we believe that coaches should stimulate and evaluate soccer players' executive functions through training sessions in which players must think and make decisions as those made in an actual match, for example, based on small-sided and conditioned games, in addition to other activities that require a fast contextual decision by players. The results of this study may contribute to the addition of cognitive markers in the technical observation of clubs. Soccer academies may also adopt cognitive assessment to choose players in talent screening.

Limitations

The present study's findings are punctual and indicate a momentary success that is important to evaluate but never definitive. The results found in the present study are essential regarding the cognitive approach to soccer and show a more holistic view. However, as a limitation, no soccer-specific validated instrument for cognitive assessment exists. Because of this, the literature uses clinical executive function tests for performance scores. Furthermore, it would be necessary to cognitively assess players after biological maturation to avoid such bias in the analysis. As a suggestion for future research in this area, longitudinal accompaniment may be interesting to observe executive function improvements related to routine training.

Conclusions

It is concluded that executive function (cognitive flexibility), deliberate practice time, and biological maturation performance were determinants for the collective efficacy in U-15 soccer teams. Moreover, in this study, executive functions (inhibitory control and cognitive flexibility), deliberate practice, and biological maturation were significantly better in a higher-ranked team compared to a lower-ranked team.

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