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Executive Functions, Physical Abilities, and Their Relationship with Tactical Performance in Young Soccer Players

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Abstract

While tactical performance in soccer is associated with the players' and teams' collective actions in the context of game stimuli, how tactical performance relates to players' executive functions (EFs) and physical abilities should be examined. In this study, we examined these relationships among 81 Under-15 male soccer players who underwent tactical evaluation (FUT-SAT), EF tests (i.e.,(Stop-Signal Test and Design Fluency Test)), and physical tests (i.e.,(Maturity Offset, Yoyo Endurance Test II, Sargent Jump Test, and Sprint Test)). Multiple linear regression modeling with the stepwise method showed that approximately 48% of overall game tactical performance variance was explained by inhibitory control, biological maturation, and sprint capacity ($p = .004$; $d = .54$; $r^2 = .479$), whereas 35% of offensive tactical performance variance was explained by the same dimensions ($p = .001$; $d = .91$; $r^2 = .353$). In addition, approximately

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28% of defensive tactical performance variance was explained by cognitive flexibility and aerobic resistance (p = .007; d = .39; r^2 = .280). These results reflect the combined importance of EFs and physical abilities for tactical performance in young soccer players, suggesting that these abilities may be targets for training when trying to improve young players' performance.

Keywords
sports, talent development, cognition, biological maturation, motor profile, youth

Introduction

In soccer, player and team performance emerge from interactions between individuals, tasks, and environmental factors (Newell, 1986; Nitsch, 1985). Because these interactions influence players' actions, players are responsible for appropriately selecting action options (Araújo, 2005; Passos et al., 2008; Williams & Ericsson, 2005). Players' abilities to select and generate effective responses to changing unpredictable game circumstances is a key aspect of tactical performance (Mesquita, 1998) that is fundamental to individual and collective soccer success (Kannekens et al., 2011). According to Mesquita (1998), tactical performance is associated with the actions performed by individual players and the team.

Players' tactical performance emerges from interactions between the environment and the players' own cognitive and physical functions (Damunt & Guerrero, 2021; Vestberg et al., 2012). Cognitive functions enable players to extract, process, discard, and use all the information from the game (Damunt & Guerrero, 2021). Adaptive cognitive functions are an aspect of executive functions (EF) (Miyake et al., 2000) that can be categorized into sub-abilities (Barkley, 2012) such as inhibitory control, cognitive flexibility, and working memory that may underlie other more complex EF (Diamond, 2013). Inhibitory control is the ability to inhibit predisposed responses in favor of selected correct responses. Cognitive flexibility involves the ability to change perspectives or mental sets by seeking new solutions to problems until the most efficient alternative is identified. Working memory is the ability to keep new information in mind and retrieve it for problem-solving (Miyake et al., 2000; Miyake & Friedman, 2012).

To understand the importance of EF for sports performance (and soccer in particular), several investigators have studied the relationship between EF and performance and have found them to be positively associated (e.g., Huijgen et al., 2015; Verburgh et al., 2014; Vestberg et al., 2017). Swedish first-division soccer players were found to have better cognitive flexibility and inhibition than fourth-division players (Vestberg et al., 2012). In youth, more technically and tactically talented athletes have demonstrated better inhibitory control ability (Huijgen et al., 2013; Verburgh et al., 2014). Scholars like Albuquerque et al. (2019) have also suggested that national competition players with better tactical performance have higher levels of inhibitory control. These findings show that EF plays an important role in young soccer players' performance.

Contemporary soccer is an intermittent game in which players must be physically prepared to deal with the game's changing intensity (Bradley et al., 2009). In the case of young players, advanced biological maturation is associated with an increase in muscle mass, a concentration of testosterone in the blood, and brain growth and development that lead to age and maturity-based improvements in cognitive and motor skills, and, consequently, in sports performance (Vänttinen et al., 2010). Among young athletes, those with greater maturity have a temporary advantage than those who may experience a growth spurt at a later age (Lovell et al., 2015). Age and maturity advantages in youth sports have become so well recognized that they are often studied under the term "relative age effect" (Nakata et al., 2017; Beals et al., 2018; Safranyos et al., 2020). Biological maturation influences physical performance due to many factors, including alterations in hormonal profiles, increases in lean body mass, myelination of motor neurons, frontal lobe brain development, and enhanced motor coordination (Romine & Reynolds, 2005; Faigenbaum et al., 2013; Lloyd et al., 2014). Furthermore, Gonçalves et al. (2020) indicated that more mature young elite Brazilian players perceived the game faster and more effectively and provided quicker responses in the game context.

Despite the growing literature on the separate importance of EF and physical abilities in youth soccer success, there is still a knowledge gap regarding the specific ways in which these variables are associated and, in particular, how they may affect players' tactical performance. Thus, we sought to better understand the relationship between tactical performance, EF, and physical abilities in young Brazilian soccer players. We applied a multidimensional approach to this research. We hypothesized that EF would be associated with physical abilities among young soccer players and that both would account for significant variance in their tactical performance.

Method

This was a descriptive, cross-sectional, and correlational study. The protocol was submitted to the first author's institutional ethical committee, registry number 52519815.4.0000.5259, and was approved under number 1645377 before data collection. Because the participants were young players, their parents/legal guardians signed the consent form on their behalf.

Participants

We recruited 81 Under-15 male soccer players from four different teams of the Rio de Janeiro State Championship to participate in this study. We estimated this sample size a priori, based on a power analysis using G*Power software version 3.1.2 (Franz Faul, Universität Kiel, Germany). In this calculation, we assumed statistical significance or α of .05, statistical power of $[1-\beta] = .80$, a small effect size of dz = .15 and test family = F tests. We also employed multiple linear regression of a fixed model, with R^2 deviation. This calculation led to an estimated required sample size of 77 participants. However, to avoid any loss of statistical power due to possible participant withdrawals from the study, we included 81 participants. These players had an average chronological age of 15.11 (*SD* = .32) years, an average height of 172.15 (*SD* = 7.03) cm, and an average weight of 63.58 (*SD* = 7.72) kg. Participant inclusion criteria were (a) to be registered as an Under-15 player in the State Soccer Federation and (b) to have engaged in systematic training for at least six months. The only exclusion criterion was the presence of any injury in the past three months prior to data collection.

Demographic and Anthropometric Data

We reviewed each participant to verify their compliance with the study's inclusion criteria. The participants self-reported the following information: date and place of birth, education, injury history, and practice time (defined as their lifetime time spent in systematic practice while registered in a soccer federation). In addition, we obtained players' biological and anthropometric data to evaluate their biological maturation.

Procedures

Data were collected in soccer club facilities over five consecutive days. All tests (see descriptions below) occurred from Monday to Friday with an interval of 24 hours, as follows: Monday – Term of Consent and Anamnesis; Tuesday – FUT-SAT and Maturity Offset (MO); Wednesday – Stop-Signal Test (SST) (group 1), Design Fluency Test (DFT) (group 2), and Sargent Jump; Thursday – SST (group 2), DFT (group 1), and Sprint test; Friday – Yoyo Endurance level ll.

Executive function tests were conducted in a counterbalanced order (groups 1 and 2) to avoid any systematic cognitive influence that one test might generate on the other. Physical tests were conducted with a 10-minute warm-up, followed by a 5-minute recovery before the beginning of the tests, again to avoid any metabolic influence one test might generate.

Measurements

Inhibitory control SST. Stop-Signal is a psychological test used to evaluate motor inhibitory control; it was validated by Logan and Cowan (1984). We conducted this test on a portable computer placed 15 cm from the lower end of the support table (Lenovo-IdeaPad S400 Touch) as per Verbruggen et al. (2008). This test was executed with the Inquisit five Lab, a platform for neuropsychological tests that is part of the Millisecond LLC software.

The test had four execution blocks: a familiarization task 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), with all blocks separated by

10 seconds. Participants were instructed to keep their eyes locked on a central fixation point during the test. After 2000 ms, arrows appeared in the center of the screen pointing to the right or left. After the particiipant's response, the arrows disappeared and a new fixation point appeared.

The test required participants to press the left response key (Z) if the arrow pointed to the left and the right response key (/) if the arrow pointed to the right, unless a sound came on after the arrow appeared, at which point the participant was not supposed to press any key. The interval between the arrow appearance and the sound signal began at 250 ms and was adjusted by the software up or down (50 ms) depending on the assertiveness displayed during the last response. Thus, the interval increased if the response to the last stimulus was correct (up to 1150 ms), and decreased if incorrect (down to 50 ms).

The performance on this test was evaluated through the stop-signal reaction time (SSRT), the inhibitory process latency estimate, and the estimate of how long it took the participant to identify the stimulus and process the motor response inhibition. We were able to derive the participant's mean reaction time (MRT – i.e., the average velocity of "go condition" answers), and the assertiveness of inhibitory responses (i.e., the correct "stop condition" answers).

Cognitive flexibility DFT. Design Fluency is a psychometric paper and pencil test requiring the respondent to draw as many different geometric figures as possible by connecting predetermined white and black dots with four straight lines, in 60 seconds. This test has shown good validity for assessing cognitive flexibility (Delis, 2001). It is divided into three stages: Stage 1 in which participants connect only black dots, Stage 2 in which they connect only white dots, and Stage 3 in which they connect black and white dots alternately. The final score of the test was the sum of the correct answers from all three test stages, with duplicate or identical answers invalidated.

Biological Maturation MO. Maturity Offset is a method for predicting a participant's maturation stage through a non-invasive mathematical equation based on demographic and self-reported anthropometric data (Mirwald et al., 2002). It is possible to identify the time (in years) that remains before the player reaches Peak Height Velocity (PHV). Players can then be classified into two groups according to their PHV: pre-PHV, if $MO<-1$ and post-PHV, if $MO>1$. The formula used to calculate the MO is as follows: $-9.236 + [0.0002708 \times (LL \text{ x } TCH)] + [-0.001663 \times (CA \text{ x } LL)] + [0.007216 \times (CA \text{ x } TCH)] + [0.02292 \times (BM + S) \text{ x } 100]$ Where LL = leg length (cm); TCH = trunk-cephalic height (cm); CA = chronological age (years); BM = body mass (kg), and S = stature (cm).

The participants' stature and trunk-cephalic height were measured with stadiometers from the participating clubs. Leg length was measured using a standard measuring tape with a millimetric scale. Body mass was measured using a digital scale (*Filizola*; São Paulo, SP, Brazil). Chronological age was calculated as the time between the player's date of birth and the date of data collection.

Aerobic Resistance (Yoyo Endurance Test level II). Yoyo endurance was used to estimate aerobic resistance (Fanchini et al., 2014). The procedure of this test was to run 20 m with a predetermined cadence provided by a progressive audio beep. The participants were asked to run non-stop until they were no longer able to maintain the required pace during two consecutive attempts. The final score was expressed as the maximum distance (in meters) that the player ran.

Lower limb power (Sargent Jump). The sargent jump (SJ) has been validated as a muscle power test for the lower limbs in youth players (Salles et al., 2012). The players had all fingers of their right hand colored with chalk. First, the players were asked to raise their right hand, touch the wall on their right side, and mark it at the highest point they could while maintaining their feet on the ground. They were allowed to freely flex their lower limbs and prepare their upper limbs for a sudden upward jump to promote the highest possible vertical jump. At the highest point of the jump, players had to touch the wall to mark their height. The test score is defined as the difference between the two marks on the wall. All players jumped three times, with a minimum 45 seconds between the jumps. Only the highest jump was computed.

Sprint (35 m Test – Sprint). The sprint test consisted of three trials of 35 m maximum sprints with a minimum of 3-minute rest periods (Ingebrigtsen et al., 2014). The participants started from a standing position with their front foot on the starting line of the first distance mark. The timing started automatically when the start signals sounded and ended when the last mark was reached at the finishing line. The sprint was timed using a chronometer (Timex®, model 85103), and only the best result was obtained.

System of Tactical Assessment in Soccer (FUT-SAT). We used the FUT-SAT to assess participants' tactical performance (Costa et al., 2011). Players engaged in a small-sided game comprised of two teams (Goalkeeper + 3 vs. 3 + Goalkeeper) that played in a 36 × 27 m space for four minutes. Each athlete played only one game and was instructed to play according to the official soccer rules, except for the offside. Through video analysis with Soccer Analyser® software (Costa et al., 2011), we analyzed the players' actions and recorded the data into an Excel spreadsheet, where a Tactical Performance Index (TPI) was generated through the following equation:

$$\text{TPI} = \Sigma \text{ tactical actions } (\text{PP} \times \text{QP} \times \text{PA} \times \text{AO})/\text{number of tactical actions}$$

Where PP = Performance of the Principle, QP = Quality of Principle Performance, PA = Place of Action in the Game Field and AO = Action Outcome. Offensive tactical performance index (OTPI) is related to offensive principles, defensive tactical performance index (DTPI) is related to defensive principles, and game tactical performance index (GTPI) is related to the sum of tactical principles in the offensive and defensive phases of the game.

These measures were calculated by the ratio between successful soccer tactical principle actions and the total number of tactical principle actions made by each player.

The 4-minute games were recorded using a *Sony DSC-H300* camera placed diagonally to the end and sidelines. The players wore numbered vests for easy identification in video analytics and were separated into teams at the coach's discretion so that the teams were balanced and leveled. Thirty seconds were allowed for players to familiarize themselves with the game. Verbal interference from the coaches or researchers was prohibited.

The test was applied to natural grass with movable goal posts with dimensions of 6 × 2 m. The size of the field was marked with stakes and tapes; the balls that came out were replaced immediately with the help of the technical committees, and the games were refereed by the coaches of the evaluated teams. All FUT-SAT evaluators took the preparatory course for training and improving the instrument. They obtained certification and were familiar with the analysis methods.

Statistical Analysis

We used the Kolmogorov-Smirnov test to test the data distribution. Multiple linear regression was conducted using the stepwise method to assess strength and association between SSRT, DFT, MO, Yoyo End. ll, Sargent Jump, Sprint Test, and TPI (offensive, defensive, and game). Regression coefficients (β) and determination coefficients (r^2) were calculated to identify the strength of each variable in explaining the result variance. Accordingly, only variables with significance set at $p < .05$ were included in the final equation. The software adopted for statistical analyses was the Statistical Package for the Social Sciences (SPSS, Version 23.0, IBM Corp., Amonk, N.Y.). Effect size (Cohen's d) and the power of the null hypothesis tests (H0) were analyzed with the *GPower 3.1* software. The classification of the effect sizes was as follows: d around .20 is considered small, d around .50 is considered moderate, and d around .80 is considered large (Cohen, 1988).

Results

Three multiple linear regressions were conducted for each TPI, as displayed in Table 1. The participants' inhibitory control performance, biological maturation, and sprint capacity explained approximately 35% of the OTPI [F (3, 23) = 5.728; $p = .004$; d = .54 (moderate effect); H0 = 0.85; $r^2 = .353$]. Aerobic resistance performance and cognitive flexibility explained approximately 28% of the DTPI [F (2, 24) = 6.027; $p = .007$; d = .39 (small effect); H0 = .78; $r^2 = .280$]. Additionally, inhibitory control, biological maturation, and sprint capacity explained approximately 48% of the game tactical performance [F (3, 19) = 7.750; $p = .001$; $d = .91$ (large effect); H0 = .94; $r^2 = .479$].

Discussion

In this study, we found that our young participants' inhibitory control, biological maturation, and sprint capacity were significantly associated (moderate effect) with

Table 1. Values of Standardized Coefficient (β), Non-standardized Coefficient (β-n), Standard Error, Degrees of Freedom (T) and Significance Value (*p*) of the Multiple Linear Regression for Offensive Tactical Performance (OTPI), Defensive Tactical Performance (DTPI) and Game Tactical Performance (GTPI).

	β-n	Standard Error	B	*T*	*p*
OTPI					
Intercept	111.526	22.299	—	5.001	<.001
SSRT	.070	.023	.504	3.070	.005
Mat. Offset	7.421	2.564	.498	2.895	.008
Sprint	11.400	4.396	.430	2.593	.016
DTPI					
Intercept	33.476	2.979	—	11.236	<.001
Yoyo End. II	.008	.002	.601	3.200	.004
DFT	.304	.113	.507	2.698	.013
GTPI					
Intercept	83.382	13.973	—	5.968	<.001
Mat. Offset	6.302	1.570	.684	4.014	.001
Sprint	8.377	2.781	.504	3.012	.007
SSRT	.041	.014	.455	2.896	.009

Notes: Mat. Offset: maturity offset; Sprint: sprint test; SSRT: stop-signal reaction time; Yoyo End. II: yoyo endurance test level II; DFT: design fluency test.

their offensive tactical soccer performance. The same variables were also associated (large effect) with their soccer game tactical performance. Cognitive flexibility and aerobic resistance are associated (small effect) with defensive tactical performance in soccer.

The positive associations between inhibitory control, offensive, and game tactical performance indices were in line with previous investigators' findings that elite soccer players have better inhibitory control (as evaluated by the stop-signal test) than do amateur players, with elite players showing enhanced inhibition of an already planned motor response (Huijgen et al., 2015; Verburgh et al., 2014). One of the reasons for this finding is the relationship between inhibitory control and reaction time (Verbruggen et al., 2008). In the offensive phase of soccer, tactical actions require considerable speed, given little time to make correct decisions during gameplay. In addition, well-developed inhibitory control helps control general impulsiveness (Cardoso et al., 2015), which is a fundamental consideration for an attacker wishing to avoid off-side penalties. Accordingly, Cardoso et al. (2015) identified a positive relationship between inhibitory control and offensive tactical performance using the Iowa Gambling Task to assess inhibitory control by non-planned impulsivity and correlation tests. The authors hypothesized that less impulsive players performed better in deep passing line creation and rupturing the opponent's defensive strategy (Cardoso et al., 2015).

Previous studies have suggested that players who present higher levels of inhibition control also show a better GTPI than their peers (Albuquerque et al., 2019). Interpreting the game situation accurately means that players should be predisposed to response inhibition and act coherently with the game's demands. Given soccer's unpredictability, the capacity to analyze game dynamics, inhibit irrelevant environmental information, and replace automatic behavior with correct behavior is vital for good play (Huijgen et al., 2015).

This study identified a positive relationship between cognitive flexibility and defensive actions. This can be explained by the characteristics of the defensive phase of the game, which requires adaptation to environmental changes and the formulation of different strategies after each new offensive action by the opposing team (Kerr & Zelazo, 2004). Thus, cognitive flexibility permits changing the line of reasoning or performing another contextual game action (Huijgen et al., 2015). Examples may include anticipating a passing line, identifying numerical superiority during an attack, managing defense transitions, and understanding movements into empty spaces. Gonzaga et al. (2014) found that players with greater EF capacity showed better defensive tactical performance. Cognitive flexibility is important since the defensive sector prioritizes the security and organization of tactical actions, as well as the risk of defensive errors (Gonzaga et al., 2014).

In addition, data from this study showed that participants' physical abilities were related to tactical performance. Biological maturation is related to both offensive and game tactical performances. Coaches prefer athletes with more accelerated biological maturation, and more mature players acquire more game minutes, display more tactical skills, and enhance game actions in the field (Bezuglov et al., 2019; Del Campo et al., 2010). Previous studies have shown that players who were advanced in their biological maturation scored better on offensive tactical performance, with a greater number of width and length actions, more offensive progress 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).

Following the same logic as biological maturation, sprint capacity also relates to offensive and game tactical performance, with faster players showing better tactical performance. Thus, better sprint capacity is related to better performance of acts with the ball (Bidaurrazaga-Letona et al., 2019). The sprint capacity to perform high-speed running actions to win possession of the ball or pass defending players is believed to be critical to the outcome of soccer matches (Bradley et al., 2009). Thus, the findings of the present study complement other studies on the relationship between sprint capacity and tactical performance.

In the present study, aerobic resistance contributed, with cognitive flexibility, to 28% of defensive tactical performance in the Under-15 players. Previous studies have demonstrated that aerobic resistance alone explains approximately 36% of defensive tactical performance in Under-13 players (Borges et al., 2018). A reason for this difference in results may be that the greater complexity of defense with increasing age places a greater demand on EF, as well as aerobic resistance. This occurs because defensive tactical principles not only require constant movement from the players to recover ball possession, such that players with superior cardiorespiratory aptitude can travel further and defend their zones more efficiently (Mujika et al., 2009). Quick flexible decision-making also helps determine defense success in slightly older players.

All the results described here are related to the variables that best explain tactical performance in each segment of the game; however, it is known that success in soccer is multifactorial. In this sense, both offensive and defensive players must train all the physical and cognitive aspects of the soccer game and its particularities. Owing to the complexity of soccer, all players need to be complete in all possible areas to increase their chances of high performance.

Limitations and Recommendations for Further Research

An important limitation of this study was the young age of our participants. As they were not yet cognitively mature, there may have been significant differences among them with respect to their EF levels (Best et al., 2009). However, this can also be considered a study strength in that this permits insight into EF and physical development among young athletes, perhaps especially because these athletes were already involved in systematic training processes in which they received cognitive and physical challenges that may have enhanced their natural development. Another study limitation is that our cognitive EF assessment tools were not soccer-specific. Of course, mirroring tools used by other researchers permits comparisons to earlier studies; but future studies might use both laboratory-based EF tests and cognitive tasks specific to sports to permit direct analyses of the degree to which these tasks correlate. Future studies should also expand this participant sample by involving both male and female athletes, perhaps including both professional and youth participant groups. Future investigations might also follow participants for an entire season to permit a longitudinal analysis of changes in their cognitive and tactical growth throughout the year.

Conclusion

In this study, young soccer players' offensive and game tactical performance were related to inhibitory control, biological maturation, and sprint capacity. Defensive tactical performance was associated with cognitive flexibility and aerobic resistance. We discussed the limitations of this study and other areas for further research. Our results may contribute to the teaching and learning of young soccer players. In terms of practical recommendations, coaches should consider inserting activities that stimulate these particular EF and physical abilities to improve their players' tactical performance. For example, small-sided and conditioned games and other activities that require player decision-making may be particularly useful in this regard. In addition, the creation of new markers in the technical observation of soccer players, such as cognitive and physical evaluations, seems to be of clear importance in analyzing player qualities.

Declaration of Conflicting Interests

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