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SPORT PLAYS A KEY ROLE IN CHILDREN'S NEURAL FUNCTION AND GROWTH

LO SPORT GIOCA UN RUOLO FONDAMENTALE NELLA FUNZIONE NEURALE E NELLA CRESCITA DEI BAMBINI

Giulia My
University of Salento
giulia.my@unisalento.it

Lorenzo Giannotta*
University of Salento
lorenzo.giannotta@unisalento.it

Santo Marsigliante*
University of Salento
santo.marsigliante@unisalento.it

Antonella Muscella*
University of Salento
antonella.muscella@unisalento.it

Abstract

Several evidence show that physical activity promotes growth and development in childhood, with multiple psychological, physiological, and cognitive and neural functioning benefits.
To verify these adaptations, we analysed the effects of a football season in young male footballers (n=29; 11.6±1.2 years) and compared with control young's (n=30; 11.4±0,8 years). Anthropometric, blood (cortisol, testosterone, growth hormone hGH) and physical assessments were measured before the start of season (T0), after training (T1), in the middle (T2), at the end of season (T3). The results showed changes for hormones values (P<0.01), with higher hGH concentration in footballers than in control group (P<0.001). Between the start of the training period and the end of the football season significant differences were observed in the anthropometric characteristics and in the physical form of the football players. In fact, a significant performance improvement, including the lower limb power (squat-jump [SqJ], the counter-movement-jump [CMJ]) and the aerobic performance (Yo–Yo intermittent recovery test level 1 [YYIRT1]) was observed in young players. Finally, significant differences emerged between the young players and the control group in the D2 cognitive performance test: the players returned a higher value of total number of responses and of correct responses minus errors of confusion, on the contrary the number of errors was higher in the control group. The results confirm that physical activity induced physiological adaptations in young players and that these adaptations positively correlated to their physical growth and also to the improvement of attention and concentration.

Numerose evidenze scientifiche dimostrano che l'attività fisica promuove la crescita e lo sviluppo durante l'infanzia, con molteplici benefici psicologici, fisiologici e del funzionamento cognitivo e neurale.
Per verificare questi adattamenti, abbiamo analizzato gli effetti di una stagione calcistica in giovani calciatori maschi (n=29; 11.6±1.2 anni) e confrontati con giovani di controllo (n=30; 11.4±0,8 anni), che non effettuavano attività fisica. Le valutazioni antropometriche, ematiche (cortisolo, testosterone,

ormone della crescita hGH) e i test di performance fisica sono state misurate prima dell'inizio della stagione (T0), dopo l'allenamento (T1), a metà (T2), a fine stagione (T3). I risultati hanno mostrato variazioni per i valori ormonali (P<0,01), con una concentrazione di hGH maggiore nei calciatori rispetto al gruppo di controllo (P<0,001). Tra l'inizio del periodo di allenamento e la fine della stagione calcistica sono state osservate differenze significative nelle caratteristiche antropometriche e nella forma fisica dei calciatori. In effetti, è stato osservato un significativo miglioramento delle prestazioni, inclusa la potenza degli arti inferiori (squat-jump [SqJ], il contro-movimento-salto [CMJ]) e la prestazione aerobica (Yo-Yo intermittent recovery test level 1 [YYIRT1]), nei giovani. Infine, sono emerse differenze significative tra i giovani e il gruppo di controllo nel test cognitivo D2: i giovani giocatori hanno restituito un valore più alto delle risposte (GZ) e risposte corrette meno errori di confusione (SKL), mentre la percentuale degli errori (F%) era più alto nel gruppo di controllo. I risultati confermano che l'attività fisica ha indotto adattamenti fisiologici nei giovani calciatori e che questi adattamenti hanno dimostrato di essere positivamente correlati alla loro crescita fisica, ma anche al miglioramento dell'attenzione e della concentrazione.

Keywords

sport-physical activity-children-neural function-growth

sport-attività fisica-bambini-funzione neurale-crescita

INTRODUCTION

Although sport has a number of positive effects on the growth of children and teens during puberty, in recent years there has been a change in the lifestyles of various age groups, including children, especially in late childhood. Today's children, in fact, lead an increasingly sedentary lifestyle that implies the time spent by watching television (TV), using computers / smartphones and playing video games. This lifestyle leads them to neglect the physical activity typical of this period of development[11]. Systematic reviews and studies regarding the effect of physical activity (PA) on health indicated that children and adolescents engaged in increased levels of physical activity had better physical and mental health and psychosocial well-being than their sedentary peers[12-14]. Promoting physical activity (BP) among children and adolescents has been shown to benefit a range of medical conditions, including obesity, cardiovascular disease and all-cause mortality and a range of psychological health problems[15]. Sedentary behavior also contributes to a delay in cognitive development and a decrease in the academic performance of children and young people[16]. Furthermore, there is growing empirical evidence of a relationship between lack of physical activity and mental health measures. For example, research suggests that overweight teens who do not play sports are more prone to risky behaviors, including suicide attempts and addiction to alcohol and illicit drugs[17]. Physical activity guidelines in a report from the National Association for Sport and Physical Education[18] stress that children should spend at least 60 minutes a day in physical activity (such as walking to school, climbing stairs and ride a bicycle).

It has long been known that physical activity and sport have a positive impact on the physical and mental health of children and young people[19]. Multi-disciplinary research on children’s play has identified the cognitive, social, and physical health and developmental benefits that it affords children[20].

First of all, activity-induced energy expenditure is the most variable component of daily energy expenditure (DEE), as determined by the activity pattern including exercise. Variation in energy expenditure determines, with energy intake, energy balance, and eventually body composition, when energy imbalance is covered by storage or mobilization of body fat. Additionally, consistent changes in physical activity through immobilization or exercise training affect body composition by changes in muscle mass.

Furthermore, physical training affects the state of hormonal status in both men and women, and in both adults and young people[1]; this is especially true for football, that is a high intensity and physical demanding sport[4]. Thus, hGH, testosterone and cortisol values, and T/C ratio are useful in assessing the impact of training and competition as a reflection of the balance among catabolic and anabolic processes[8]. Furthermore, concentrations of hGH, another anabolic hormone produced by the pituitary, fluctuate widely, reflecting not only endogenous plasticity but also responses to stress and training[21]. Therefore, the values of hGH, testosterone and cortisol and the T/C ratio are useful for evaluating the impact of training and competition as a reflection of the balance between catabolic and anabolic processes[22].

From a psycho-physiological perspective, acute physical activity triggers an increase of neurotransmitters (e.g. epinephrine, dopamine, brain-derived neurotrophic factors), which are thought to enhance cognitive processes[10]. Acute aerobic exercise can facilitate cognitive functioning by facilitating specific aspects of information processing[23]. The findings of Hillman and colleagues[23] also imply acute exercise can increase the allocation of attention and memory resources and thus benefits executive control function in college students. In this context, the relation of physical activity and fitness to academic performance is of special interest because physical education programs in schools are required to contribute to the primary mission of schools, i.e. the promotion of academic performance. Current studies have focused on the relation between physical activity and the academic performance of school-age children. A meta-analysis with children[24] has demonstrated that physical activity participation is associated with better cognitive performance. In this study was used the D2 test of attention, that is a widely used paper and pencil measure of sustained and selective attention in which both components of speed and accuracy have been taken into consideration in its scoring system. It is a cancellation test in which respondents have to cross out target variables among similar no target stimuli.

In the present report we aimed to study the adaptations provoked by exercise over the course of a competitive season in football players; therefore, we assessed in youth football players belonging to southern Italy team the changes of hormonal concentrations (i.e., cortisol, hGH, testosterone and T/C ratio), linked to their school performance.

METHODS AND MATERIALS

Experimental designs

Football players were evaluated at four different time points, as shown in Figure 1: before the beginning of the training period (T0), just after the training period (T1), at the middle of the season (T2), and at the end of the season (T3). The blood samples were collected 24 hr after different matches, at 8.00 a.m., in the fasting state. In each period (T0, T1, T2 and T3) were performed physical tests and anthropometric measurements. Finally, in the last period (T4) in both group (control group and footballers) was performed the D2 test performance.

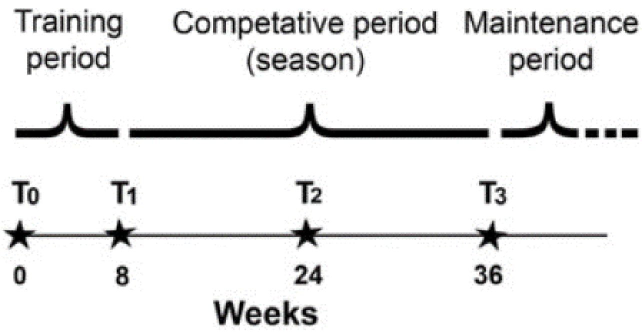

Figure 1. Organization of the research study protocol applied during a football season (36 weeks). Testing time-points were before the start of season (T0), after training (T1), in the middle (T2), at the end of season (T3).

Subjects

In this study were recruited young male footballers (mean age: 11.6 ± 1.2 years), compared to 30 control males (mean age: 11.4 ± 0.8 years), competing in a southern Italy team (youth category). All the players had experience on the football field (participated for at least 3 years in youth categories) and consisted in differing positional roles (forward, midfielder, defender, and goalkeeper). The study excluded players who suffered injuries during the season and had not trained for more than a month, so the study ultimately focused on 29 young players. The young players trained five times per week and competed in a match every week.
A control group composed of 30 nonathletic boys of the same ages (range 15–18 years), was recruited volunteered.
All procedures performed were in accordance with the ethical standards of the institutional and/or national research committee and the Helsinki Declaration of 1964 and its subsequent amendments or similar ethical standards. All study participants were informed about the purpose and nature of the procedures used. Therefore, their written informed permission was obtained from each participant or from his / her parents (for minors).

Anthropometric characteristics

Body weight and height of youth footballers were ascertained with standard techniques to the nearest 0.1 kg and 0.1 cm for each subject. The body fat percentage was calculated from four skins fold measurements (triceps, biceps, sub scapular, and suprailiac) using a Harpenden caliper (HaB International Ltd., Southam, UK) on the right side of the body. Starting from the measurement of the folds, the percentage of body fat was calculated through the Jackson and Pollock equation[25]. Table 1 shows the anthropometric characteristics of both groups, before the beginning of the training period (T0) and at the end of the season (T3).

	Young footballers		Control group	
	T0	*T3*	*T0*	*T3*
Age (years)	11.6 ± 1.2	12.3 ± 1.3	11.4 ± 0.8	12.1 ± 0.7
Height (cm)	159.7 ± 1.6	165.8 ± 1.6	159.8 ± 1.2	164.3 ± 1.4
Weight (kg)	38.3 ± 0.8	39 ± 1.3	38.4 ± 1.0	38.9 ± 0.8
Body fat (%)	12.1 ± 1.1	10.1 ± 1.8	12.3 ± 0.8	12.2 ± 0.9

Table 1. Anthropometric characteristics of young footballers and control group, before the beginning of the training period (T0) and at the end of the season (T3).

Physical fitness characteristics

To get information regarding the athletic status of youth footballers, we have asked them to performed athletic tests: maximal vertical jumping (SqJ-CMJ test), Yo–Yo test, maximum oxygen consumption and running speed test. The subjects familiarized with testing procedures and equipment before the measurements. The maximal vertical jumping was performed as described by Komi & Bosco[26]: each subject performed maximal jumps, the squat-jump (SqJ), starting with knees bent at 90° and without previous counter movement; then, each player performed maximal CMJ on the contact platform from a standing position with a preparatory movement from the extended leg position down to the 90-degree knee flexion. The ground reaction force generated during these vertical jumps was estimated with an ergo jump (Opto Jump Microgate, Microgate, Bolzano, Italy).
The Yo–Yo intermittent recovery test level 1 (YYIRT1) was used as a predictor of high-intensity aerobic capacity and VO_2max: each youth player continues running between two parallel lines 20 meters apart, at a progressively increasing speeds controlled by the “beeps” on a CD. The subjects had a 10 s active rest period between each series. From this test it was possible to estimate the VO_2max (ml/min/Kg), using the Bangsbo equation[27].
In the running speed test, the participants performed three maximal 30-m sprints, measured with an infrared photoelectric cell (Speedtrap II Wireless Timing Sistema; Brower Timing System, Draper, UT) positioned at different distances from the starting line: 5, 10, 20 and 30 m. During the 3-min recovery periods in between sprints, the participants walked back to the starting, for the next sprint. Youth players began the sprint when ready from a standing start 0.5 m behind the first timing gate. Velocity (m/s) and acceleration (m/s^2) were calculated by dividing the distance by the time required during the specific distance interval.

Blood analysis

Blood samples were taken at the same time of day to decrease the effects of daily variation on hormonal levels. Serum testosterone and cortisol were analysed by Immulite 2000 Immunoassay System. Growth hormone was analysed using LIAISON® hGH. This assay uses chemiluminescent immunoassay technology for the in vitro quantitative determination of hGH in human serum specimens. The test has been performed on the LIAISON® Analyzer (DiaSorin S.p.A., Gerenzano, Italy).

Cognitive test

In the periods T0-T3, both groups (control group and baby players) were subjected to the D2-test, a tool for assessing attention and concentration. The D2 test was administered to all subjects according to its standard procedures[28]. The test consists of 14 lines of characters where respondents should cross out d's with two dots in 20 seconds. This time limit is allotted for each line separately. As recommended in the literature [2, 42], both pre-test and post-test evaluations were performed for each subject and each participant performed the test only once. Performance in the d2 test was assessed using: (i) the total number of responses (German: << Gesamtzahl aller bearbeiteten Zeichen >>; GZ), including correct answers and errors in the D2 test, a quantitative measure of working speed, (ii) the standardized number of correct answers minus commission errors (German: << Standardwert der Konzentrationsleistung >>; SKL), an objective measure of concentration, and (iii) the number of all errors (omission error + commission error) relating to the total number of responses (German << “Fehlerprozentwert

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>>; F%) - a qualitative measure of accuracy and completeness. Errors are defined as omission errors (number of correct answers (e.g. "d" with two dashes) missed) and errands of commission (any distracting element such as a "p" or "d" with a dash or more than two incorrectly marked dashes).

Statistical analysis

Data were analysed by GRAPHPAD PRISM 5 software (GraphPad Software, La Jolla, CA). Student's unpaired t-test, Kolmogorov-Smirnov tests, or one-way analysis of variance (ANOVA) were used; when ANOVA returned $p < 0.05$, post hoc analysis by Bonferroni test was carried out for the comparison across time points. The correlations between independent variables (T, C, T/C, and hGH) and the dependent variables (physical performances) were determined by simple regression. The *t*-test was used for comparison between two groups of data. $p < 0.05$ was accepted as a level of statistical significance.

RESULTS

Anthropometric characteristics

Figure 2 shows the anthropometric data (body mass, height, and percentage of body fat) of the young football players during the entire season. Height significantly increased (ANOVA, $p < 0.05$) and the percentage of body fat decreased during the entire follow-up period (ANOVA, $p < 0.05$). The football player's weight decreased between T0 and T1 and then it significantly increased ($p<0.05$). From these results, it was clear the football player's change in values was significantly higher ($p < 0.05$) between T2 and T3 for height. The percentage of body fat and weight decreased significantly at the first follow - up period T0 - T1 and in the total followed period (T0 - T3) comparison. Instead, in the control group, the body weight ($p > 0.05$) and the percentage of fat mass ($p > 0.05$) did not undergo significant changes; and the significant increase in height was less than in young athletes (Fig 2, dashed line)

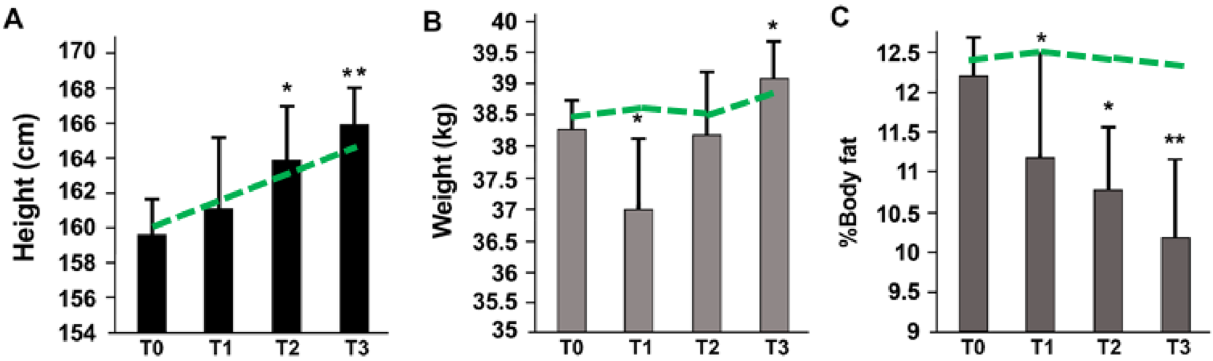

Figure 2. Anthropometric characteristics. Height (a), weight (b) and % body fat (c) of the football players were evaluated at four different time points. The data are presented as mean ± SD and significant differences between T1, T2, T3, and T0 were evaluated by t-test. The dashed line is referred to the trend of control group. *$p < 0.05$; **$p < 0.00$, by *t*-test.

Physical performance

Figure 3 shows the changes in physical parameters (CMJ, SqJ, YYIRT1 (m), and VO2max (ml/kg/min). Before the beginning of the training period (T0), the means (± SD) for SqJ and CMJ were 34.3 ± 3.5 cm and 38.0 ± 5.4 cm, respectively. In T0, Yo-Yo intermittent recovery tests showed a mean of 2297.6 ± 481m. Significant increases were observed in SqJ, CMJ and Yo-Yo test in all periods. Significant differences ($p < 0.05$) were also noted for VO_{2max} in T0-T1, T1-T2, and in T2-T3. The control group parameters, which did not show any significant changes during the sampling period ($p > 0.05$, for all).

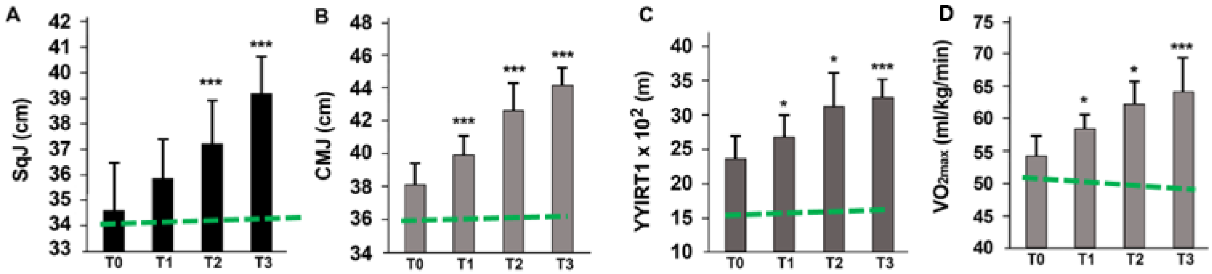

Figure 3. Physical parameters in young football players during the entire season. SqJ: Squat Jump (A); CMJ: Counter Movement Jump (B); YYIRT: Yo-Yo Intermittent recovery test level 1 performance (C) and VO_{2max} (D). The data are presented as mean ± SD and significant differences between T1, T2, T3, and T0 were evaluated by t test. The dashed line is referred to the trend of control group. *p < 0.05; **p < 0.001, ***p < 0.0001, by *t*-test.

Blood analysis

The concentration of testosterone increased in T1 and T2 (from 18.4 ± 3.8 ng/dl to 36.4 ± 7.5 ng/dl; $p < 0.0001$) and decreased in T3 to the initial levels, to 19.6 ± 3.7 ng/dl (Fig. 4A).
The cortisol concentration increased in T1 (from 16.6 ± 4.7 µg/dl to 18.9 ± 4.9 µg/dl; T1, p < 0.001), then, decreased during mid-season (T2: 14.2 ± 1.2 µg/dl) (Fig. 4B).
T/C ratio also showed significant changes along the season. It increased just after the training period (T1) to reach high levels at the middle of the season in T2; then it returned to initial levels at the end of the season (Fig. 4 C)
Young player's hGH levels were significantly higher than those of control subjects assayed in all the assessment periods (T0-T3; $p < 0.001$ Fig 4D). Consistently, height increased more in the young football players than in the children of the control group (Fig 1A).

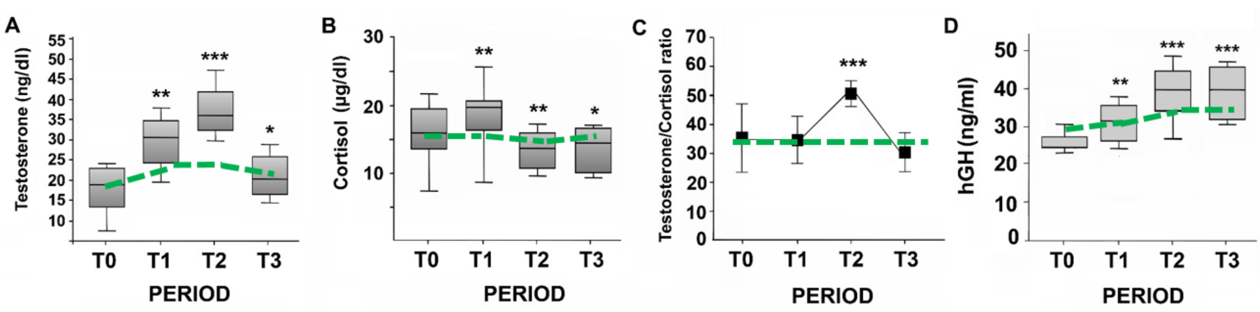

Figure 4. The effects of training on hormonal concentrations. Total serum testosterone (A), serum cortisol (B), testosterone to cortisol ratio (C) and hGH concentrations (D) were analysed each point - time during the football seasons follow - up (mean ± SD). In this

representation, the central box covers the middle 50% of the data values, between the upper and lower quartiles. The bars extend out to the extremes, whereas the central line is at the median. The dashed line is referred to the trend of control group. *p < 0.05; **p < 0.01; ***p < 0.001 by *t*-test between each point - time and T0.

Cognitive test

Finally, significant differences emerged between the young players and the control group regarding the total number of responses (GZ) and the correct responses minus errors of confusion, in D2 performance (Table 2). Conversely, the number of errors related to total number of responses (F%) is higher in the control group.

Measure	Football player (mean ± SD)	Control group (mean ± SD)
Total number of responses (GZ)	450.5 ± 50.1	432.1 ± 63.2
Correct responses minus errors of confusion (SKL)	107.4 ± 5.6	100.1 ± 8.7
Number of errors related to total responses (F%)	4.0 ± 3.7	6.8 ± 2.8

Table 2. D2 test performance. GZ: total number of responses in the d2 test (higher score represents better performance); SKL: standardized number of correct responses minus errors of commission (higher score indicates better performance); F%: number of all errors related to the total number of responses (lower score indicates better performance).

DISCUSSION

Although various factors football-related can influence endocrine physiological responses[1], few studies have investigated the effects of training on hormonal concentrations over a long period, especially in young football players. Analysing the hormonal status, we showed significant alterations during the follow-up period, due to high-level football training. Since cortisol has a catabolic effect on tissues (muscle breakdown) and is associated with a decrease in anabolic (muscle growth) hormones like hGH, the decrement of cortisol levels is healthy for the young football player as it should allow both tissue growth and positive physical adjustments to be achieved. Testosterone operates in repair and recovery of aerobic and anaerobic practicing muscle fibers and may improve the neural adaptations to gain capacities and physical performance. Specifically, these changes, mainly seen between T0 and T2 periods, may represent a typical modulation of homeostatic concentrations in response to adaptive process to the football training and to a stressful environment and competitions[29]. Another parameter used to evaluate an athlete's training state is the testosterone/cortisol ratio. Despite the controversial role of this ratio, it should be functional in indicating the general stress of training and the early identification of a disproportion between catabolic and anabolic metabolism[30]. Because a ratio with elevated cortisol indicates overtraining, it may suggest the need to make changes in the players' training schedule during the football season. Whereas our results showed an increase in the ratio at mid-season, and a re-entry to regular ratio at the end of the season, it is possible to assume that the young players were not tired and could adequately respond to coaching without accumulating fatigue.

Regarding the anthropometric characteristics, our results showed that the changes of young football players were equivalent to those previously tested[4]. In fact, a significant increase in the young football players' height was observed, supporting the suggestion that sport has beneficial effects on growth[31]. Furthermore, our results showed significant alterations in physical fitness parameters in the young football players during the season follow-up: these differences probably represent an adaptation to the exercise occurring during football training. Furthermore, the hormonal status significantly correlated with indicators of the power of the lower limbs (CMJ, SqJ) and aerobic performances (VO2max, YYIRT1) in young football players.
Finally, results of the D2 test revealed an enhanced attention and concentration performance in football players than in control groups. Given that the neurobiological mechanisms causing the exercise-induced improvement of cognitive performance are yet not fully understood[32], this explanation remains speculative and needs to be empirically proven (or rebutted) by future studies. However, even though the exact neurobiological mechanisms driving the exercise-related improvements of cognitive performance are yet not fully understood, it is undoubted that the cognitive enhancement relies on changes on different levels of analysis[32-34]. For instance, there is evidence in the literature showing that changes on a functional brain level (e.g., changes in cognition-related brain activity patterns)[35] or even on a molecular and cellular level (e.g., changes in the blood concentration of peripheral lactate[36] or brain-derived neurotrophic factor (BDNF)[37]) are associated with acute exercise-induced improvements in cognitive performance. This probably indicated that changes in the peripheral blood lactate levels were linked to cognitive performance improvements in the exercise conditions. Thus, our findings buttress the idea that peripherally muscle-expressed lactate, which can cross the blood–brain barrier via monocarboxylate transporters, is utilized as "fuel" for cognitive processes[38-39]. In accordance with other studies[8;10], we hypothesize that in addition to an activation of neural parts of the brain like the frontal lobes, football players are supposed to lead to a greater excitation of the cerebellum which is also responsible for mediating cognitive functions.

CONCLUSIONS

Results suggest that physical activity caused in young football players physiological adaptations, from anthropometric characteristics to hormonal status. These adaptations are also positively related to attention and concentration.

REFERENCES

[1] Carson, V., Hunter, S., Kuzik, N., Wiebe, S. A., Spence, J. C., Friedman, A. Hinkley, T. (2016). Systematic review of physical activity and cognitive development in early childhood. Journal of Science and Medicine in Sport. 19(7), 573–578.

[2] Urhausen, A., Gabriel, H., Kindermann, W. (1995). Blood hormones as markers of training stress and overtraining. Sports Medicine. 20(4), 251–276.

[3] Wood, R. I., & Stanton, S. J. Testosterone and sport: Current perspectives. (2012). Hormones and Behaviour. 61(1), 147–155.

[4] Hammami, M. A., Ben Abderrahman, A., Hackney, A. C., Kebsi, W., Owen, A. L., Nebigh, A., Zouhal, H. Hormonal (cortical-gonadotropic axis) and physical changes with two years intense exercise training in elite young soccer players. (2017). Journal of Strength and Conditioning Research. 31(9): 2388–2397.

[5] Slimani, M., Baker, J. S., Cheour, F., Taylor, L., Bragazzi, N. L. Steroid hormones and psychological responses to soccer matches: Insights from a systematic review and meta-analysis. (2017). PLoS One. 12(10), e0186100.

[6] Hammami, M. A., Ben Abderrahman, A., Rhibi, F., Nebigh, A., Coppalle, S., Ravé, G., Zouhal, H. Somatotype hormone levels and physical fitness in elite young soccer players over a two-year monitoring period. (2018). Journal of Sports Science & Medicine. 17(3): 455–464.

[7] Donnelly JE, Hillman CH, Castelli D, Etnier JL, Lee S, Tomporowski P, Lambourne K, Szabo-Reed AN. Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children: A Systematic Review. (2016). Med Sci Sports Exerc. 48(6):1197-222.

[8] Jackson, W. M., Davis, N., Sands, S. A., Whittington, R. A., & Sun, L. S. Physical Activity and Cognitive Development. (2016). Journal of Neurosurgical Anesthesiology. 28(4), 373–380.

[9] Santana CCA, Azevedo LB, Cattuzzo MT, Hill JO, Andrade LP, Prado WL. Physical fitness and academic performance in youth: A systematic review. (2017). Scand J Med Sci Sports. 27(6):579-603.

[10] de Greeff JW, Bosker RJ, Oosterlaan J, Visscher C, Hartman E. Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis. (2018). J Sci Med Sport. 21(5):501-507.

[11] Graf C, Koch B, Klippel S, Buttner S, Coburger S, Christ H, Lehmacher W, Bjarnason-Wehrens B, Platen P, Hollmann W. Relationship between physical activity and concentration in childhood—Initial results of the CHILT project. (2003). Dtsch. Z. Sportmed. 54: 242–246.

[12] Janssen I, Leblanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. (2010). Int J Behav Nutr Phys Act. 7:40.

[13] Leung MM, Agaronov A, Grytsenko K, Yeh MC. (2012). Intervening to Reduce Sedentary Behaviors and Childhood Obesity among School-Age Youth: A Systematic Review of Randomized Trials. J Obes. 2012:685430.

[14] Wu XY, Han LH, Zhang JH, Luo S, Hu JW, Sun K. (2017). The influence of physical activity, sedentary behavior on health-related quality of life among the general population of children and adolescents: A systematic review. PLoS One. 12(11): e0187668.

[15] Iannotti RJ, Kogan MD, Janssen I, Boyce WF. (2009). Patterns of adolescent physical activity, screen-based media use, and positive and negative health indicators in the U.S. and Canada. J Adolesc Health. 44(5): 493-9.

[16] Tremblay MS, LeBlanc AG, Kho ME, Saunders TJ, Larouche R, Colley RC, Goldfield G, Connor Gorber S. (2011). Systematic review of sedentary behaviour and health indicators in school-aged children and youth. Int J Behav Nutr Phys Act. 8:98.

[17] Lipowski M, Lipowska M, Jochimek M, Krokosz D. (2016). Resiliency as a factor protecting youths from risky behaviour: Moderating effects of gender and sport. Eur J Sport Sci. 16(2): 246-55.

[18] Graf C. Active at any age—Sports and nutrition in various stages of life: Children. (2016). Aktuel Ernahrungsmed. 41: 32–34.

[19] Di Maglie, A., Marsigliante, S., My, G., Colazzo, S., Muscella, A. (2022). Effects of a physical activity intervention on schoolchildren fitness. Physiological reports, 10(2), e15115.

[20] Pellis SM, Pellis VC, Bell HC. (2010). The function of play in the development of the social brain. Am J Play. 2: 278–96.

[21] Cuneo, R. C., & Wallace, J. D. (1994). Growth hormone, insulin-like growth factors and sport. Endocrinology and Metabolism. 1: 3–13.

[22] Urhausen, A., Gabriel, H., Kindermann, W. (1995). Blood hormones as markers of training stress and overtraining. Sports Medicine. 20(4), 251–276.

[23] Tomporowski PD. (2003). Effects of acute bouts of exercise on cognition, Acta Psychol. (Amst.). 12: 297–324.

[24] Sibley BA, Etnier JL. (2003). The relationship between physical activity and cognition in children: a meta-analysis. Pediatr. Exerc. Sci. 15: 243–256.

[25] Jackson, A. S., & Pollock, M. L. (1978). Generalized equations for predicting body density of men. British Journal of Nutrition. 40(3): 497–504.

[26] Komi PV, Bosco C. (1978). Utilization of stored elastic energy in leg extensor muscles by men and women. Medicine and Science in Sports. 10(4): 261–265.

[27] Bangsbo, J., Iaia, F. M., Krustrup, P. (2008). The Yo-Yo intermittent recovery test: A useful tool for evaluation of physical performance in intermittent sports. Sports Medicine. 38: 37–51.

[28] Bates, M., Lemay, E. (2004). The d2 Test of Attention: Construct validity and extensions in scoring techniques. Journal of the International Neuropsychological Society. 10(3): 392-400.

[29] Young, W. B., Hepner, J., & Robbins, D. W. (2012). Movement demands in Australian rules football as indicators of muscle damage. Journal of Strength Conditioning Research, 26, 492–496.

[30] Adlercreutz, H., Härkönen, M., Kuoppasalmi, K., Näveri, H., Huhtaniemi, I., Tikkanen, H., Karvonen, J. (1986). Effect of training on plasma anabolic and catabolic steroid hormones and their response during physical exercise. International Journal of Sports Medicine, 7(Suppl 1), 27–28.

[31] Brown, K. A., Patel, D. R., & Darmawan, D. (2017). Participation in sports in relation to adolescent growth and development. Translational Pediatrics, 6(3): 150–159.

[32] Pontifex M.B., McGowan A.L., Chandler M.C., Gwizdala K.L., Parks A.C., Fenn K., Kamijo K. (2019). A primer on investigating the after effects of acute bouts of physical activity on cognition. Psychol. Sport. Exerc. 40:1–22.

[33] Stillman C.M., Cohen J., Lehman M.E., Erickson K.I. (2016). Mediators of physical activity on neurocognitive function: A review at multiple levels of analysis. Front. Hum. Neurosci. 10:626.

[34] Herold F., Müller P., Gronwald T., Müller N.G. (2019). Dose-response matters!—A perspective on the exercise prescription in exercise-cognition research. Front. Psychol. 10: 2338.

[35] Herold F., Wiegel P., Scholkmann F., Müller N.G. (2018). Applications of functional near-infrared spectroscopy (fnirs) neuroimaging in exercise⁻cognition science: A systematic, methodology-focused review. J. Clin. Med. 7:466.

[36] Hashimoto T., Tsukamoto H., Takenaka S., Olesen N.D., Petersen L.G., Sørensen H., Nielsen H.B., Secher N.H., Ogoh S. (2018). Maintained exercise-enhanced brain executive function related to cerebral lactate metabolism in men. FASEB J. 32:1417–1427.

[37] Hwang J., Brothers R.M., Castelli D.M., Glowacki E.M., Chen Y.T., Salinas M.M., Kim J., Jung Y., Calvert H. (2016). Acute high-intensity exercise-induced cognitive enhancement and brain-derived neurotrophic factor in young, healthy adults. Neurosci. Lett. 630:247–253.

[38] Törpel A., Herold F., Hamacher D., Müller N.G., Schega L. (2018). Strengthening the brain—Is resistance training with blood flow restriction an effective strategy for cognitive improvement? J. Clin. Med. 7:337.

[39] Brooks G.A., Arevalo J.A., Osmond A.D., Leija R.G., Curl C.C., Tovar A.P. (2021). Lactate in contemporary biology: A phoenix risen. J Physiol. 1–23.