Sport Training

Relationship between aerobic fitness and technical performance of semi-professional male soccer players in real play situation

Pedro Victor Felisberto da Silva[1,2,5], Sylvia Chedid Seidinger[1], Rennan Vaz[1], Ricardo Ribeiro Agostinete[1,4,5], Camila Buonani da Silva[1,3]

[1]Universidade Estadual Paulista, Departamento de Educação Física, Presidente Prudente, SP, Brazil; [2]Universidade Estadual Paulista, Departamento de Educação Física, Grupo de Estudo do Desporto e Exercício de Força, Presidente Prudente, SP, Brazil; [3]Universidade Estadual Paulista, Departamento de Educação Física, Grupo de Estudos e Pesquisa dos Esportes, Presidente Prudente, SP, Brazil; [4]Universidade Estadual Paulista, Departamento de Educação Física, Grupo de Investigações Científicas Relacionadas à Atividade Física, Presidente Prudente, SP, Brazil; [5]Universidade Estadual Paulista, Departamento de Educação Física, Programa de Pós Graduação em Ciências do Movimento – Interunidades, Presidente Prudente, São Paulo, Brazil.

Associate Editor: Paulo Henrique Guerra, Universidade Estadual Paulista "Júlio de Mesquita Filho", Instituto de Biociências, Departamento de Educação Física, Rio Claro, SP, Brazil. E-mail: paulo.guerra@unesp.br.

Abstract - Purpose: To analyze whether aerobic fitness is related to technical actions (TA) of semi-professional soccer players in a real game situation. **Methods:** The sample consisted of 10 semi-professional male soccer athletes who competed in a championship belonging to the São Paulo Soccer Federation. Data collection took place in three stages, as follows: I) measurement of anthropometry and body composition; II) physical test (aerobic power); III) game analysis and TA registration. To establish the objectives of the study, the Wilcoxon tests were used to compare the frequencies of TA; Spearman correlation to analyze the correlation between the maximum oxygen consumption ($VO2_{max}$) and TA and Simple Linear Regression to analyze the magnitude of the effect of $VO2_{max}$ on TA. **Results:** The correlation analysis allowed us to observe that the $VO2_{max}$, the lower the frequency of errors in some TA during the games. It was also evidenced that more than 45% of incorrect TA in games are explained by a low $VO2_{max}$ and that athletes with higher $VO2_{max}$ make fewer errors during games when compared to those with lower $VO2_{max}$. **Conclusion:** A direct and conditioning relationship between $VO2_{max}$ and technical performance of semi-professional soccer players was evidenced, indicating that higher levels of $VO2_{max}$ act as a possible protective factor against poor technical performance during matches, suggesting physical training programs aimed at the increase of $VO2_{max}$, as a good strategy to guarantee the maintenance of a good technical performance of the players during matches.

Keywords: aerobic power, technical actions, sports performance, physical performance, team sport.

Introduction

The literature shows that the improvement of the quality of play in soccer depends on different factors, one of which is physical fitness[1]. Good physical fitness is one of the main variables that condition a good game performance (technical performance aligned with tactical performance)[2,3]. Knowledge of the interaction between these factors is essential for the correct planning and prescription of training and, consequently, for competitive success[4,5].

In this sense, maximum aerobic fitness is one of the main variables of physical fitness that can directly influence the practical development of soccer, since the average metabolic load of a game varies from 70% to 80% of the maximum oxygen consumption ($VO2_{max}$ = maximum aerobic fitness)[6,7]. Thus, high levels of maximum oxygen consumption ($VO2_{max}$) can play an essential role, as they support the ability of soccer players to perform intermittent (technical and tactical) actions at high intensity and for long periods[8,1].

Along these lines, studies have sought to evidence the influence of $VO2_{max}$ on the technical performance of soccer players, such as the classic study developed by Helgerud et al. (2001)[9] with elite players, where an increase in technical performance and in game participation was observed after eight weeks of training focused on improving $VO2_{max}$. At the end of the study, an improvement in the involvement of the athletes with the ball and a decrease in incorrect passes was observed, suggesting that the improvement in $VO2_{max}$ is directly linked to the improvement in game performance, which can play a fundamental role in the success of a competitive team.

From this, it is also worth noting that, during a soccer match, the players perform different functions within the tactical scheme adopted by the team, which result in technical actions (TA) and specific tactics, in which the success of such actions depends directly on the individual technical level of the athlete[2,3]. Therefore, the improvement of the technical level of the athlete, mediated by a good $VO2_{max}$, presents itself as a good strategy to improve the individual and, consequently, the collective performance of the team.

From this, it is vitally important that the investigations on the possible interactions between TA and $VO2_{max}$ are done with great precision, so that they provide full information about the technical condition of players in real game situations, thus providing accurate data for further improvement and/or maintenance of vital technical skills for soccer practice. However, most contemporary studies that analyze the theme use software to classify TA, a method that has some deficiencies.

In software, TA are not analyzed from their origin to their conclusion, thus causing limitations of interpretation for their subsequent classification. Many of the soccer TAs have wide ranges of interpretation. If they are not analyzed from their origin and considering all the contexts involved in TA, they may not be accurately classified. Thus, it can be said that these ranges of interpretation are difficult to understand by software due to the complexity of the biomechanical kinematics involved in TA.

Therefore, from the premises presented above, the present study intended to advance in this gap left by the studies that are based on software classification. The use of previous concepts of each TA analyzed, added to the use of trained evaluators with experience in game analysis, both supported by the statistical method of Cohen's Kappa coefficient, support software use. Thus, the present study aimed to analyze whether a low maximal aerobic fitness may be related to errors in TA in semi-professional soccer players in real game situations. With this, it was assumed as a hypothesis that lower levels of aerobic fitness may act as a conditioning factor for poor technical performance during soccer matches.

Methods

Experimental design and sample selection

All study procedures were previously approved by the Research Ethics Committee of the University (protocol number: 31023314.2.0000.5402/2015) where the study was carried out and were in accordance with the Declaration of Helsinki (DoH) regarding Research Involving Human Subjects, and it was conducted according to the ethical standards for scientific research in sport, established by Harris and Atkinson, (2009)[10].

The present study is a cross-sectional study carried out at the end of the pre-season (May 2016) of a semi-professional soccer team. The sample was formed by convenience, and, was composed of 10 semi-professional male soccer athletes (paid athletes, however, who do not have exclusive dedication to the sport [athletes play the following positions: defenders, full-backers, defensive midfielders, midfielders, and forwards]) from a local team that played in a championship (official) belonging to the São Paulo Soccer Federation (Taça Paulista de Futebol). Such championships give access to the second division of state championships in Brazil, that are recognized and supported by FIFA. This championship featured 25 semi-professional football teams and was played in two phases, (qualifying round and knockout round), in which the analyzed team was eliminated in the quarterfinals of the competition.

The training (before and during the season) consisted of training sessions with weights, plyometrics, and proprioception, taking place three times a week with a minimum duration of 60 min, always in the opposite period to specific soccer training. Specific physical, technical, and tactical training sessions took place five times a week on a soccer field with official measures, with an average duration of 180 min. During the pre-season period, the team held practice games at the end of each training week against teams that were participating in the same competition (friendly and preparation games). It is worth noting that the analyzed soccer players were also divided into two groups (higher and lower $VO2_{max}$), in which the median of the $VO2_{max}$ was used as a cut-off point for dividing the groups. Finally, all training periods were structured and applied by a trained and qualified physical education professional specialized in football training.

For participation in the study, the inclusion criteria were: (I) male; (II) semi-professional level soccer athlete; (III) carry out all assessments; (IV) participate in at least 70% of the matches related to data collection; (V) be an outfield player, and (VI) sign the consent form and formal clarification for participation in the study. After applying the inclusion criteria, the final sample consisted of 10 athletes [median age 20.9 (confidence interval 19.2 - 27.4) years] according to the data presented in Table 1.

Data collection

The sample calculation was performed at G-Power software 3.1, the minimum sample size was estimated taking into account a correlations model, a minimum correlation of $r > 0.71$ between the VO2máx and technical performance[11], a statistical power of 95% and an alpha error of 5%. According to the statistical sample size calculation, sample should be composed of at least 10 athletes.

Table 1 - Anthropometric, body composition, and physical performance characteristics of male semi-professional soccer players (N = 10).

Variable	Median (IQI)
Age (years)	20.9 (19.2-27.4)
Weight (kg)	77.7 (69.3-100.7)
Stature (cm)	1.78 (1.71-1.95)
Yo-Yo Distance (m)	1120 (560-1760)
VO_{2max} estimated (mL/kg/min)	45.8 (41.1-51.2)
Total mass (kg)	77.2 (68.7-98.3)
Total lean mass (kg)	61.3 (52.7-81.2)
Total body fat (kg)	12.9 (7.3-18.7)
Total lean mass (%)	78.6 (72.6-85.2)
Total body fat (%)	16.6 (9.8-22.1)

IQI = interquartile range; $VO2_{max}$ = maximum oxygen consumption. Statistical Test: Shapiro-Wilk.

Thus, the present study met the minimum sample size to establish clinical (statistical) significance.

The study procedures took place in three stages: I) collection of general information from the players (name and chronological age), at which time the experimental and ethical procedures of the collection of anthropometric and body composition and physical tests and game footage data was informed to the participants. After the transmission of information about the experimental procedures, including benefits and potential risks of participating in the study, the players were given the terms of formal and informed consent to sign in order to participate in the study. After collection of the terms was carried out the measurement of anthropometric and body composition components; II) two day after the collection of morphological data was made the unitary application of the maximum Yo-Yo intermittent running recovery test (level 1) in order to measure and characterize physical performance; and III) filming and recording of TA in real game situations. It is worth noting that the collections of the first two stages took place over a period of one week. The collected TA, on the other hand, occurred in a period of 30 days right after the completion of the first two stages of the study.

The athletes were instructed not to ingest licit and illicit drugs or consume stimulant drinks or sodium bicarbonate before any of the collections of dice carried out. They were also instructed to have a minimum of six uninterrupted hours of sleep in the days prior to the collections, in addition to not having performed any type of strenuous physical activity in the last 24 h prior to the experimental procedures. In addition, such instructions were given because the highlighted behaviors could influence the final test results.

Anthropometry and body composition

To characterize the sample, the total body mass was measured using a Filizola electronic scale, with a maximum capacity of 180 kg and a precision of 0.1 kg. Height was measured using a Sanny fixed stadiometer, with a precision of 0.1 cm and a maximum extension of 2.20 m[12].

Body composition was measured using Dual Energy X-ray Absorptiometry (DXA [General Electric Medical Systems, Lunar DPX MD, Madison, WI, USA]), 4.7 software that uses the three-compartment model (lean soft tissue, body fat mass and mineral mass). For the present study, the values of lean body mass and fat body mass, expressed in absolute and relative values, were estimated.

Intermittent Yo-Yo test (level 1)

The Yo-Yo Intermittent Run Recovery Test (Level 1) was performed as described by Bangsbo, (1996)[13]. The total distance covered (in meters) was recorded in order to quantify the physical performance and estimate the $VO2_{max}$ based on the equation developed by Bangsbo, Iaia and Krustrup, (2008)[14]. It is worth noting that the procedure was applied during the day, in a sunny climate, in which the athletes were wearing cleats and light clothing. During the test, the participants received verbal incentives at each stage.

Collection of technical performance and game analysis

The analyzed team was accompanied during the performance of two official games referring to the São Paulo Soccer Cup, which took place in the afternoon between June and July. The games were filmed using a fixed camera (*Sony*, Brazil; 60 Hz frequency acquisition) positioned 10m above and 65m in front of the center of the field. The records were later analyzed to quantify the TAs, which were reported by scouts[15].

All TA were previously conceptualized and are presented as supplementary material 01. They were based and adapted for the present study from the concepts described by Liu et al. (2015 and 2016)[16,17] and Yi et al. (2019)[18]. To determine the technical performance, the TAs (presented in as supplementary material 01) were recorded and quantified. The final technical performance was indicated from the sum of the TA frequencies performed during both games. All TAs were quantified and analyzed by two independent evaluators with experience in analyzing soccer matches. The reliability of the technical performance analyses was determined through the two-trial repetition test for each moment and evaluator (Cohen's Kappa coefficient). The degrees of agreement of Kappa indexes for all analyzed variables ranged from 0.6 to 1 (inter-rater and intra-rater, respectively)[3,19].

Statistical treatment

The Shapiro-Wilk normality test was performed to verify the framing of all data sets analyzed in the Gaussian distribution model. Based on the obtained results, it was decided to use non-parametric statistics. The presentation of the results referring to the characterization of the sample was carried out through descriptive statistics, with median and interquartile range, respectively.

The comparisons of the TA frequencies in the first and second periods (1st and 2nd P, respectively) of the games, as well as the sum of the TAs of the two games were performed using the Wilcoxon test. The Spearman correlation test was used to investigate the correlations between TA and $VO2_{max}$, complemented by simple linear regression analysis, used to analyze the magnitude of the effect of $VO2_{max}$ on TA from the significant correlations.

For the interpretation of the magnitudes of the correlations, the classification described by Hinkle et al. (2003)[20] of the correlation coefficients was adopted, being: trivial ($r < 0.1$), small ($r = 0.11$ to 0.3), moderate ($r = 0.31$ to 0.5), strong ($r= 0.51$ to 0.7), very strong ($r = 0.71$ to 0.9), close to perfect ($r > 0.91$), and perfect ($r = 1$)[21]. Statistical significance was considered at values lower than 5% (*p-value* < 0.05). All analyzes were performed using the BioEstat software (version 5.0).

Results

While descriptive information about the sample is presented in Table 1, the Table 2 shows the descriptive analysis of the technical performance variables of the games, presented as the frequency of correct, incorrect, and total TAs (sum of correct and incorrect TAs of the two games) in relation to each period of the analyzed games (both). Note that there was a drop in performance in the AT gain of aerial ball from the 1st to the 2nd P of the games (*p-value* = 0.010).

Table 2 - Descriptive analysis of the frequency of correct, incorrect, and total technical actions, related to each game period of semi-professional soccer players during two official games (N = 10).

	1st Period			**2nd Period**		
	Correct	**Incorrect**	**Total 1st P**	**Correct**	**Incorrect**	**Total 2nd P**
Variables of technical actions						
Finalization/ shooting	07	08	15	07	07	14
Pass	198	31	229	158	27	185
Key Pass	06	00	06	02	00	02
Assistance	00	00	00	02	00	02
Cross	02	17	19	06	16	22
Through ball	10	18	28	10	19	29
Dribble	28	08	36	17	03	20
Air ball*a	26	**13*a**	39	25	**27*a**	52
Lost ball	00	28	28	00	23	23
Tackle	19	13	32	23	12	35
Interception	32	12	44	30	12	42
TBDZ	11	01	12	06	00	06
Kick Block	03	01	04	00	00	00
Total game participation	342	150	492	286	146	432
Defensive actions	91	40	131	84	51	135
PCA	244	74	318	195	65	260

1st P = first period; 2nd P = second period; Total 1st P = sum of correct and incorrect actions from the 1st periods of both games; Total 2nd P = sum of correct and incorrect actions of the 2nd periods of both games; PCA = played building actions; TBDZ = taking the ball out of the danger zone. Statistical test = Wilcoxon; * = Difference between the first and second periods of the games; **a** = p-value < 0,05.

Correlation analyses between incorrect $VO2_{max}$ and TA are shown in Table 3. It is noted that there were strong to very strong negative correlations between $VO2_{max}$ and incorrect through ball TA in the 1st P (Rho = - 0.741 and p-value = 0.014), total incorrect through ball (Rho = - 0.733 and *p-value* = 0.016), incorrect play building actions in 1st P (Rho = - 0.728 and *p-value* = 0.017) and total incorrect play building actions (Rho = - 0.716 and *p-value* = 0.020).

Variables with significant correlations were inserted into simple linear regression models, which are shown in Table 4. Values for $VO2_{max}$ point to a variance of 54% in incorrect through ball actions in the 1st P, 50% in total incorrect through ball actions in the 1st P, 58% in incorrect play building actions in the 1st P, and 46% in total incorrect play building actions.

Finally, the comparison of the frequency of total incorrect technical actions (sum of incorrect TAs from both periods of the two games), relative to each period of the two games between the group of athletes with the highest and lowest $VO2_{max}$ these are presented as supplementary material 02. The results show that the group with the highest $VO2_{max}$ committed fewer errors in incorrect through ball actions during the 1st P (*p-value* = 0.024), total incorrect through ball actions in the 1st P (*p-value* = 0.017), total incorrect participation with ball in the 2nd P (*p-value* = 0.042), incorrect play building actions in the 1st P (*p-value* = 0.046), incorrect play building actions in the 2nd P (*p-value* = 0.013) and total incorrect play building actions (*p-value* = 0.016).

Discussion

The present study aimed to investigate the relationship between aerobic fitness ($VO2_{max}$) and technical performance of semi-professional soccer players in real game situations. In view of this, the main findings showed that $VO2_{max}$ was negatively related to different incorrect technical actions (Tas) such as throwing and play building (sum of all analyzed ATs), explaining at least 46% of the variance. In addition, athletes with higher $VO2_{max}$ had fewer incorrect ATs compared to those with lower $VO2_{max}$.

The method of video analysis added to the statistical test of repetition of two attempts for each moment and

Table 3 - Correlation between $VO2_{max}$ and incorrect technical actions of semi-professional soccer players during two official matches (N = 10).

	1st Period		2nd period		Total periods	
	r	*p-value*	r	*p-value*	r	*p-value*
Variables of technical actions						
Finalization/shooting	-0.373	0.170	-0.056	0.841	-0.429	0.216
Pass	-0.632	0.050	-0.325	0.339	-0.617	0.058
Cross	-0.289	0.418	-0.092	0.799	-0.303	0.394
Through ball	-0.741	**0.014**	-0.435	0.209	-0.733	**0.016**
Dribble	-0.208	0.564	0.061	0.868	-0.058	0.873
Air ball	-0.533	0.113	-0.178	0.623	-0.411	0.238
Lost ball	-0.442	0.200	0.281	0.432	-0.068	0.852
Tackle	-0.316	0.374	0.006	0.986	-0.125	0.731
Interception	-0.210	0.560	-0.165	0.649	-0.111	0.760
TBDZ	0.000	1.000	0.000	0.000	-0.000	1.000
Kick Block	0.000	1.000	0.000	0.000	-0.000	1.000
Total incorrect participation	-0.549	0.100	-0.442	0.200	-0.610	0.061
Defensive actions	-0.414	0.243	-0.173	0.633	-0.416	0.232
Building actions	-0.728	**0.017**	-0.603	0.065	-0.716	**0.020**

$VO2_{max}$ = maximum oxygen consumption; Total Periods = sum of incorrect actions of both periods of the two games; TBDZ = talking the ball out of the danger zone; Rho = correlation coefficient. Statistical Test = Spearman.

Table 4 - Association between $VO2_{max}$ and incorrect technical actions of semi-professional soccer players during two official matches (N = 10).

	B	R^2	*p-value*	D-W
Variables of technical actions				
Incorrect through ball 1st P	-0.738	0.545	**0.037**	1.137
Total incorrect through ball	-0.712	0.507	**0.047**	1.632
Building actions 1st P	-0.765	0.585	**0.010**	2.228
Total incorrect through ball	-0.683	0.466	**0.030**	1.860

$VO2_{max}$ = maximum oxygen consumption; 1st P = first period of the games; R^2 coefficient of determination. Statistical Test = Simple Linear Regression; D-W = Durbin-Watson test to verify the autocorrelation between the residues of the Simple Linear Regression model.

evaluator (Cohen's Kappa coefficient) provides reliability to the study results. This method, in addition to being accessible and covering the most varied technical-competitive levels of soccer, also corresponds to the software used for game analysis. It is worth noting that this analysis may even be prominent since it is possible for TAs to be fully interpreted from their origin to their conclusion.

Soccer TAs have a wide range of interpretation and, when they are not analyzed from their origin point, not all contexts involved in the AT are considered (such as player positioning and the presence of other players), thus, they may not be understood and, consequently, not accurately classified. Additionally, the scenario described recently is not commonly understood by software due to the varied contexts that can involve TAs (due to the dynamism of collective invasion modalities such as soccer) and, mainly, given the complexity of the biomechanical kinematics involved in them, which may lead to limitations in interpretation, and consequently, in classification.

Thus, the findings of the present study help to strengthen the theme, due to the use of an accessible and reliable game analysis method. In addition, the present study included semi-professional athletes, highlighting the importance of our findings, since most of the studies that analyzed physical and technical performance in soccer used professional and/or elite athletes, a fact that makes it difficult to extrapolate the results to the context of semi-professionalism. It is worth remembering that most soccer practitioners in Brazil an Latin America are semi-professional.

The findings presented validate the hypothesis of the study, in addition to suggesting that $VO2_{max}$ plays a significant role in the technical performance of semi-professional soccer athletes during real game situations, since in the current study, the group of athletes with the highest $VO2_{max}$ made fewer mistakes during the games. However, the findings of the present study are in contrast with the findings of the study by Modric et al. (2020)[22], who concluded after analyzing 16 real/official games of an elite soccer team that $VO2_{max}$ had no influence on the players' game performance. This contrasting scenario helps to foster the premise presented above, of difficulty in extrapolating results with professional and/ or elite athletes to the context of semi-professional soccer due to the difference in structure that involves both contexts. Hence, the context of semi-professionalism in soccer cannot be neglected from studies that support its practices.

The relationship between $VO2_{max}$ and technical performance previously evidenced can be explained by the fact that high levels of $VO2_{max}$ are positively associated with fatigue resistance (FR). Adequate FR supports a good technical performance during the match[23,24]. Athletes with reduced FR (and consequently reduced $VO2_{max}$), when subjected to high workloads, suffer a cascade of reactions that generate the accumulation of metabolites, which, when accumulated in excess, tend to influence motor capacity. That happens due to their negative interference in the action of enzymes responsible for muscle contraction (via decreased myosin energy resynthesis and calcium ion availability)[25,26,27]. In this manner, such a scenario reduces the capacity and power of muscle contraction, thus causing peripheral fatigue, which promotes poor motor action, resulting in poor technical performance[26,23,24]. In view of this, can assume that athletes with reduced $VO2_{max}$, when subjected to high workloads for long periods, are unable to sustain important TAs, which can be decisive for competitive success, namely submission actions, tackles, passes and the like[28,29,30,31].

In addition to the increase in concentrations of metabolites harmful to muscle power and strength, these high workloads during the match tend to promote increased concentrations of interleukin 6 (IL-6) due to constant muscle contraction[32,33,26]. During high-intensity physical activities, IL-6 is a myokine that plays an important role in muscle metabolism due to its pleiotropic effect, especially in the homeostasis of glucose availability, which is also responsible for mobilizing glycogen stores to supply the high metabolic demand of exercise or intense physical activity[32,33,26].

During intense physical activities, the expression of IL-6 from muscle fibers can increase considerably. This way, this myokine starts to present a concrete characteristic in motor action[32,33]. Specifically, IL-6 produced during physical activity inhibits the significant expression of pro-inflammatory cytokines, in addition to inducing glycogen degradation via AMPK (adenosine monophosphate-activated protein kinase), providing increased sensitivity to insulin[33]. Thus, this range of operations induced by IL-6 keeps the availability of energy substrate at levels that are sufficient to meet the intense metabolic demand of physical activity, thus increasing the FR and, consequently, stabilizing the motor efficiency of TA.

Another important point to highlight is that the increase in IL-6 can also act to induce an increase in serotonin hormone concentrations, which directly influences the ability of the central nervous system to maintain exercise and motor efficiency[34,26]. Because TAs are idealized and performed via the central nervous system, the motor cortex becomes deficient in supplying the motor demand of decisive TA when exposed to high workloads (for long periods) by an athlete with a low FR, and consequently, a low ability to mobilize energy substrate[28-31]. As a result, the occurrence of imminent central fatigue tends to negatively influence the technical performance and, consequently, the game performance of athletes with reduced FR and reduced $VO2_{max}$[23,24]. Finally, it is worth noting that other immunometabolic variables may also appear in the scenario just described, since IL-6 does not play a major role in this system.

From the premises presented so far, it can be said that a reduced $VO2_{max}$ is concomitantly associated with a low FR, and consequently, a low ability of the athlete to withstand physical activities at high intensity for a long period, and therefore, to maintain satisfactory technical performance during matches. As mentioned earlier, the expression of IL-6 increases during intense physical activity, therefore, the athlete who has a higher $VO2_{max}$, and consequently, a higher FR, will last longer in a high intensity physical activity, thus expressing IL-6 longer. Accordingly, can assume that athletes who have a higher $VO2_{max}$ tend to endure high intensity matches for a longer time and without showing a decline in technical performance, in which this factor is essential for competitive success due to the high technical-competitive level and competitive intensity of current soccer[32,33]. In view of this, it is possible to infer that the $VO2_{max}$ presents itself as a relevant intervening variable for a good technical quality of the team, being able to positively influence the competitive success due to the apparent protective effect that high levels of $VO2_{max}$ can exert against the onset of early central and/or peripheral fatigue, and, consequently, the decline in the technical quality of the TA during matches.

In addition, it is known that the average total distance covered by athletes during a soccer match varies from 10 to 14 km, and most of these distances are completed through low intensity walking and running, which demand low metabolic activity muscles[01,35]. In this context, the resynthesis of energy for the continuity of muscle activity occurs mainly via aerobic metabolism. However, a large part of the decisive TAs in a soccer match happens via anaerobic metabolism, which are characterized as fast, maximal and of short space, occurring between 10-20 m[36,37]. In this context, it is acceptable to propose that high levels of $VO2_{max}$ directly reflect a high anaerobic threshold, and as a consequence, an efficient economy of biomechanical work[09,38,06]. Thus, $VO2_{max}$ can be presented as a predictor for efficient performance of motor actions at high intensities, such as the TAs that are decisive for a match[39,40].

The present study also displayed a small drop in the technical performance between match periods. In addition to that, significant relationships between technical performance and $VO2_{max}$ in the second periods of the matches were not evidenced. Such results can be explained by the degradation and resynthesis of phosphocreatine (PCr)[08,37]. This premise was confirmed in the study by Mendez-Villanueva et al. (2012)[40], who concluded that the inability to maintain and recover muscle power during intense and repetitive physical activity is mainly mediated by signs of intramuscular peripheral fatigue, which is associated with the control of PCr metabolism. As mentioned before, good levels of $VO2_{max}$ and FR are essential factors for success in competitive soccer in view of the highly competitive intensity of the sport currently, since the decisive TAs of soccer are carried out via anaerobic metabolism[32,33].

One of the main limiting factors for PCr resynthesis is the availability of oxygen, therefore, a low anaerobic threshold. Consequently, a low $VO2_{max}$ and FR can lead to a decrease in technical performance during the match[37-39]. Thus, increases in $VO2_{max}$ and FR can directly reflect on the improvement of muscle buffering capacity and efficient supply of metabolic demand. In the long term, this is an effective strategy to avoid the decline of an efficient TA motor performance during the match[38,39].

It is also worth noting that, in a relative way, the present study found a significant relationship between TA and $VO2_{max}$ only for through ball technical actions. However, in an absolute way, a significant relationship was found between $VO2_{max}$ and the range of TAs that make up play building, which are important for competitive success, since they are the union of a set of TAs that can promote potential moves, goal situations and defense against the opponent. This presupposes that $VO2_{max}$ can introduce yourself as an important predictor for an efficient and successful technical-competitive development, since it was presented in an influential and integral way in the TAs that involve the systematic and competitive practice of soccer. However, future studies should further explore this interaction-aiming to strengthen it-by analyzing a larger number of games and involving different teams, as the data from the present study may not be sufficient to confirm this interaction.

Based on the data and premises presented, it is evident that $VO2_{max}$ is an potential physiological variable for a technical-competitive performance. That happens due to the improvement in the ability to withstand high workloads based on the increase in $VO2_{max}$, and consequently, the anaerobic threshold and FR. This is shown to be a good method for improving economy of work, as well as effectively meeting the metabolic demand of soccer players. Therefore, high levels of $VO2_{max}$ can act as a possible protection factor against the drop in the quality of the technical and, consequently, the tactical performance of the team, especially if such a scenario is based on matches with a high physical intensity character.

The present study displays relevant results; however, the limitations need to be mentioned. Firstly, a small number of players belonging to a lower technical level team may not be sufficient to draw robust conclusions in different scenarios, such as leagues with a higher technical level and a greater number of players. Nevertheless, the sample represents the reality of Brazilian soccer (and Latin America), composed largely of semi-professional athletes, who cannot be neglected from studies that strengthen the sports practice of this group. Furthermore, it is worth highlighting that longitudinal studies following different teams throughout a competitive season may provide broader and more precise results, as tactical actions TAs can be influenced by the tactical schemes and playing styles adopted by each team in response to match demands.

And with that, it is worth highlighting the strengths of this study, once the TAs were collected in real soccer game situations and through a broader interpretation method. Most studies of this theme are done under laboratory conditions or training/reduced games. In those cases, it also happens that the TAs are collected by software, which frequently do not understand the full context of the TA. Such conditions escape the reality of the sport and make it difficult to extrapolate their findings to teams of lesser economic importance.

Additionally, even regarding the intermittent Yo-Yo test as an indirect method to measure $VO2_{max}$, such a test guarantees the specificities of soccer. The mechanics of running when performed on hard ground (treadmill, for example) is altered and, consequently, overestimated when compared to running on the grass field, since running on hard ground provides a mechanical advantage for the athlete, as well as, even on a smaller scale, ends up overestimating test performance[26,27,37,39].

When running on hard ground, elastic force is produced, which is generated from the contact of the skeletal muscles and tendons with the hard ground (strength-length relationship), thus generating, in addition to mechanical energy, kinetic energy, at the same time which drives the athlete towards the direction of the race. On that account, even if to a lesser extent, such an advantage can overestimate the results of the athlete's fatigability kinetics[26]. Therefore, even the intermittent Yo-Yo test being characterized as an indirect method to measure $VO2_{max}$, such a test has its strengths, as it is an accessible and effective method, which also provides a reliable extraction and extrapolation of the physiological parameters data for the elaboration of training protocols.

Together with the evidence here presented, it should be interesting to consider that variables such as physical readiness, experience with the modality, time of practice of the modality, structural conditions, and training can also directly influence the technical performance of soccer players[1,38-40]. Thus, the combination of such variables allied to the increase in $VO2_{max}$ can play a potential differentiating role for sporting and competitive success, being able to present itself as a differential strategy for semi-professional players to reach higher competitive levels, professional players to reach the competitive elite, and for players who already belong to the competitive elite to remain in it.

Finally, in addition to informing the direction of future research, the present study advances the understanding of the complex relationship between aerobic fitness and technical performance in soccer-particularly within the context of semi-professional play. It emphasizes the use of accessible tools that address the specific demands of the sport. To date, few studies in the literature have identified significant relationships between aerobic fitness and technical performance. This suggests that a possible obstacle to detecting such interactions may lie in the tools and methodologies employed in previous experimental designs.

Conclusion

Aerobic fitness, measured by $VO2_{max}$, proved to be a negative predictor of incorrect technical actions (TAs), explaining at least 46% of the variance of an incorrect TA during a match. In addition, athletes with lower $VO2_{max}$ had a higher number of incorrect TAs during the analyzed games. Thus, based on our findings, physical training protocols aimed at increasing $VO2_{max}$ to ensure the maintenance and possible improvement of technical performance and involvement with the ball (participation in decisive throws) during soccer matches. Such protocols are presented as a good strategy to reduce technical errors during matches, with an improvement in game performance, being able to direct the choice of players and the technical as well as tactical improvement of the team, and consequently, the sporting and competitive success. In addition, $VO2_{max}$ can be considered as a predictor variable during player selection processes.

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Supplementary material

Chart S1. - Description of the conceptualization of the characteristics analyzed for the determination and quantification of technical actions.

Table S1. - Comparison of the frequency of technical actions with the ball according to VO2max of semi-professional soccer players.

Corresponding autor. Pedro Victor Felisberto da Silva.
Universidade Estadual Paulista, Departamento de Educação Física, Bloco III, 19060-900, Presidente Prudente, SP, Brazil.
E-mail: pedro.f.silva@unesp.br.

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Chart S1. Supplementary material . Description of the conceptualization of the characteristics analyzed for the determination and quantification of technical actions.

Offensive Actions with Ball		**Defensive Actions with Ball**	
Technical Action	**Concept**	**Technical Action**	**Concept**
Right Finish	Attempt to score a goal, (hitting the goal), with any legal part (according to the rules of soccer) of the body, and that requires an intervention (by the opposing players) to prevent the ball from entering the goal	**Aerial Ball Gain**	When both players compete for a ball in the air. In which, at the time of the aerial ball contest, the players involved in the contest must have both feet without any contact with the ground. The player who gains control of the ball or wins the ball so that it is in the possession of his team
Wrong Finish	Attempt to score a goal (not hitting the goal) made with any legal part (from the rules of soccer) of the body	**Lost Aerial Ball**	When both players compete for a ball in the air. In which, at the time of the aerial ball dispute, the players involved in the dispute must have both feet without any contact with the ground. The player who loses control of the ball or is unable to make the ball in the possession of his team loses the dispute
Pass Right	A ball intentionally passed from one player to another and reaching the target	**Disarm Right**	Action to regain possession of an opponent's possession
Wrong Pass	A ball intentionally passed from one player to another, however, the pass did not go towards the target	**Wrong Trip**	Attempt to regain possession of an opponent's possession, however, the marker is defeated by a dribble or foul
Key Pass	Final pass or cross that leads the receiver to try to score the goal, however, without doing so	**Removing the Ball from the Right Danger Zone (RBDZ)**	A player's successful attempt to get the ball out of the danger zone (his defense area) under pressure from opponent attack
Assistance	Final pass or cross that leads the receiver to score	**Ball Removal from the Wrong Danger Zone (RBDZ)**	A player's unsuccessful attempt to remove the ball from the danger zone (his defense area) when there is pressure from the opponents to attack
Right Cross	Any ball placed in the opponent's area from a wide position (up to a distance of 23 meters) and which reaches the target	**Right Interception**	When a player intercepts a pass (from the opponent) during its trajectory to another opponent
Wrong Cross	Any ball placed in the opponent's area from a wide position (up to a distance of 23 meters), however, that does not reach the target	**Wrong Interception**	Player tries to intercept the ball that was passed (to an opponent), however, does not reach it, and the ball reaches its final target
Right Release	Successful attempt to pass over a distance of 23 meters, in which the ball hits the target	**Right Kick Block**	Action to block an attempt to finish towards the goal with any legal part (from soccer rules) of the body
Wrong Release	Passing attempt over a distance of more than 23 meters, in which the ball does not reach the target	**Wrong Kick Block**	Attempting to block a submission attempt (from the opponent) towards the goal with any legal part (from the rules of soccer) of the body, however, without success
Right Dribble	Successful attempt by a player to win / overtake the opponent with the ball		
Wrong Dribble	Unsuccessful attempt by a player to win / overtake the opponent with the ball		

Table S2. Supplementary material. Comparison of the total frequency of incorrect technical actions by period of the analyzed games according to the VO2max of semi-professional soccer players (N = 10)

Incorrect Technical Actions	> $VO2_{max}$ (N = 5) Median (IQ)	< $VO2_{max}$ (N = 5) Median (IQ)	*p-value*
Finalization/Shooting 1st P	0 (0 – 3)	1 (0 – 2)	0.214
Finalization/Shooting 2nd P	0 (0 – 1)	1 (0 – 3)	0.419
Total Finalizations/Shootings	0 (0 – 4)	1 (1 – 5)	0.128
Pass 1st P	2 (0 – 5)	4 (3 – 5)	0.287
Pass 2nd P	1 (0 – 5)	3 (2 – 5)	0.202
Total Passes	3 (1 – 10)	7 (6 – 8)	0.114
Cross 1T	0 (0 – 3)	2 (0 – 7)	0.190
Cross 2nd P	0 (0 – 3)	2 (0 – 4)	0.228
Total Crosses	3 (0 – 3)	4 (0 – 10)	0.068
Through Ball 1st P	1 (0 – 2)	3 (1 – 4)	**0.024**
Through Ball 2nd P	0 (0 – 1)	4 (0 – 7)	0.081
Total Through Balls	2 (0 – 2)	7 (2 – 11)	**0.017**
Dribble 1st P	0 (0 – 1)	1 (0 – 4)	0.419
Dribble 2nd P	0 (0 – 2)	0 (0 – 1)	0.881
Total Dribbles	1 (0 – 2)	1 (0 – 5)	0.919
Air Ball 1st P	1 (0 – 2)	1 (1 – 5)	0.288
Air Ball 2nd P	2 (1 – 7)	2 (1 – 6)	0.585
Total Air Balls	2 (1 – 9)	3 (2 – 11)	0.239
Lost Ball 1st P	1 (0 – 7)	2 (1 – 9)	0.239
Lost Ball 2nd P	3 (1 – 5)	1 (0 – 5)	0.511
Total Lost Balls	4 (1 – 12)	3 (1 – 14)	1.000
Tackle 1st P	0 (0 – 6)	1 (0 – 2)	0.381
Tackle 2nd P	1 (0 – 3)	1 (0 – 2)	0.827
Total Tackles	1 (0 – 9)	2 (1 – 3)	0.591
Interception 1st P	1 (0 – 4)	1 (0 – 1)	0.735
Interception 2nd P	1 (0 – 2)	2 (0 – 2)	0.496
Total Interceptions	3 (0 – 5)	3 (1 – 3)	0.662
TBDZ 1st P	0 (0 – 0)	0 (0 – 1)	0.317
TBDZ 2nd P	0 (0 – 0)	0 (0 – 0)	1.000
Total TBDZ	0 (0 – 0)	0 (0 – 1)	0.317
Kick Block 1st P	0 (0 – 0)	0 (0 – 1)	0.317
Kick Block 2nd P	0 (0 – 0)	0 (0 – 0)	1.000
Total Kick Blocks	0 (0 – 0)	0 (0 – 1)	0.317
Participation with Ball 1st P	6 (2 – 27)	19 (13 – 26)	0.209
Participation with Ball 2nd P	14 (5 – 14)	19 (13 – 19)	**0.042**
Total Participation with Ball	20 (8 – 39)	38 (26 – 45)	0.094
Defensive Actions 1st P	1 (0 – 11)	3 (2 – 7)	0.339

Defensive Actions 2nd P	4 (1 – 12)	5 (3 – 7)	0.396
Total Defensive Actions	6 (4 – 23)	8 (5 – 14)	0.248
Play Building Actions 1st P	4 (1 – 11)	9 (7 – 14)	**0.046**
Play Building Actions 2nd P	5 (1 – 6))	9 (6 – 13)	**0.013**
Total Play Building Actions	7 (3 – 16)	18 (13 – 27)	**0.016**

VO2max = maximum oxygen consumption; Total = sum of incorrect actions from both game periods; TBDZ = taking the ball out of the danger zone; Participation with Ball = sum of all incorrect technical actions of all players. Statistical test = Mann-Whitney, p-value <0.05. The division of the groups > VO2max and < VO2max was performed using the median of VO2max as the cut-off point.