Aerobic Fitness Ecological Validity in Elite Soccer Players: A Metabolic Power Approach

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Abstract

Manzi, V, Impellizzeri, F, and Castagna, C. Aerobic fitness ecological validity in elite soccer players: a metabolic power approach. *J Strength Cond Res* 28(4): 914–919, 2014—The aim of this study was to examine the association between match metabolic power (MP) categories and aerobic fitness in elite-level male soccer players. Seventeen male professional soccer players were tested for $\dot{V}O_2$max, maximal aerobic speed (MAS), $\dot{V}O_2$ at ventilatory threshold ($\dot{V}O_2$VT and %$\dot{V}O_2$VT), and speed at a selected blood lactate concentration (4 mmol·L^{-1}, V_{L4}). Aerobic fitness tests were performed at the end of pre-season and after 12 and 24 weeks during the championship. Aerobic fitness and MP variables were considered as mean of all seasonal testing and of 16 Championship home matches for all the calculations, respectively. Results showed that $\dot{V}O_2$max (from 0.55 to 0.68), MAS (from 0.52 to 0.72), $\dot{V}O_2$VT (from 0.72 to 0.83), %$\dot{V}O_2$maxVT (from 0.62 to 0.65), and V_{L4} (from 0.56 to 0.73) were significantly ($p < 0.05$ to 0.001) large to very large associated with MP variables. These results provide evidence to the ecological validity of aerobic fitness in male professional soccer. Strength and conditioning professionals should consider aerobic fitness in their training program when dealing with professional male soccer players. The MP method resulted an interesting approach for tracking external load in male professional soccer players.

Key Words association football, intermittent exercise, maximal oxygen uptake, endurance, match analysis

Introduction

Competitive soccer imposes important physiological demands on players who must be physically fit to cope with game energy requests (1,22). Indeed, during an official match, players are reported to attain 80–90% and 70–80% of their maximal heart rate (HR) and oxygen uptake ($\dot{V}O_2$max), respectively. Elite-level players perform 1,200–1,400 activity changes and accumulate 150–250 short-duration bouts (1–4 seconds) at high intensity (1,22). Despite the lower average match speed (10–12 km·90 min^{-1}), soccer players may experience a remarkable glycogen depletion during the game (16). This results from the reiteration of high-intensity accelerations, decelerations, and sprints throughout the game (1,22).

In soccer, physical match analysis considered mainly distances covered or time spent in arbitrary chosen running speed categories using various movement caption systems (3,22). However, the speed category approach, not accounting for match accelerations and decelerations, may provide only a partial figure of actual game physiological demands (18).

Indeed, important energetic demands may be imposed to players also when speed is low but acceleration is elevated (18). Recently, a kinematic approach considering the instantaneous interplay of player's running speed and acceleration was proposed (18), with the aim to provide a more detailed description of match demands. With this approach, player's activity was assumed as distance covered in arbitrary chosen energy-expenditure categories indicated as metabolic power (MP). Using this novel approach were reported higher anaerobic demands than previously found with the speed categories approach (18). This finding may affect the supposed importance of aerobic fitness in soccer (12,14,22). As a result, knowledge about the relationship between aerobic fitness and MP may result useful for guiding specific training intervention in soccer.

Information on the association between aerobic fitness and MP categories would be also of value for understanding the nature of MP during actual match play. Indeed, a given MP, being the product of player's instantaneous acceleration and speed, may potentially be achieved with different metabolic pathways (18).

Differently from what reported for the speed category approach, no study was published addressing the effect of intersubject variance of aerobic fitness on MP production during highly competitive matches (12,14,15,22). Information in this regard would result of great interest to pose evidence-based hypothesis helpful to guide training prescription and future training studies.

Therefore, the aim of this study was to examine the association among aerobic fitness variables and match MP

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categories in male professional elite-level soccer players. The existence of significant associations between aerobic fitness components and MP categories were assumed as work hypothesis.

Methods

Experimental Approach to the Problem

The MP approach was devised in the attempt to accurately describe the physical match activities usually performed by players during a match (18). Considering at the same time the effects accounted for acceleration and movement velocity, MP may constitute an integrated measure of aerobic and anaerobic game demands (18). Indeed, a given MP may potentially be the result of the interplay of different metabolic pathways (i.e., aerobic and anaerobic), depending on the underpinning exercise intensity and/or mode producing it (i.e., acceleration and velocity interaction). In this regard, the study of possible association of MP variables with players' individual level of aerobic fitness may provide a preliminary figure of the nature and constitute a validation (i.e., construct convergent validity) of MP variables. This at the same providing a picture of the relevance of players' aerobic fitness using this supposes more comprehensive match analysis approach.

In this study, association between variables were performed pooling data of 19 championship home matches in which players were observed a minimum of 3 times and a maximum of 15 times during the study period (i.e., 2010–11 Italian Serie A Championship). With the aim to foster data consistency, players' aerobic fitness was considered as the mean of 3 seasonal assessments. Specifically, tests were conducted at the end of the preseason and 12 and 24 weeks after the beginning of the Championship.

Aerobic fitness variables were assumed as maximal oxygen uptake ($\dot{V}O_2max$), maximal aerobic speed (MAS), oxygen at ventilatory threshold ($\dot{V}O_2VT$), percentage of $\dot{V}O_2max$ at ventilatory threshold (%$\dot{V}O_2VT$), and running speed at a blood lactate concentration of 4 $mmol \cdot L^{-1}$ (V_{L4}) (14,22). These aerobic fitness variables were reported to be relevant for soccer players' fitness development and to be related to match activities (1,12,22).

Match activities were classified according to the procedures suggested by Osgnach et al. (18) and expressed as distance covered in the arbitrary selected MP categories. The MP calculations were performed as per Osgnach et al. (18). Specifically, the MP method considers the normalized (i.e., in Watt per kilogram) external load sustained by players as the product resulting from instantaneous speed and the equivalent energetic cost of the corresponding acceleration. This assuming the energetic cost of accelerated running as equivalent to running up hill at constant speed and at an inclination provided by the estimated forward body tilt at the corresponding acceleration. All the MP calculations were performed using the following formula:

$$MP = \ EC \times v^{\rightarrow}.$$

where EC is the energetic cost of running up hill at the translated inclination coming from the corresponding running acceleration vector (18).

In this study, to limit possible occurrence of type I errors, a preplanned comparison approach addressing association between aerobic fitness variables and arbitrary chosen high MP activities was used (23). This assuming that high MP categories were the reflection of activities leading to actions relevant to match outcome (1,3,18,22). A cutoff value of 20 $W \cdot kg^{-1}$ was chosen according to Osgnach et al. (18). This MP value was considered as corresponding to a $\dot{V}O_2$ of 57 $ml \cdot kg^{-1} \cdot min^{-1}$ above resting, thus in line with this study players' $\dot{V}O_2max$ (see Results) (18). As a result, those activities performed at or above this cutoff value (i.e., $\geq$20 $W \cdot kg^{-1}$) were assumed as reflection of mainly anaerobic match activities (18).

Subjects

Seventeen (age 28.2 ± 2.2 years, height 182 ± 7.1 cm, body mass 80 ± 5.4 kg) male, professional, Italian Serie A soccer players (5 defenders, 6 midfielders, and 6 forwards) volunteered to this study. Player had at least 7 years of competitive experience in premiership. All the players were active members of the same Serie A team during the 2010–11 season. Ten players were starters of their own country national A team.

Players trained 7 times a week throughout the preseason with a friendly match played on Thursday or during the weekend. Training sessions were mainly devoted to technical-tactical skill development, with fitness training drills performed as single training session during preseason.

The training time during the observed period was 15 and 13% devoted to ball-drills and generic aerobic training, respectively; 21 and 8% of the training time was spent training for technical-tactical skill development and matches, respectively. Mainly anaerobic training (strength and sprint training, 5 and 9%, respectively) accounted for 14% of all the training time. Explosive power training was performed 2 times a week as single morning session (i.e., plyometric training). Training load of players involved in this study were monitored for internal load according to Manzi et al. (17) to avoid training maladaptations.

During championship weeks, players performed 9 training sessions with a match played during the weekend. Friendly and cup matches usually occurred on Thursday and Wednesday, respectively. Team and individual skill development accounted to 55–60% of total training time, with the remaining time used for fitness training and warmup routines (approximately 20% each).

Potential confounding effects of previous exercise fatigue on variables was minimized ensuring that coaches refrained their players from heavy training on the day preceding assessments. A record of the nutrient content was taken to provide the sufficient carbohydrate intake during the week before assessments. Before, during, and after all testing

Table 1. Time, distance, and estimated energy cost of running in the selected metabolic power categories.*

Variables ($W \cdot kg^{-1}$)	Time (s)	Distance (m)	Energy ($J \cdot kg^{-1}$)
LP (0–10)	3,812 ± 209	4,716 ± 204	19,137 ± 1,103
MedP (10–20)	1,189 ± 96	3,309 ± 387	16,481 ± 1,401
HP (20–35)	463 ± 71	1,643 ± 288	12,002 ± 1,858
VHP (35–55)	168 ± 36	703 ± 161	7,203 ± 1,550
MaxP (>55)	73 ± 22	367 ± 115	5,439 ± 1,650

*LP = low power, MedP = medium power, HP = high power, VHP = very high power, MaxP = maximal power.

sessions and games, hydration was promoted allowing "ad libitum" drinking in all players. Throughout the study, all testing sessions took place at the same time of the day (between 9.00 and 13.00 hours) to avoid circadian influences.

All the players were made aware of the risk and benefits from participating to these study procedures and acknowledged that they can withdraw from the study at any time without penalties. Written informed consent was obtained from all players before the commencement of the study and after local Institutional Research Board research design approval.

Procedures

Aerobic fitness was assessed having players submitted on separate occasions (i.e., at least 24 hours apart) to a progressive long-stage (i.e., 5 minutes) treadmill test for lactate profiling and to a short-stage (i.e., 1 minute) running field test for $\dot{V}O_2$max.

Players' lactate profile was assessed using a 2-phase progressive treadmill test (Technogym Run Race 1400 HC, Gambettola, Italy) for the assessment of individual blood lactate concentration profiles and maximal HR, respectively (HRmax). The progressive treadmill test consisted of 4–5 submaximal exercise bouts at initial running speed of 9 $km \cdot h^{-1}$ followed by a maximal incremental test to volitional fatigue. The treadmill running velocity was increased during submaximal test by 1 $km \cdot h^{-1}$ every 5 minutes. Once capillary blood lactate concentrations were elevated above 4 $mmol \cdot L^{-1}$, the treadmill speed was increased by 0.5 $km \cdot h^{-1}$ every 30 seconds until exhaustion (12,15). Capillary blood samples were taken from the earlobe immediately after each submaximal bouts and 3 minutes after exhaustion and analyzed to assess exercise blood lactate concentrations using a portable amperometric microvolume (5 μl) lactate analyzer (LactatePro, Arkray, Japan). Before each test, the analyzer was calibrated after the manufacturers' recommendations.

The $\dot{V}O_2$max was assessed using a progressive maximal test completed on a 400-m athletic track, until exhaustion (19). For every 20 m, a cone was positioned as a reference. After an acoustic signal, the subjects performed the incremental field test, starting from 8.0 $km \cdot h^{-1}$, with the speed then increased by 0.5 $km \cdot h^{-1}$ every minute. The end of the test was considered when the player twice failed to reach the next cone at the required time (objective evaluation) or he felt unable to cover another interval at the dictated speed (subjective evaluation). During the test, players were verbally encouraged by the test leaders and coaches to provide maximal effort in the late stages of the test.

Achievement of $\dot{V}O_2$max was considered as the attainment of at least 2 of the following criteria: (a) a plateau in $\dot{V}O_2$ despite increasing speeds, (b) a respiratory exchange ratio above 1.10, (c) a HR ± 10 $b \cdot min^{-1}$ of age-predicted HRmax (208-0.7 age). Expired gases were analyzed using a breath-by-breath automated gas analysis system (K4b^2; COSMED, Rome, Italy) (7,8).

The highest HR measured in either maximal incremental test was used as HRmax. Criteria for HRmax achievement

Table 2. Correlation matrix of the resulting associations among aerobic fitness and the metabolic power categories considered.*

Variables ($W \cdot kg^{-1}$)	$\dot{V}O_2$max	$\dot{V}O_2$VT	%$\dot{V}O_2$VT	Maximal Aerobic Speed	V_{L4}
>20	0.68† (0.30–0.88)	0.83‡ (0.58–0.94)	0.62† (0.20–0.85)	0.72§ (0.36–0.89)	0.73‡ (0.58–0.94)
>35	0.63† (0.22–0.85)	0.79‡ (0.50–0.92)	0.64† (0.23–0.86)	0.64† (0.23–0.86)	0.67† (0.50–0.92)
>55	0.55§ (0.10–0.81)	0.72† (0.37–0.89)	0.65† (0.24–0.86)	0.52§ (0.05–0.80)	0.56§ (0.37–0.89)

*Data are reported as coefficient of correlation and 95% confidence intervals.
†$p < 0.01$.
‡$p < 0.001$.
§$p < 0.05$.

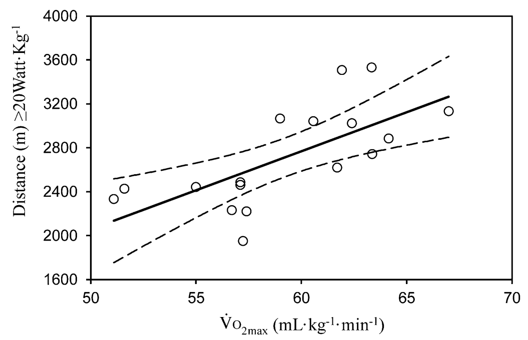

Figure 1. Scatter plot of the resulting relationship between distance covered at metabolic power ≥20 W·kg^{-1} and V̇O_2max; $r = 0.68$ (95% confidence interval, 0.30–0.88); $p = 0.0024$.

were attainment of subjective and visual exhaustion, blood lactate concentrations higher than 8 mmol·L^{-1}, and HR plateau achievement despite speed increments.

Match analysis was performed using a validated multi-camera video analysis system (SICS, Bassano del Grappa, Italy) operating at 25 Hz (18). Rampinini et al. (21) determined the reliability of this device with a typical error of 1.0% for total distance. Match activities MP (in Watt per kilogram) were considered as distance covered in the following arbitrary intensity categories: low power (LP, from 0 to 10 W·kg^{-1}), medium power (MedP, from 10 to 20 W·kg^{-1}), high power (HP, from 20 to 35 W·kg^{-1}), very high power (VHP, from 35 to 55 W·kg^{-1}), and max power (MaxP, >55 W·kg^{-1}) (18). Data were filtered according to the procedures suggested by Osgnach et al. (18).

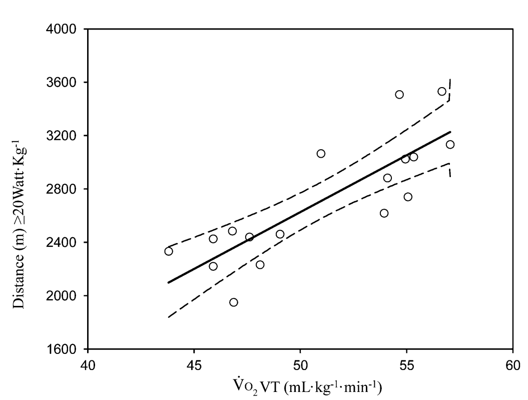

Figure 2. Scatter plot of the resulting relationship between distance covered at metabolic power ≥20 W·kg^{-1} and V̇O_2VT; $r = 0.83$ (95% confidence interval, 0.58–0.94); $p < 0.0001$.

Statistical Analyses

The results are expressed as mean ± *SD*s. Assumption of normality was verified using the Shapiro-Wilk *W*-test. Variables association was assessed using Pearson's product-moment correlation coefficients (i.e., *r*) and provided with the corresponding confidence interval at 95%. Linearity was assumed after visual inspection of variable-associated scatterplots and in case of doubt, comparing *r* values with eta values. Qualitative magnitude of associations was reported as follows: trivial $r < 0.1$, small $0.1 < r < 0.3$, moderate $0.3 < r < 0.5$, large $0.5 < r < 0.7$, very large $0.7 < r < 0.9$, nearly perfect $r > 0.9$, and perfect $r = 1$ (17). Significance was set at $p \leq 0.05$. Power calculations revealed that to achieve a power of 80%, at least 12 subjects were required at the required level of significance.

The intraclass correlation coefficient for the fitness measurements ranged between 0.89 and 0.92 in a preliminary quality control, performed before the commencement of the study with a population similar to this study (i.e., semi-professional soccer players, $n = 16$).

Results

On an average, match players covered 10,910 ± 809 m (range: 9,797–12,512 m). The distances covered by players in the considered MP categories are reported in Table 1. In the LP, MedP, HP, VHP, and MaxP, players covered 43.2, 30.3, 15.1, 6.4, and 3.4% of the total match distance, respectively.

Values of V̇O_2max, V̇O_2VT, %V̇O_2VT, MAS, and V_{L4} were 59.2 ± 4.3 ml·kg^{-1}·min^{-1}, 51.0 ± 4.4 ml·kg^{-1}·min^{-1}, 86.1 ± 2.9%, 16.5 ± 1.0 km·h^{-1}, and 14.7 ± 0.8 km·h^{-1}, respectively. The association between aerobic fitness and MP variables is reported in Table 2. The V̇O_2max showed large association with all MP match variables (Figure 1). Maximal aerobic speed and V_{L4} were large to very large associated with MP. Very large correlations were found between MP match categories and V̇O_2VT (Figure 2). When V̇O_2VT was expressed as percentage of V̇O_2max, it showed large associations with MP variables.

Discussion

This is the first study that addressed the ecological validity of aerobic fitness variables using the MP approach. Results showed that players' external load assumed as reflection of the instantaneous interplay between acceleration and speed, here, considered as MP was large to very large associated with all aerobic fitness variables considered in this study. These findings confirmed the original work hypothesis.

Match-speeds categories are not suitable to fully explain the reported remarkable metabolic demands imposed by actual match-play in soccer (1,16,22). As a result, match demands (i.e., external load experienced) of elite-level soccer players should be ideally monitored considering instantaneous match kinematics (i.e., acceleration-speed interplay) (18).

The MP approach enables the quantification of the energetic demands of a soccer player during actual match play providing a normalized (i.e., Watt per kilogram) measure of players external load (18). However, the MP equation, resulting from the product of instantaneous acceleration-deceleration and speed, does not express per se the nature of the involved metabolic pathway. Indeed, a given MP may be actually achieved in remarkably different movement conditions considering the opposing interplay of speed and acceleration. This MP feature may result a method limitation when considered for training prescription. A viable preliminary way to tackle the understanding of the metabolic nature of MP is through descriptive correlative design (23).

In this study, we provided descriptive evidence of an association between aerobic fitness and match MP categories. This information supports the notion that soccer "chaotic" motion (i.e., randomly undertaken accelerations and decelerations) may be informed by the individual level of aerobic fitness. Interestingly, $\dot{V}O_2VT$ showed to be very largely associated with all the MP categories. This was different from what observed for the other aerobic fitness variables that showed a decrement of common variance with the increment of MP magnitude. It could be hypothesized that movement efficiency assumed as $\dot{V}O_2VT$ informs high-intensity MP expressions. However, the same variable when expressed as percentage of $\dot{V}O_2max$ (i.e., in relative terms) resulted evenly largely associated with all the MP categories. It could be speculated that absolute more than relative VT expression may affect MP zones' permanence during actual match play.

The association between variables showed a decrement from lower to higher MP values (i.e., from 20 to above 55 $W \cdot kg^{-1}$). A greater involvement of anaerobic pathway with increasing MP production may partially explain the observed trend (1,16,22). Because of the interest of this issue for training prescription, further studies examining this occurrence are warranted.

The match analysis data reported in this study are in line with those provided by Osgnach et al. (18) for male professional soccer players competing in the Italian Championship. Indeed, the total mean distance performed during the game by this study players resulted almost the same of that reported in the article by Osgnach et al. (18) (10,950 ± 1,044 m) but lower than that reported in most successful Italian Serie A male soccer players (11,647 m) (21). Additionally, the distance profile at the selected MP categories was very similar to that reported for Serie A male soccer players competing in official matches with MP $>20\ W \cdot kg^{-1}$ accounting for approximately 25% of total distance (TD) covered (18). The match activities at MP $>20\ W \cdot kg^{-1}$ were reported to be mainly anaerobic in nature (18). Consequently, the provided large to very large association of MP $>20\ W \cdot kg^{-1}$ with aerobic fitness variables further promotes the global interest of aerobic training in soccer. It could be speculated that given the intermittent nature of soccer, the reported association between high MP activities and aerobic fitness may be the result of a superior inter high-intensity bouts recovery kinetic in those players possessing greater aerobic fitness (2,10). This enables a larger distance accumulation at high MP. Given the composite nature of MP, studies examining the metabolic pathways that inform MP during actual match play are warranted. This examining the MP demands and the physiological (i.e., HR, blood lactate, and $\dot{V}O_2$) response during ball-drills and simulated matches (i.e., friendly and experimental) (4,5).

In this study, match analysis and physiological data suggest that the considered players were representative of elite standard male professional soccer players (18,22). Indeed, the average aerobic fitness level of these study players was in line to what reported in the international literature for male professional soccer players (22). In light of these findings, this study results may be generalized to players competing at the same professional level and used accordingly for training and research purposes.

It is concluded that aerobic fitness is a relevant performance component in male professional soccer as per its convergent construct validity with match MP variables. This is a novel finding as previous studies provided information deriving from cross-sectional designs and training studies only used a speed approach, thus not considering match acceleration-decelerations. Given the supposed ability of the MP approach to provide a more detailed profile of players match physical performance, the information gained from this study provide further evidence to the importance of aerobic fitness development in soccer (12,14,22).

Practical Applications

The study findings provided novel evidence to the interest of aerobic fitness for performance development in male elite-level soccer (22). Results showed that match activities of basically different nature, as per instantaneous interplay between acceleration and speed, are associated with either maximal and submaximal aerobic fitness variables. Interestingly, the interindividual aerobic fitness profile was associated with high MP match categories mainly anaerobic in nature (18). Therefore, suggesting the development of maximal and submaximal aerobic fitness component as a prerequisite for successful playing as high intensity to maximal bouts (i.e., sprinting) are considered to be associated with activities influencing match outcome (22).

This descriptive evidence is of great practical interest for training prescription to guide generic and specific training (9,12). Ideally, sprint and repeated sprint ability (i.e., specific anaerobic training) should be developed in parallel with aerobic fitness in male professional soccer (concurrent training) (6,9,10). In this regard, training studies showed that aerobic fitness variables may be successfully improved with ecologically designed sprint training protocols (6,9). Furthermore, high-intensity training (i.e., 90–95% of maximal HR) showed to provide enhancements of all the aerobic fitness profile variables either in the form of generic or specific training (12). Improvement in aerobic fitness showed to positively affect match activities and technical skills (12,13,20).

The MP approach constitute an integrated method potentially useful to track players' game and training demands (18). The resulting association of MP with aerobic fitness variables provided, for the first time, evidence for concurrent validity of this novel approach. This may support the use of MP tracking for the assessment of external load during match and training in male soccer. Given the advancement of portable match analysis devices using GPS technology, MP may be easily assessed gaining information useful for improving specific fitness in soccer players during ball training (i.e., small-sided games) (11). However, further studies should be carried out examining MP responsiveness to training in professional soccer (i.e., responsiveness or longitudinal validity).

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