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MULTIVARIATE RELATIONSHIPS BETWEEN MORPHOLOGY, MOVEMENT PATTERNS AND SPEED ABILITIES IN ELITE YOUNG, MALE ATHLETES

MULTIVARIATNI ODNOSI MED MORFOLOŠKIMI ZNAČILNOSTMI, GIBALNIMI VZORCI IN HITROSTJO PRI VRHUNSKIH ŠPORTNIKIH

ABSTRACT

Speed and agility are crucial abilities in many team sports such as soccer, basketball or handball. Therefore determing factors affect speed abilities is relevant. To investigate multidimensional correlations of the FMS test results with speed abilities.

35 male team sport players, aged 21.31±0.93. Body weight and body height were measured and BMI was calculated (kg/m^2). Three modules of the FMS test were used to analyse: Deep Squat, Hurdle Step, In-line Lunge. Linear speed was measured based on the 20m Linear Speed test, agility was evaluated using the Agility T-test. Data were analysed by Canonical Correlation Analysis (CAA).

The CCA analysis demonstrated statistically significant correlation between morphological features and agility. Correlation was found between 20m Linear Speed and In-line Lunge. However it was not revealed any significant correlations of neither speed skills nor morphological characteristics with chosen FMS subtests. High canonical loadings and weights suggested the presence of correlations (not significant) between individual measurements. The correlations between morphological measurements and functional movement were very close to statistical significance.

The CCA analysis allowed for showing multivariate links between morphological features and functional

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IZVLEČEK

Hitrost in agilnost sta ključni sposobnosti v veliko ekipnih športih, kot so nogomet, košarka ali rokomet. Zato so pomembni odločilni dejavniki, ki vplivajo na sposobnost hitrosti. V raziskavi večdimenzionalnih korelacij testa FMS smo pridobili rezultate testov hitrosti pri 35 športnikih iz ekipnih športov, ki so bili stari 21,31 ± 0,93. Telesna teža in telesna višina sta bili izmerjeni ter izračunan BMI (kg/m^2). Trije moduli testa FMS so bili uporabljeni za analizo globokega počepa, prestopa ovire in izpadnega koraka. Linearna hitrost je bila izmerjena s pomočjo 20-metrskega testa linearne hitrosti, agilnost pa s T-testom agilnosti. Podatke smo analizirali s kanonično korelacijsko analizo (KKA).

Analiza KKA je pokazala statistično značilno korelacijo med morfološkimi značilnostmi in agilnostjo. Korelacija je bila ugotovljena med 20-metrsko linearno hitrostjo in izpadnim korakom. Vendar pa izbrani podtesti FMS niso pokazali nobenih korelacij med hitrostjo ali morfološkimi značilnostmi. Visoke kanonične uteži in deleži so pokazali na prisotnost korelacij (neznačilna) med posameznimi meritvami. Korelacije med morfološkimi meritvami in funkcionalnim gibanjem so bile zelo blizu statistični značilnosti.

Analiza KKA je omogočila prikaz multivariatnih povezav med morfološkimi značilnostmi in

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abilities. This results demonstrated moderate correlations between body morphology and agility and between movement patterns and agility. Better scores in agility were correlated with good performance in In-line Lunge and Hurdle Step test.

Key words: Athletes, Movement Patterns, Speed, Body Mass Index

funkcionalnimi sposobnostmi. Rezultati so pokazali zmerne korelacije med telesno morfologijo in agilnostjo ter med gibalnimi vzorci in agilnostjo. Boljši rezultati agilnosti so korelirali z uspešno opravljenimi testi izpadnega koraka in prestopa ovire.

Ključne besede: športniki, gibalni vzorci, hitrosti, telesna sestava

INTRODUCTION

Speed and agility are key abilities determining motor performance. Especially in team sports such as soccer, basketball or handball, they are critical to the final score (Chelly et al., 2011). Speed and agility are significantly correlated with athletic performance manifested in strength, power, coordination and reaction time. They represent part of skill-based fitness (Liye, 2016). However, they also develop biologically and are highly dependent on genes which determine the dominant type of muscle fibres or anthropometric characteristics such as body mass or body height (Bishop & Girard, 2013). These anthropometric characteristics are common indicators of body build, especially useful in sport selection (Klimczyk, 2012). Physical build is especially critical in sports such as football or handball (Nikolaidis, 2012 & 2013). It often determines desired motor abilities. e.g. speed (Bovet et al., 2007).

On the other hand, there are well-known and described training strategies used to improve speed abilities (Gjinovici et al., 2017). Besides the metabolic pathways, speed is determined by the use optimal running technique which depends on stride length and step frequency (Bishop & Girard, 2013). This requires optimal coordination, global control, mobility and stability of body segments. Some authors have demonstrated that disorders in these areas could have a negative effect in athlete performance (Gamble, 2013). A well-known tool designed to assess the quality of movement patterns from the standpoint of optimal coordination, mobility and stability is Functional Movement Screen (FMS™). Primarily, the FMS is used as a screening tool to determine injury risk in different groups of athletes e.g. soccer players (Kiesel et al., 2007; Garrison et al., 2015) and handball players (Slodownik et al., 2018). It consists of seven movement patterns used to assess movement quality. It has been proved that movement patterns are related to individual functional limitations and asymmetries (Bishop & Girard, 2013; Liye, 2016). According to literature concerning the injury risk assessment, the cut-off score is 14. Above this value, the injury risk rises significantly (Kiesel et al., 2007). Researchers have attempted to examine the links between FMS score and athlete performance. Studies in this field have shown opposite results (Parchman & McBride, 2011; Atalay et al., 2018 Liang et al., 2018). However they have often differed in study groups, or motor tests used. The FMS test is a seven-task tool which can provide much information about single movement patterns and their relationships with athlete performance (Cook et al., 2006a; 2006b). A few studies in the literature have used similar approach (Hartigan et al., 2014). In our study, we chose Deep Squat (DS), Hurdle Step (HS) and In-line Lunge (I-IL). They are used to evaluate specific movement skills for the movements performed in a closed cinematic chain. Importantly, simple relationships between morphological characteristics, movement patterns and motor skills are most often analysed. This allows for evaluation of strength and direction of the correlation between only two characteristics, but prevents from a wider, multidimensional view of the phenomenon observed. The human body is not a simple sum of single characteristics but it represents a multidimensional system where every single element connects with each other in a multidirectional way. A useful method of evaluation the multidimensional connections is Canonical Correlation Analysis. It allows for indicating the relationships between groups of parameters taking into account individual contribution of single factors in the whole correlation and describing the redundancies.

AIM

The present study examines multivariate relationships among morphology, fundamental movement patterns and speed skills. The aim of this study was to investigate multidimensional correlations of the FMS test results with the results obtained during the T-test and 20 m sprint run.

MATERIAL AND METHODS

Participants

The study group consisted of 35 male university team athletes aged 21.31±0.93 years with training experience of 7.52±2.74 years. They were qualified for the study based on inclusion and exclusion criteria. Inclusion criteria were no injuries in the period of 6 weeks before the tests and practising team sports. Players were not from the same sport clubs in the area of each sport. They were students of the same university year.

Morphological measurements

Body height was measured with a Swiss anthropometer with accuracy of 0.1 cm. Body weight was measured using electronic scales with accuracy of 0.1 kg. Based on the measurements obtained, the Body Mass Index (BMI) was calculated using the following formula: body weight (kg)/body height$(m)^2$

Movement patterns

Functional Movement Screen (FMS) is a test used for injury risk assessment. It consists of 7 various movement patterns. Three of these patterns were used in our study: Deep Squat, Hurdle Step and In-line Lunge, which assess entire body mobility, stability, and coordination. These abilities are critical to performance level of the athlete. The above movement patterns reveal the athlete's ability to move in a closed kinematic chain. All FMS modules are performed based on clear guidelines. The participant scores 3 points if the task is completed perfectly, 2 points if the task is completed with compensation, and 1 if the task cannot be completed.

Motor performance: speed skills

The 20m run test and agility T-test (Fig.1) were performed to evaluate speed and agility, respectively. The common biological basis for performance of these tests is nervous control and work of fast-twitch muscle fibres using the anaerobic processes.

Athletes started running from the standing position with feet placed behind the start line, with no rocking movements, on a voice command.

Testing procedures

All tests were conducted indoor, in a sports hall. Before speed and agility tests, three modules of the Functional Movement Screen (Deep Squat, In-line Lunge and Hurdle Step) were performed before speed and agility tests. In the next stage, the athletes made a 20-minute warm-up which included light jogging, stretching, and explosive exercises. Every participant performed both tests twice. Each trial was followed by a 5-minute rest. The better score was used for the analysis. Our testing procedure was adopted as proposed by Pauole et al.(2000). Smartspeed PT 1 photocells (Fusion Sport) were used to measure time.

Statistical analysis

Replicate measurements of FMS were made by the same researcher for the entire group at one-week intervals. Both evaluations were conducted by the same expert. Intraclass correlation coefficients ($ICC_{2,1}$) between the original and replicate tests were used for the chosen FMS modules (shrout; fleiss, 1979).

Descriptive statistics were calculated for all anthropometric measurements and motor and functional results obtained from the tests. Normality of the data was assessed using the Shapiro–Wilk

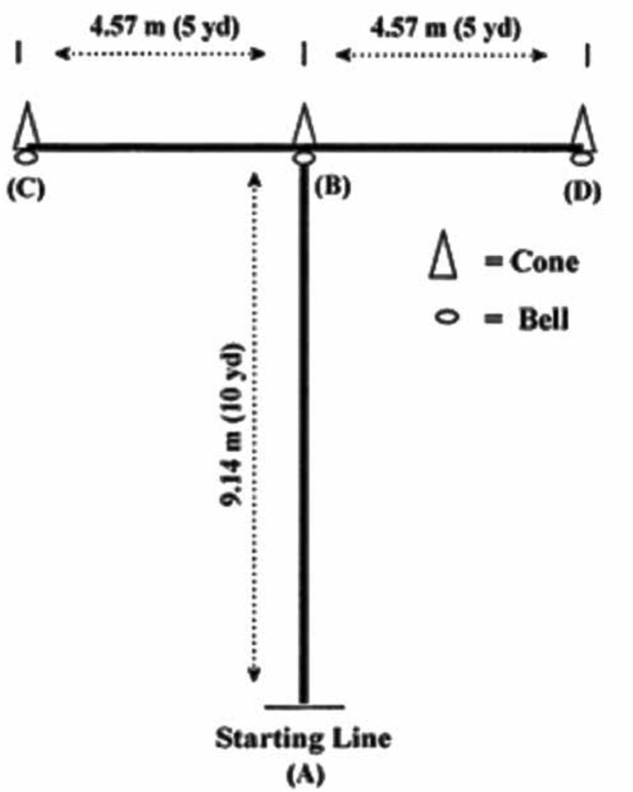

Fig 1. Layout of the T-test. Source: Pauloe et al. (2000)

test. Bivariate correlations were calculated to examine simple Pearson's correlations between all measurements. Correlation coefficients were interpreted as trivial ($r<0.1$), small ($0.1<r< 0.3$), moderate ($0.3<r<0.5$), large ($0.5<r<0.7$), very large ($0.7<r<0.9$) and nearly perfect ($r>0.9$) (Hopkins et al., 2009).

Canonical correlation analysis (CAA) was used to assess the correlations between three groups of measurements: anthropometric, motor and functional. After Pearson's correlation analysis, the most proper measurements were chosen in each group. The number of measurements had to be reduced due to the small number of participants. Therefore, similar variables (most correlated) were omitted in each group. We decided to leave two morphological characteristics, both motor speed skill test results and three functional results.

Measurements were collapsed into a canonical variate, which is the linear combination of variables that maximize the relationship between domains: Y=a1Y1+a2Y2…+anYn; Z=a1Z1+a2Z2+…+anZn. The canonical coefficient (rc=ry,z) provided an indication of the magnitude of correlation between the two sets of variables, while its squared value (rc^2) provided and estimate of the shared variance between the two variables. The Wilk's Lambda was also calculated (Stanisz, 2007).

The study was conducted in accordance with developed by the World Medical Association and concerning human research ethics WHO, 2014). The project procedures also complied with the ethical standards for sports medicine (Harriss & Atkinsons, 2016).

RESULTS

In tables, abbreviations was used: DS- Deep Squat; HS L- Hurdle Step Left Side; HS R- Hurdle Step Right Side; Il-L L - In-line Lunge Left Side; Il-l R- In-line Lunge Right Side; 20m Linear Speed – 20m; Agility T-test – T-test

Table 1 presents intraclass correlation coefficients. It suggests excellent quality of measurement and repeatability of rater (Koo & Li, 2016)

Table 1. Intraclass correlation coefficients ($ICC_{(2.1)}$)

FMS scores	$ICC_{2.1}$ value
FMS total score	0,95
DS	1
HS L	0,928
HS R	1
IL-L L	0,954
IL-L R	1

Descriptive statistics and Pearson's correlations between anthropometric characteristics, FMS and speed are presented in Tables 2 to 4.

Table 2. Descriptive statistics of anthropometric, motor and functional movement variables of players

Variable	Statistics	
	Mean/Me	Sd
Body height	180,99	8,25
Body weight	76,34	12,04
BMI	23,15	2,19
T-test	10,79	0,77
20m	3,15	0,21
FMS™total	14,34	2,50
DS	2,03	0,71
HS L	2,14	0,69
HS R	2,09	0,66
IL-L L	2,40	0,69
IL-L R	2,00	0,84

Coefficients were calculated for total FMS score, DS, HS L, HS R, IN-L L, and IN-L R. Results of the replicate analyses indicated reasonable quality, consistency and reliability of the measurements and testing procedures used in the present study.

Table 3. Pearson correlations between anthropometric, motor and functional movement measurements

Pearson coefficients					
Height—T-test	**-0,444**	Weight—T-test	-0,287	BMI—T-test	-0,094
Height—20m	-0,269	Weight—20m	-0,059	BMI—20m	0,123
Height—FMS total	-0,149	Weight—FMS total	-0,146	BMI—FMS total	-0,140
Height—DS	0,081	Weight —DS	0,168	BMI —DS	0,194
Height—HS L	**-0,373**	Weight —HS L	**-0,438**	BMI —HS L	**-0,391**
Height—HS R	-0,243	Weight —HS R	-0,215	BMI —HS R	-0,134
Height— IL-L L	0,050	Weight — IL-L L	-0,071	BMI —IL-L L	-0,210
Height— IL-L R	0,006	Weight — IL-L R	-0,206	BMI —IL-L R	**-0,366**

Table 2 shows correlations of morphological characteristics with movement patterns scores and motor performance tests. Body height was negatively significantly correlated with T-test time, and Hurdle Step Left. Similarly, body weight was negatively correlated with Hurdle Step Left. BMI was correlated with Hurdle Step and In-line Lunge.

Table 4. Pearson's correlations between anthropometric, motor and functional movement measurements

Pearson coefficients			
T-Test—FMS total	**-0,400**	20m sprint—FMS total	-0,293
T-Test —DS	-0,069	20m sprint —DS	-0,044
T-Test —HS L	-0,038	20m sprint —HS L	-0,074
T-Test —HS R	-0,141	20m sprint —HS R	-0,028
T-Test — IL-L L	-0,055	20m sprint — IL-L L	**-0,267**
T-Test — IL-L R	**-0,269**	20m sprint — IL-L R	**-0,296**

The results of the T-test were significantly and negatively correlated with total FMS score. A weaker correlation with the same direction was found for In-line Lunge. Significant negative correlations were recorded for 20m run and In-line Lunge pattern for both sides. A substantial but insignificant correlation was also found between total FMS scores.

After examination of the Pearson's correlations, we decided to leave body height and weight in the anthropometric set (removing BMI which is a linear combinations of both parameters), DS (which is well-correlated with FMS total), HS L and IL LOUNGE L (which had higher means of scores) and both T-test and 20m run in motor speed skills set.

Results of the canonical correlation analysis are presented in Tables 4 to 6 (only the highest canonical correlation (R) for each pair of groups is presented).

As it is seen in Table 4, two significant linear functions between morphology and speed skills were apparent (Wilk's Λ =0.618, R=0.611, p=0.04). The significant linear function explained 78.45% of the variance in motor domain by morphological domain. High value of canonical correlation confirmed the usefulness of linear model between anthropometric and speed skills measurements. The correlation between anthropometric measurements and movement patterns was very close to statistical significance (p=0.063).

A significant canonical correlations between FMS and speed skills was not evident (Wilk's Λ =0.906, R=0.300, p=0.799).

A significant canonical correlations between morphology and FMS also was not evident (Wilk's Λ =0.704, R=0.498, p=0.063). However, statistical significance was very close (0.063). The linear function explained 67.74% of the variance in the functional movement domain.

Table 5. Canonical correlations (R), eigenvalue c^2 test with p-values, Wilk's Lambda and explained variances between morphology and motor speed skills, fundamental movement patterns and motor speed skills, morphology and fundamental movement patterns in team sports players.

Set	Canonical correlations					
	R	*Eigen value*	c^2	*p*	*Wilk's L*	*% variance*
Morphology–Speed skills	**0,611**	**0,374**	**15,148**	**0,004**	**0,618**	**78,45%**
Movement patterns- Speed skills	0,300	0,090	3,077	0,799	0,906	63,98%
Morphology–Movement patterns	0,498	0,248	10,853	0,063	0,704	67,74%

Examination of the mutual relations between the elements of the sets requires the analysis of the internal structure of the pairs of sets. It was carried out based on the calculated factor loadings. This allows for the evaluation of the strength of the relationships between each variable and a canonical variable. The higher the value carried by the factor loading, the more important is the raw variable for the canonical correlation.

Using a criterion of the loading value of >0.4, both morphological features were contributors to speed skills. Therefore in case of speed tests, both tests loaded substantially to first canonical variate, but only 20m run loaded to second canonical variate (0.659) (Table 5).

Taking into account the same criterion, IL Lunge L (0,872) and HSL (-0,435) were contributors to speed skills. Only 20m test loaded to first canonical correlate.

Both morphological features had magnitude loading on the respective canonical function. The corresponding variables in the functional movement domain were DS (-0.402) and HSL (0.856).

The redundancies were also analysed. They provide information about the part of the average variance in one set which is explained by a given canonical variable in a known second set.

The most favourable value of total redundancy was obtained for a pair of morphology-speed skills (28,947). The basic morphological characteristics explain almost 30% variation in the results of running tests. Other pair combinations are much less advantageous.

Although the factor loadings presented in Table 5 provide information about the correlations between input variables and canonical correlations, they do not include the contribution of the original variable.

Table 6 presents the canonical weights. Canonical weights describe how canonical variables are formed. They are standardized coefficients and therefore they can be directly compared. They indicate the specific contribution of each original variable to the weighted sum. However, factor loadings should be taken into account for their interpretation. This means that the variables with factor loadings of >0.4 are analysed.

In the first set of variable groups, the highest absolute values of weights are body height (-1.65), body weight (0.847) and T-test (0.841). This means a strong relationship between low and medium

Table 6. Factor structure (canonical factor loadings) and redundancies

Anthropometrical-motor			FMS-motor			Anthropometrical-FMS		
	Canonical Roots			Canonical Roots			Canonical Roots	
1st set variables	CR1	CR2	1st set variables	CR1	CR2	1st set variables	CR1	CR2
	Canonical loads			Canonical loads			Canonical loads	
Height	-0,911	0,412	DS.	0,045	0,974	height	-0,698	-0,716
Weight	-0,595	0,804	HS L	-0,435	-0,132	weight	-0,958	-0,286
			IL-L	0,872	-0,054			
Variance extracted	0,592	0,408	Variance extracted	0,317	0,323	Variance extracted	0,703	0,297
Total redundancy	28,947		Total redundancy	9,919		Total redundancy	3,013	
Redundancies of the 2nd set	0,286	0,003	Redundancies of the 2nd set	0,020	0,004	Redundancies of the 2nd set	0,080	0,019
	Canonical Roots			Canonical Roots			Canonical Roots	
2nd set variables	CR1	CR1	2nd set variables	CR1	CR2	2nd set variables	CR1	CR2
	Canonical loads			Canonical loads			Canonical loads	
T-test	0,984	-0,180	T-test	-0,224	-0,975	DS	-0,402	0,327
20m run	0,751	0,660	20m run	0,625	-0,780	HS L	0,856	0,420
						IL-L L	0,270	-0,795
Variance extracted	0,766	0,234	Variance extracted	0,221	0,779	Variance extracted	0,322	0,305

Table 7. Canonical weights of the variable in pairs of anthropometrical, motor and functional movement sets

Anthropometrical-motor				Functional-motor				Anthropometrical-functional			
Variables CR1		Canonical Roots		Variables CR1 CR2		Canonical Roots		Variables CR2		Canonical Roots	
		CR2					CR1				
morphological	Height	-1,651	-1,223	FMS	DS	-0,017	0,996	morphological	Height	0,588	-1,969
	Weight	0,847	1,872		HS L	0,589	-0,175		Weight	-1,472	1,434
Motor	T-test	0,841	-0,958		IL-L	0,904	-0,138	FMS	DS	0,472	0,386
	20m	0,229	1,255	motor	T-test	-0,996	-0,798		HSL	0,864	0,453
					20m run	0,243	-0,285		IL-L	0,262	-0,860

heavy (but not stocky and not slim) body build and better agility results (there is no such relationship for acceleration).

In the case of the second set, the highest absolute values of weights in the group of basic movement patterns were observed for IL L (0.904) and HSLL (0.589). In the case of a set of speed tests, this was again the T-test (-0.995). This means noticeable links between the correct general movement patterns and agility.

The third set examines the relationships between the morphology domain and movement patterns. In this case, high absolute values of both weights were found for both morphological characteristics (0.587 for body height and -1.471 for body weight), HSL (0.864) and DS (0.472). This means that people with leptosomatic built (tall and lean) have better movement patterns.

DISCUSSION

The study analysed multivariate relationships among morphological, functional and motor variables in a group of male athletes. Canonical correlation analysis found strong and statistically significant relationships between morphology and speed skills. Canonical loads and weights indicated relationships of both somatic characteristics (body height and weight) and agility (T-Test). A simple correlation was found between the results of 20m linear run test and In-line Lunge. However, canonical correlation analysis (CCA) failed to identify any significant correlations between speed skills and chosen fundamental movement patterns (FMS). It suggested that agility and acceleration measured during the T-test and 20m run were independent of interindividual variation in morphology. The same concerns morphology and movement patterns. Therefore, high canonical loads and canonical weights suggested the relationships (although not significant) between individual measurements. Furthermore, relationships between morphological measurements and functional movement were very close to statistical significance.

Lockie et al. (2016) did not find any correlations between movement patterns and speed and agility skills. They used the 505 test and the Agility T-test similar to those used in our study. However, their study was performed in a group of 9 elite female athletes who practised different sports. Parchmann & McBridge (2011) were examining a group of golfers and failed to find any correlations between speed and agility. The researchers conducted the same tests as in our study, i.e. 20m Linear Speed test and Agility T-Test with FMS scores. hartigan et al. (2014) used a single FMS module (In-line lunge test) as a locomotive model with a changing centre of gravity. The study found no correlations of the chosen pattern with jump height and sprinting time (36.6 m). However, slightly different results can be found in the literature.

Liang et al. (2019) stressed that baseball players with better movement patterns (higher FMS scores) had better speed abilities than people with poorer FMS scores. Similarly, Atalay et al. (2016) found links between movement patterns and motor abilities. Silva et al. (29) emphasized that single modules of FMS would be more useful in the assessment of athlete performance than the total score.

BMI was taken into account during the analyses as the index representing body proportions and a factor affecting speed abilities. Our tests showed that participants with lower height and higher body weight but still with proper BMI had better times in the Agility T-Test. Nikolaidis examined many groups of athletes and found a negative effect of abnormal BMI on motor skills. In groups of soccer or handball players, he observed poorer results of motor tests, including speed at higher BMI values (Nikolaidis, 2012 & 2013). Boveta et al. (2007) reported negative correlations between high BMI and motor skills. Their study was conducted in a large group of young people. The researchers showed that excessive body weight and consequently a higher BMI value have a negative effect on motor skills. There is little evidence about the correlations between movement patterns and morphological characteristics. The study (Duncan et al., 2013) conducted in a group of 1,000 children showed that greater obesity is linked with poor quality of movement patterns. Similarly, Nicolozakes et al. (2018) indicated that high BMI score has a potentially negative effect on the quality of movement patterns. Our finding did not confirm the findings of the above cited authors. It should be emphasized, however, that our study group was characterized by normal BMI. The negative effect of BMI on the quality of movement patterns is most noticeable in the case of overweight athletes.

Our findings provide new insights into this field of research. It was shown that there is still some question about correlations between movement patterns, morphological features and speed and agility abilities, both simple and multidimensional. However, new findings in this area could be help athletes and trainers improve their sports skill level. This area of research needs further exploration using reliable tests and in bigger groups.

CONCLUSIONS

Canonical Correlation Analysis allowed for the description of the correlations between morphological features, basic movement patterns, speed and agility in team sports players. No studies have examined the multivariate correlations of morphology and FMS movement patterns with speed skills. Results of the present study demonstrated moderate multivariate correlations between body morphology and agility and between movement patterns and agility. In contrast, the relationships between morphology and FMS were very poor. The observed correlations showed that participants with lower height and higher body weight but still with proper BMI had better times in the Agility T-Test. The good quality of In-line Lunge pattern, which represents locomotion ability, was a favourable factor in the achievement of better times in the Agility T-test. The results do not explain the total effect of the analysed factors on speed and agility. Therefore, further research should search for other morphological and functional factors that allow for a comprehensive explanation of determinants of speed and agility skills.

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