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MULTIDIMENSIONAL STRUCTURE AS A DETERMINANT OF PERFORMANCE OPTIMIZATION IN MIDDLE-DISTANCE RUNNING (800 M – 1500 M) AMONG 18-YEAR-OLD MALE ATHLETES.

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ABSTRACT

Background: Performance in middle-distance running is the product of a complex interaction of morphological, physiological and neuromuscular factors. Previous studies pointed out the importance of variables such as maximal oxygen uptake (VO_2max), maximal aerobic speed (MAS) and body composition, but the joint contribution of these variables to the performance of young runners is not yet sufficiently understood. Thus, the aim of the present study was to analyse the multidimensional determinants of performance in male 800-m and 1500-m runners aged 18.

Method: The study included 62 middle-distance runners. Morphological variables were muscular, skeletal and energetic indexes. Physiological variables were VO2max and MAS. Neuromuscular characteristics associated with strength and strength endurance were also measured. The structural relationships among variables were identified by principal component analysis (PCA), and the data redundancy was reduced by PCA. The data were suitable for factor analysis as indicated by the Kaiser–Meyer–Olkin (KMO) value of 0.712 and a significant Bartlett's test of sphericity ($p < 0.05$).

Results and Discussion: The two dominant components accounted for 85.19% of the total variance. The first factor (F1) accounted for 73.48% of the variance and was highly correlated with MAS ($r = 0.97$), 800 m performance ($r = 0.98$) and 1500 m performance ($r = 0.98$). It was also highly correlated with the energy index ($r = 0.98$), skeletal component ($r = 0.94$), muscular component ($r = 0.82$) and strength endurance ($r = 0.86$). The second factor (F2) explained 11.71% of the variance and was characterised mainly by VO_2 max ($r = 0.97$). The results indicate a high synergy between morphological, physiological and neuromuscular characteristics in determining middle-distance running performance. The results of this study emphasise the necessity of a complete assessment and training strategy for athletes, where MAS is a major performance determinant and VO_2 max and body composition are complementary factors for competitive outcomes.

KEYWORDS: performance, middle-distance running, Aerobic capacities, anthropometry; neuromuscular capacities, young athletes

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INTRODUCTION

The interaction between anthropometric characteristics and functional capacities producing the predominant essential energy for middle-distance running performances is the potential for a close interaction between body morphological structure (muscle mass and body proportions) and the biomechanical efficiency of gesture execution, as well as physiological components, VO_2max and MAS, which are considered part of the aerobic energy potential and effort tolerance.

The synergy of these factors forms a determining index, as Aleksandra Stachoń et al. (2023) and Martin Mooses et al. (2013) remind us, for whom the conjunction of morphological and functional characteristics is essential for the systematic structuring of training and the optimization of middle-distance running performance.

The analysis of performance factors in middle-distance running is conducted through a multidimensional approach that combines anthropometric and physiological variables, whose interaction determines the athlete's performance level. As Ross Tucker (2012) notes, this performance results from a significant combination of hereditary and environmental factors, interacting in a dynamic system where energy potential, morphological type, and physiological adaptation to effort interact according to a nonlinear principle.

Anthropometric characteristics, especially the muscular and skeletal components and energy indices, are determinants of performance. Aleksandra Stachoń et al**.** (2023) conducted research that sheds light on the differences in the morphological profiles of runners based on their speciality. They found that middle-distance runners tend to have a more slender profile, lower body fat, and an ideal muscular structure for achieving optimal biomechanical efficiency in movement gestures.

The perfect muscular structure for achieving the best biomechanical efficiency in movement gestures. In this context, the use of principal component analysis (PCA) proved particularly productive, revealing the structural punctuality of the latent dimensions of anthropometric variables. The muscular composition and the type of body proportions are important for better movement execution. The relevance of multifaceted study approaches is evident as an appropriate tool for determining the optimization of sports performance.

The works of Adrien Sedeaud (2013) and B. Poujade et al. (2003) converge towards an integrated understanding of sports performance, highlighting the decisive role of anthropometric and physiological characteristics. On the one hand, Sedeaud highlights the existence of structured relationships between morphology and performance in high-level athletes, identifying optimal morphological profiles and specific anthropometric profiles according to disciplines and levels of practice. On the other hand, the study by Poujade et al., conducted on young swimmers, highlights that performance in the 400m freestyle is strongly correlated with maximum oxygen consumption and energy cost at high speeds, regardless of certain biometric characteristics. Thus, these two complementary approaches suggest that performance results from a complex interaction between morphological factors, reflecting an efficient body classification, and physiological capacities, particularly aerobic ones, confirming the need for a multidimensional approach in the analysis and detection of athletic potential.

In parallel, functional and energetic variables support the achievement of high performance in middle-distance running. According to Martin Mooses (2013), parameters such as VO_2max and ventilatory thresholds are predictive of performances in middle-distance and long-distance races. Maximum strength is thus associated with a significant improvement in running economy and the time to exhaustion threshold of sustained MAS, as highlighted by the work of Oyvind Storen et al. (2008), who mention the major role of neuromuscular capacity in predicting performance in endurance sports. Moreover, M. Thuany et al. (2023) also highlight anthropometric variables such as BMI and training as predictors of performance over various running distances.In this context, a correlational treatment by PCA indicates a significant link between training modalities and middle-distance running performance in pre-elite runners (Badreddine et al., 2006).

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Nevertheless, despite the multitude of previous works, several limitations must be highlighted. First of all, most studies have focused separately on anthropometric or physiological variables, detailing them separately without delving into their structural interaction. Secondly, few studies have, to date, employed advanced multivariate statistical approaches to model the synergy between these variables in homogeneous populations of young middle-distance runners, particularly principal component analysis (PCA). Lastly, studies focusing on the behavior of male athletes aged 18 are rare, which poses a problem because this age group corresponds to a period ....

Moreover, in contemporary models of sports performance prediction, such as those proposed by Blythe et Király (2015), individual performance is no longer understood in a unidimensional manner but rather as a process with multiple and nonlinear dimensions, where several variables must be simultaneously considered rather than isolated (there is no single factor that could account for performance). The work of Ross Tucker (2012) also supports a holistic model where performance results from a social action considering multiple factors such as environmental, genetic, and training aspects...

Considering the literature on the subject, we have noticed a relative lack of factor analyses (PCA) of the multidimensional relationships between anthropometric variables (muscle component, bone component, energy index) and functional variables (VO_2 max, MAS, performances in the 800 m and 1500 m, arm strength, and strength endurance), which constitute the main determinants of performance optimization in this population. It then appeared to us that our main question could be formulated as follows: What are the nature and structure of the relationships between one or more relevant structural dimensions between anthropometric variables and energy variables of 18-year-old male middle-distance runners, explaining the optimization of performance?

Thus, the main objective of this article is to analyze the factorial structure of the relationships between anthropometric variables (muscle component, bone component, and energy index) and energy and functional variables represented by VO_2max, MAS, performances in the 800 m and 1500 m, arm strength measured by dynamometer, and strength endurance in 100 m bounding strides using the Principal Component Analysis (PCA) method among 18-year-old male middle-distance runners. More specifically, our aim is to identify the main factors of performance variability and to characterize the redundancy of the most relevant variables for detecting the optimization of athletic potential.

Finally, the working hypothesis favors the idea that middle-distance performance is organized around a large number of principal components incorporating strong redundancies of anthropometric and functional variables. It is postulated that variables related to aerobic capacity (VO_2max and MAS) and neuromuscular efficiency (muscle strength and endurance), which are involved in certain correlations between anthropometric variables (particularly in muscular components and the motor index), can be related to certain main explanatory axes of performance. The challenge is to improve the understanding of the morphology-function synergy in the performance of young middle-distance runners.

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Materials and methods

Participants

The athletes involved in this study were randomly selected from 7 regional clubs throughout eastern Algeria. Of all participants, 62 were included in this research, where they are registered with the Algerian Athletics Federation as having running as their specialty. These athletes train 5 to 6 times each week and participate in an annual competition schedule at both the regional and national levels. The average age of the athletes is 17.73 ± 0.31 years old , the average weight is 57.67 ± 3.8 kg, the average height is 174.5 ± 0.9 cm, and the average number of years of experience in the sport is 3.73 ± 1.77 years.

Assessement

Anthropometric measurements

To identify the necessary elements for our research concerning the performance of appropriate tests for the evaluation of morphological components, we used a Harpenden brand anthropometric suitcase to measure the indices and selected morphological indicators, which are stature, muscle component, bone component, and energy expenditure index. The anthropometric measurement tests and data collection were carried out according to the recommended protocol during the period from May 2 to 4, 2025.

Tests and description

The stature is measured by a metal stadiometer, going from the vertex point to the ground. Muscle and bone mass are calculated using the Matheika method (1921) from measurements; one can determine the absolute amount of muscle mass obtained from height in cm, as well as arm, forearm, thigh, and leg circumferences in cm. Also, the skin folds of the arm, forearm, thigh, and leg. Skin folds are measured using a caliper graduated in millimeters. And by using the Matheika formula, we can estimate the muscle component in kilograms. The bone component in kilograms is calculated using the formula that incorporates the distal diameters in millimeters of the arm, forearm, thigh, and leg, along with the previously mentioned skin folds and height. Furthermore, the energy expenditure index, also called the Shreider index (1953), indicates the robustness of the individual; the smaller its value, the better the robustness. It is indicated in the formula by weight in grams divided by height in cm^2 .Body weight is measured using a medical scale graduated in grams. Arm strength is tested with a generic-brand dynamometer graduated in mm.

Measuring physical tests

The energy components retained as essential variables of our research are translated into physical indicators examined using the indirect method of evaluating the mechanical efficiency component of aerobic energy capacity, which is predominant and necessary for achieving and optimising performance in middle-distance races. These indicators are the evaluation of the values of maximum oxygen consumption (VO_2max), maximum aerobic speed (MAS), 100m

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bounding strides, arm strength, and performance achieved in 800m and 1500m. Our physical tests and data collection were conducted during the period from 10 to 26, May 7 to 2025.

Tests and description

This measurement is the maximum value of oxygen consumption (VO_2max) and the maximum aerobic speed (MAS), obtained according to the VAM-EVAL test protocol **(Cazorla et Léger 2004).** The VAM-EVAL test is an indirect method to determine an individual's Maximum Aerobic Speed (MAS) and maximum oxygen consumption (VO_2max). The test took place on a 400m synthetic athletics track, which was marked with cones every 50m; the athletes started the race at a speed of 9 km/h and increased their speed by 0.5 km/h every minute, as announced by a beep from the soundtrack placed in the middle of the track. The athlete could not keep up with the pace if he were in front of the marker. We signaled that he had to stop, and that's how the process went, and we counted his last sustained level as an indicator of his MAS. Subsequently, we calculated the VO_2max value using the equation.

Regarding our test, it is conducted in 03 sessions according to the availability of the athletes and their grouping in different locations. Strength endurance is evaluated based on the 100m bounding strides test, and we record the time taken during this event. The 100m bounding strides test is established as a specific test expressing the quality of strength endurance in middle-distance runners (Tschkalov,**1980).**

Additionally, we conducted the test to evaluate upper limb strength using a Hand Grip dynamometer calibrated in millimeters. Which involves applying maximum pressure with the left hand. In order to provide more indicators that could demonstrate the physical qualities of strength and its importance in contributing to the achievement of gestural performance.

To ensure the validity and viability of estimating energy efficiency in aerobic capacity for middle-distance races, it is essential to express the inertia of maximum oxygen consumption, which necessitates intense execution conditions during exercise (Billat et al., 2001).

We had opted for the collection of performances over the distances of 800 m and 1500 m, recorded during the official regional and national competitions that took place during the period from 10 to 24, May 2025. The nature of these performances involves extreme intensity and reflects a VO_2max at its highest level of intensity and execution. Similarly, we find accessibility to the test procedure and viability of data collection thru the electronic tool.

Statistical analysis

Principal component analysis (PCA) is a multivariate statistic that can reduce the number of dimensions in a data set without losing too much of the important information. The process of PCA is to take a number of correlated original variables and convert them into a new uncorrelated set of variables (referred to as principal components). These new variables are each independent of one another and are ordered in terms of how much variance can be explained by them (i.e., the first principal component explains more variability than the

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second).
If you had a data set that has p variables, PCA will determine an orthogonal basis of new variables, with the first principal component capturing the maximum amount of variance, the second component capturing the second-most variance, and so on. This transformation of the original data into new variables can be done using either singular value decomposition (SVD) or eigenvalue decomposition (EVD) of the covariance or correlation matrix. In the simplest geometric and multi-dimensional way, PCA is performed using a series of rotations in variable space to determine how many correlated variables are needed to represent the maximum variability in the data set.

The contribution of PCA in this work is to extract a reduced number of components using the Varimax rotation method with Kaiser normalisation, which best covers the variability of shape and the nature of correlation of morphological variables and functional (energy) variables. As a result, we used the *XLSTAT 2025* software as a statistical analysis tool.

Results

Table1. Descriptive analysis of the subject's characteristics

Variable	Observation	Mean	Standard deviation
VO_{2max} (ml/kg/min^{-1})	62	67,362	2,152
MAS (Km/h^{-1})	62	18,179	0,963
Race 800m (min)	62	1,54	0,223
Race1500m (min)	62	3,55	0,275
Arm Strenght -Dynamometer (mm)	62	31,709	5,904
Bounding stride- Test 100m (sec)	62	19,22	4,788
Muscle Component (kg)	62	19,730	3,172
Bone Component (kg)	62	10,379	2,702
Energy Index (gr/cm^2)	62	4,081	0,763

The descriptive analysis on table 1 illustrates the numerical values of morphological variables and functional (energetic) variables, which will be examined in multidimensional statistical analyses. In order to determine the redundancies that may exist between the variables and the factors and the correlations between the variables. We observe that the indicators related to energy efficiency represent the level of performance in young competitive runners by the VO_2max index, which is 67.36 ± 2.15 (ml/kg/min^{-1}); furthermore, the MAS is produced at a threshold of 18.17 ± 0.96 (km/h^{-1}). These two indicators are methodologically considered as independent variables.

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The dependent variables chosen for the analysis are the performance of the maximum aerobic effort provided by the aerobic energy potential measured during official competitions, which are the 1500m race time of 3.55±0.27 min and 1,54±0,22 min for the 800m. Among the tests conducted, it is observed that the strength endurance capacity is estimated at an average of 19.22±4.78 seconds for the 100m bounding strides event. The arm strength estimated by the anthropometric hand Grip dynamometer is 31.7 ± 5.9 mm. We also find that the body's energy potential expressed by the anthropometric index indicated an average of 4.08 ± 0.7 g/cm². Other essential indicators designated primarily for our study are the muscular Body component, evaluated on average at 19.73 ± 3.17 kg, whereas the body component is 10.37 ± 2.7 kg.

The analysis of the dataset related to our subject involves a preliminary verification of certain conditions of validity and reliability of the test, such as the coexistence of a correlation matrix using all the inserted variables defined at a coefficient magnitude of $p > 0.05$. The evaluation of the adequacy of our sample using the Kaiser-Meyer-Olkin (KMO) index provided an overall assessment of the quality of the correlations between the items, which complements the examination of the correlation matrix that was evaluated at 0.712, indicating a significance level of $p > 0.05$. The significance of Bartlett's sphericity index is $p < 0.05$.

Analysis of Data in Principal Component Analysis (PCA)

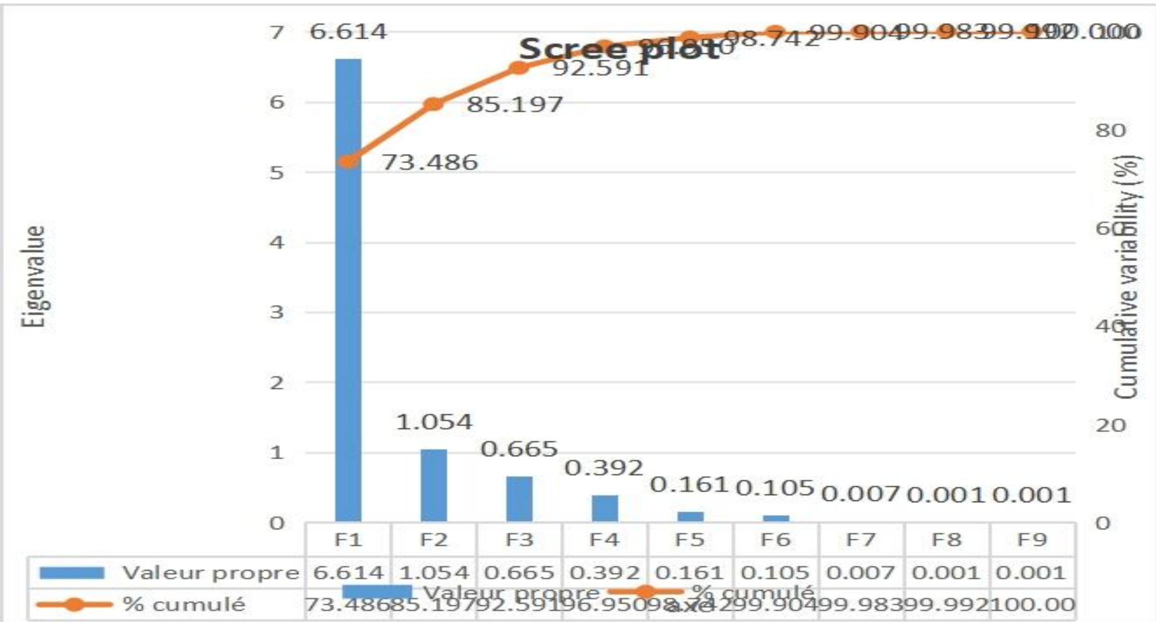

Figure 1.Analysis of variance

The PCA kept only the eigenvalues greater than 1 from the analysis of the energy variables and the morphology variables within the dataset, according to the figure 1 . Based on Figure number 1, the first component accounted for 73.48% of the variance, and the second component accounted for an additional 11.7%; together, these two components explained a total of 85.19% of the cumulative variance necessary to clarify the relationships between the variables and their relative locations. Essentially, both components are used to estimate the total size of the two-dimensional projection of the data points on the first and the second components (axes).

Specifically, the first component produced an eigenvalue of 6.614 while the eigen value of the second component was 1.054. Therefore, both components can be considered adequate representatives of all other variables or the redundancy in the data. Thus, we conclude that the two principal components of the datasets are comfortable enough to represent the total size of the relationship and redundancy that exists between energy and morphology variables, respectively, as well as the size and nature of all other relationships that exist on the two principal components.

Table2. Correlations between variables and factors

Variable	F1	F2
VO_2max (ml/kg/min-^{1})	0,075	0,979
MAS (Km/h^{-1})	0,975	0,156
Race 800m (min)	0,987	-0,042
Race 1500m (min)	0,988	-0,045
Arm Strenght- Dynamometer (mm)	0,653	-0,246
Bounding Stride- Test 100m (sec)	0,867	0,032
Muscle Component (kg)	0,827	0,043
Bone Component (kg)	0,941	0,018
Energy Index (gr/cm^2)	0,980	-0,060

Table 2 illustrates the projection contribution of all variables on the factors or axes; the linear combination of 8 variables with the first principal component proves to be significant. And that we observe the MAS component is strongly correlated with the first axis at a value of r = 0.95. While the two variables express the efficiency of the aerobic energy system, as indicated by performance in competitions, they are significantly correlated with the first factor: the 800m race by r=0.98 and the 1500m race by r=0.98. In addition to this, the two variables related to the evaluation of the quality of muscle strength are also correlated with the first factor at significant values ; the 100m bounding striker is r=0.86 and the arm strength test appeared in correlation to a lesser degree at r=0.65.

Furthermore, the variables represent the morphological component announced in our study; the muscular component is also strongly correlated with the first factor by a coefficient of r=0.82. The bone component is also correlated with the first axis by a coefficient of r=0.94 ; the body's anthropometric energy indicator is also strongly correlated with the first factor by an estimated coefficient of r=0.98. Apart from that, we observe that the most important variable in terms of its nature and energy contribution in middle-distance races is strongly positively correlated with the second factor by a coefficient estimated at 0.97. This variable essentially contributes

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to a variance of 90.96% in the second factor and highlights an increased importance in the representation of the second principal component.

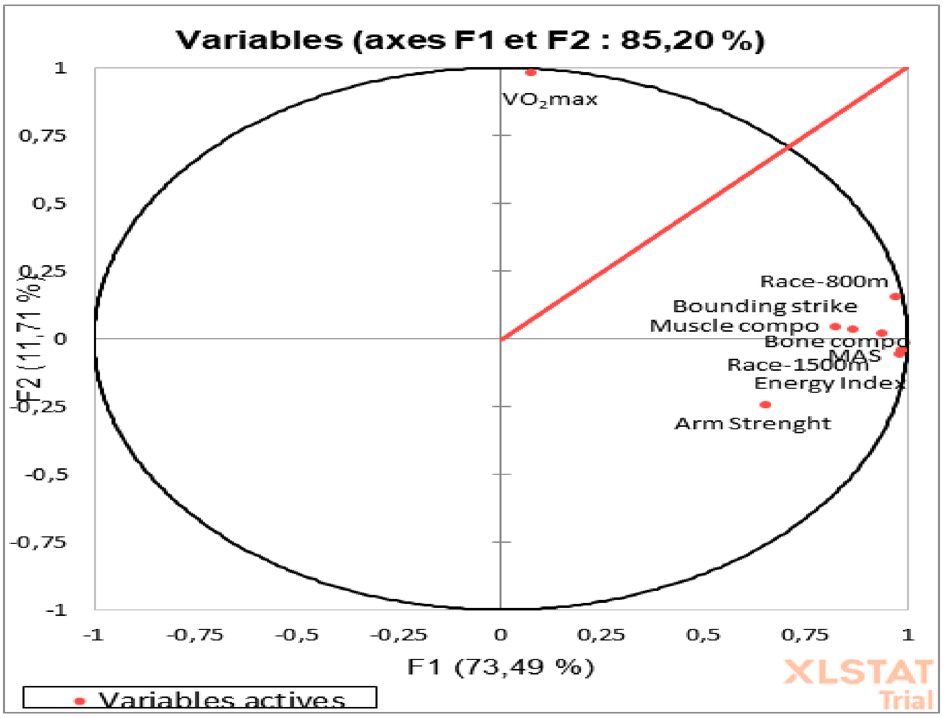

Figure 2. Corrélation between variables and factors

The standardisation of the data leads to the analysis of the variables in the correlation circle in figure 2, according to the PCA results. This highlights a solid factorial structure, with the first two axes explaining 85.20% of the total variance. Such a high proportion demonstrates a very high quality of data representation and confirms the interest of dimensionality reduction in better explaining the significant links between variables. According to Jolliffe et Cadima (2016) as well as Abdi et Williams (2010);Abdi et al. (2017) a PCA becomes fully interpretable when the first axes concentrate almost all the information; this situation is exactly the case in our study.

Axis F1 (73.49%) is the most important principal factor (component) in the factor structure. It has a strong and significant link with a set of variables that represent aerobic performance, neuromuscular constitution, and energy expenditure. These variables include maximum aerobic speed (MAS); performance in the 800m and 1500m, as well as energy indices, muscle component, bone component, arm strength, and strength-endurance capacity. The strong angular proximity between these variables shows that there is a lot of redundant inertia; this means they share a large part of their common variance. This redundancy can have three nuanced theoretical arguments:

For better understanding, we observe a structural redundancy between anthropometric and morphological indices (muscle component, bone component, and Shreider's energy expenditure index), as these variables are directly derived from fundamental body dimensions such as height and weight. Malina et al. (2004) Confirm that these indicators have a common biological basis that indicates their strong correlation. Secondly, a functional redundancy is observed between the variables of arm strength and strength endurance, which can be explained by common neuromuscular mechanisms (motor unit recruitment, intermuscular coordination, and force production). Turner et Comfort (2017) state that these physical qualities undergo metamorphosis concurrently during the training adaptation processes. A partial redundancy between physiological indices is quite apparent between endurance and VO_2max variables (800m, 1500m, MAS), which indicate a joint contribution of energy systems even though the metabolic mechanisms are different.

This phenomenon of collinearity observed in our case study in PCA refers to a situation where several variables are strongly correlated with each other, meaning they convey almost the same information. This case is widely cited in the literature. Lever et al. (2017) as well as Dormann et al. (2013) stated that highly related variables form the same principal component and show a common latent dimension. In sports science studies, this redundancy is due to the interconnection of physical qualities, especially neuromuscular and energetic ones, which change simultaneously during the training process (Turner & Comfort 2017; Sarmento et al., 2018).

The F2 axis, with an estimated variance of (11.71%), explains a secondary dimension of functional differentiation; VO_2max (ml/kg^{-1}/min^{-1}) is placed in the upper part of the circle, in contrast to the muscle strength variable, which is located in the lower part. This organisation shows that there is no direct correlation explaining a functional opposition between these two variables. This indicates that VO_2max and muscle strength represent different physiological functions. VO_2max represents aerobic capacities and the efficiency of the cardiorespiratory system, while muscle strength mainly depends on neuromuscular and anaerobic mechanisms. This opposition is a physiological compromise between energy pathways widely described in the scientific literature. Wilson et al. (2012) as well as Hickson (1980) have shown that the simultaneous development of endurance and strength qualities can lead to antagonistic effects due to divergent physiological adaptations. Buchheit et Laursen (2019) as well as Sandford et al. (2021) also confirm that these two dimensions rely on different physiological determinants, which explains their opposite position in the factorial structures.

The strong representative projection of the variables MAS, 800 m, 1500 m, energy indices, and strength endurance near the circle confirms their major contribution as active variables in the formation of F1. The strong correlation observed between maximal aerobic speed (MAS) and performances in the 800 m and 1500 m confirms that the ability to sustain an intensity close to VO_2max is a major determinant of middle-distance performance. As demonstrated by some studies, the maximum aerobic speed (MAS) represents a central indicator integrating both the physiological and energetic components of the effort, thus explaining a significant portion of the variance in performances over these distances (Billat, 2001; Ingham et al., 2008).

In contrast, the differentiated contribution of VO_2max to the second factor F2 and the almost balanced projection of muscle strength, indicated by the muscle tensions of the arm on the same factor, highlight an inverse secondary structure based on physiological specificity. This hierarchical structure shows that sports performance is the result of both a general factor and

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specific physiological components. This is in line with modern methods of multivariate modelling in sports science (Meylan et al., 2017; Sarmento et al., 2018).

CONCLUSION

The present research aimed to explore the multidimensional structure of the determinants of middle-distance running performance (800 m – 1500 m) in a sample of 18-year-old male athletes, using the principal component analysis tool. Prominent results allow us to conclude that performance results from complex, dynamic, and hierarchical interactions between anthropometric, physiological, and neuromuscular indices, rather than from a single isolated factor, as one might think in an isolated approach. For the implementation of such a system, factor analysis demonstrates the ability to identify a highly robust data structure within our sample, with the first two components explaining more than 85% of the total variance. The first factor (F1), largely dominant, groups together a set of highly correlated variables, including maximum aerobic speed (MAS) and performances in the 800m and 1500m, as well as the muscular and skeletal components, the energy index, and indicators of muscle strength and endurance, which here show significant informational redundancy. One can consider that there is a more global performance factor, which is the index of morphological dimensions linked to functional ones; this result reinforces the idea of a systematic and constant model in optimising middle-distance running performance, suggesting that adaptation responses to training act not in isolation but simultaneously across most systems.

Moreover, the analysis of the second factor (F2) reveals a functional difference that immediately contrasts VO_2max with muscle strength variables, between which a physiological understanding could exist, in the sense of individually distinct and potentially opposing physiological adaptation effects. Certainly, VO_2max undeniably plays a major role in endurance performance, but it cannot be confined to a specific framework; rather, it appears that VO_2max reflects the compensatory development of an individual's strength capacities.

All these results invite us to consider the prediction of sports performance in the light of a relevant multidimensional approach, similar to contemporary models, which view performance as the product of nonlinear interactions between biological, functional, and environmental factors. In practical terms, this research provides notable content elements related to talent detection, with as many types of typological athlete profiles highlighted as in the optimisation of training, directing programmes towards the particularities of a harmonious development of aerobic, neuromuscular, and morphological qualities. However, this approach must be tempered by the limited scope of this sample of 18-year-old male athletes and the inability to generalise the results to other populations (females). In perspective, it would be pertinent to broaden this type of analysis to diverse populations, to integrate biomechanical and genetic variables, and to resort to longitudinal approaches to better understand the evolution of performance profiles. The integration of advanced multivariate statistical tools thus appears as a promising avenue to refine the understanding of the underlying mechanisms of middle-distance running performance.

Ethical approval and consent to participate: All methods of this protocol would be carried out in accordance with the guidelines and regulations of the Declaration of Helsinki. Ethical approval for the given project was obtained from the ethics committee of the Laboratory of Expertise and Technology in Physical and Sports Activities, University of Algiers 3, (Ref. no 1. lsetaps/ce/2025/ ieps-alger3). Informed consent will be obtained from each participant before the data collection procedure.

Availability of data and material: Individual data and supplementary files can be made available upon request to the corresponding author after the publication of complete research findings through email- b.berbagui@univ-setif2.dz

Competing Interests: All authors confirm that they do not have any conflicts of interest to disclose.

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