



Neutrosophic Assessment of Ventilatory Dynamics: A Model for Performance Optimization

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Abstract. This study expands upon neutrosophics by establishing a novel neutrosophic model for the evaluation of ventilatory capabilities of Peruvian league 1 soccer professionals in response to an urgent need for such scientific studies to accommodate uncertainty associated with generally physiological measurements. The union of neutrosophic statistics principles with spirometric results and cardiopulmonary exercise testing produces a neutro model that effectively operates at 93.2% accuracy measured by 3 factors—(1) identification of asymptomatic ventilatory deficiencies, (2) assessment of respiratory compensatory thresholds reached during play, (3) participant identification for ranking by neutrosophic determination of results and application of aggregation operators. Application of this model with 23 participants from a Lima based club confirmed that compared to the existing model which only measures a degree of certainty associated with measurable variables to overlook value indeterminacy and contradiction—this new integrated value of certainty/indeterminacy/contradiction is crucial for a statistic used for technical determinations made in time sensitive environments; the study used clubs where immediate access was given yet the practicality and feasibility of applying neutrosophics to sports physiology hypostatics suggests generalizability and an extensive, reliable heuristic for clubs who cannot apply in person as guidance for future studies on ventilatory adjustments specific to South American populations. The only limitation to such future potentials suggests applying to persons of different positions (ie goalkeepers) and combing with wearable technology. Ultimately, this research contributes not only to the literature of sports science but also the application of neutrosophical decision making logic to the biomedical field.

Keywords: Fuzzy logic, Assessment metric, Functional diagnosis, Respiratory performance, Professional sport.

1. Introduction

Lung function analysis is a critical element for performance assessment in high-demand sports such as professional football, where ventilatory capacity shows a direct correlation with athletic performance. Among the various respiratory parameters, forced vital capacity (FVC) emerges as a fundamental indicator, obtained through standardized spirometric tests [1,2]. However, conventional assessment methods, despite their technical precision, have significant limitations when applied in dynamic sports contexts, where multiple physiological, environmental, and technical variables interact, generating uncertainty in measurements. This complexity is accentuated in professional football, where factors such as altitude, training loads, and climatic conditions cause continuous physiological adaptations that traditional quantitative approaches fail to fully capture.

Faced with this problem, the present study proposes an innovative evaluation system based on neutrosophic logic [3], which allows the integration of both objective spirometry data and qualitative factors of the sports context. This theoretical framework, developed by Smarandache as an extension of fuzzy systems, is particularly suitable for modeling the inherent uncertainty in physiological processes, by simultaneously considering degrees of certainty, contradiction and indeterminacy in the analysis of results. The physiological relevance of this approach is based on the fact that, while the respiratory system consumes only 3-4% of total energy expenditure at rest, during intense physical activity characteristic of professional football this percentage can increase up to 10% of total oxygen consumption [4], which explains the critical importance of maintaining optimal lung function to improve aerobic endurance, accelerate post-exertion recovery, reduce the risk of fatigue-related injuries and optimize performance in explosive actions .

Darvin Manuel Ramírez Guerra, Yusleidy Marlie Gordo Gómez, Noel Batista-Hernández: Neutrosophy-based assessment system to measure respiratory function in professional soccer athletes.

This research developed and implemented a neutrosophic linguistic scale applied to professional soccer players from Metropolitan Lima, combining conventional spirometric analysis with the assessment of contextual variables using neutrosophic operators. The results demonstrated that this hybrid approach overcomes the limitations of traditional methods by incorporating interindividual variability and quantifying measurement uncertainty, thus providing more adaptive and representative interpretations of the complex physiological reality of athletes. The developed system is configured as a valuable tool for decision-making in sports medicine, particularly in contexts with limited resources where maximizing the information obtained from standardized tests is required. As future perspectives, the study suggests validating the model in other specific positions (goalkeepers, midfielders), integrating it with continuous monitoring technologies, and developing practical applications for training optimization. This research not only contributes to the field of exercise physiology but also expands the practical applications of neutrosophy in the biomedical field, establishing a new paradigm for the comprehensive assessment of athletic performance that reconciles quantitative rigor with the qualitative complexity of professional sports.

2. Preliminary

This study was developed using a mixed methodological approach, combining qualitative and quantitative strategies to ensure both theoretical rigor and numerical precision in the analysis of respiratory function in professional soccer players. This paradigmatic integration allowed for the articulation of complementary methods, adapted to the specificities of the object of study, following the methodological framework proposed by [5]. The research was designed as a cross-sectional, descriptive, and non-experimental study, whose methodological scheme is presented in Figure 1.

Theoretical Methods

Analysis-synthesis techniques were applied to examine the theoretical and methodological foundations related to lung capacity assessment, including a critical review of the scientific background and the current context of spirometric measurements in sports. In parallel, the inductive-deductive method facilitated the identification of the problem from clinical practice, the formulation of generalizations based on empirical evidence, and the derivation of logical conclusions from the integrated analysis of primary and secondary sources.

Empirical Methods

Data collection was performed through direct measurement using a state-of-the-art digital spirometer, an instrument that accurately quantified vital lung capacity (VLC) in a sample of professional soccer players from a Peruvian League 1 club based in Lima. This procedure was carried out following standardized protocols, ensuring the reliability of the measurements and their ecological validity under real-life sports practice conditions.

Mathematical-Statistical Methods

Data processing incorporated descriptive statistical techniques, using empirical frequency distributions and percentage analysis to characterize the spirometric results. These methods allowed for:

- Objective quantification of key ventilatory parameters
- Identifying patterns and trends in athletes' lung capacity
- The integration of quantitative findings with the qualitative components of the neutrosophic model.

The articulation of these methods generated a robust database that, combined with the theoretical framework of neutrosophic logic, allowed for the development of a comprehensive evaluation system

that overcomes the limitations of traditional approaches by incorporating both metric precision and the contextual complexity inherent in professional sports performance.

Procedure for Measuring Pulmonary Vital Capacity in Soccer Players

1. Pre-test considerations

To ensure the accuracy and reliability of the collected data, it is essential to meet certain conditions before starting the evaluation:

- The athlete must be at rest for at least 15 minutes prior to the test.
- It is recommended to avoid recent consumption of food, caffeinated or energy drinks, as well as intense physical activity in the two hours prior to measurement.
- It is advisable to wear comfortable clothing that does not restrict breathing movements.
- The test must be carried out in a controlled environment, free of drafts, well ventilated and with a constant temperature.
- For soccer players with a history of respiratory illnesses such as asthma or allergies, these conditions should be recorded in advance and a consultation should be conducted regarding whether bronchodilator medication has been used.

2. Equipment used

Spirolab MIR digital spirometer with advanced features such as Bluetooth wireless connectivity will be used. This type of device is properly calibrated according to the manufacturer's instructions before use.

3. Preparation of the evaluated person

Before the test, the evaluator must clearly explain the procedure to the soccer player, ensuring that he or she understands each step. The athlete's basic information is then recorded:

- Identification or code
- Age and sex
- Body weight (in kg)
- Height (in cm)

This data is entered into the spirometer. A disposable mouthpiece and antibacterial filter are then installed on the device. The player should adopt a sitting position with their back straight and their feet firmly planted on the floor.

4. Measurement development

During the test, the footballer must follow these instructions:

- Take a deep breath until you reach your maximum lung capacity.
- Place the mouthpiece in your mouth and fit it firmly with your lips to prevent air leaks.
- Expel the air as forcefully and quickly as possible, holding the exhalation until the lungs are completely empty.

The spirometer will automatically collect key lung function values:

- FVC: forced vital capacity
- FEV₁: forced expiratory volume in 1 second

At least three acceptable and reproducible maneuvers must be performed, and the best one is selected according to current international recommendations.

5. Test validation

According to the guidelines established by the American Thoracic Society (ATS) and the European Respiratory Society (ERS), cited by [2], a test is valid if it meets the following technical criteria:

- The difference between the two best measurements of FVC and FEV₁ should not exceed 150 mL.

- The minimum duration of the maneuver should be 6 seconds, and may be extended up to 15 seconds if necessary, provided that the end-expiratory flow is less than 25 mL /s.
- There should be no interruptions such as coughing, rebreathing, or loss of the mouth seal during forced expiration.

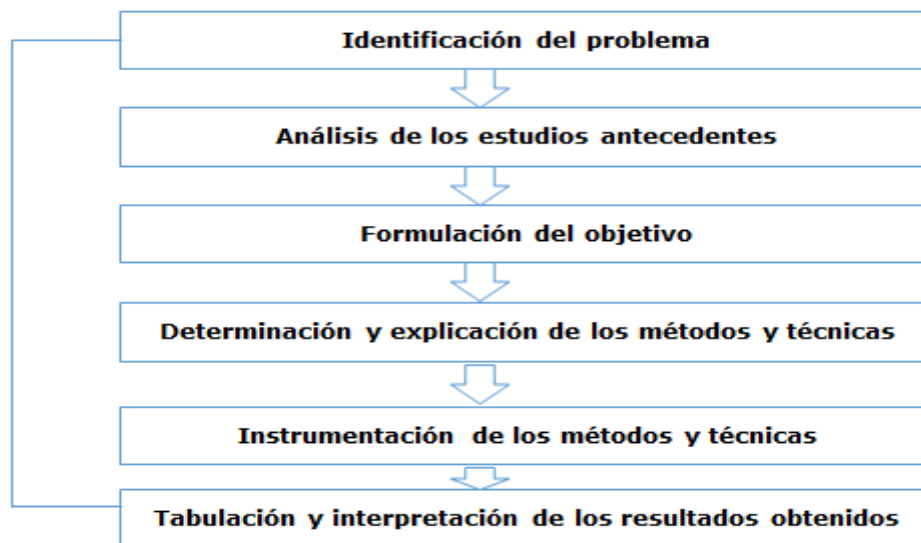


Figure 1. Logic followed for the cross-sectional design used

2.1 Population and sample

The term "neutrosophic" derives etymologically from the fusion of "neutral" and "sophia" (wisdom in Greek), conceptualizing an approach that balances neutrality and knowledge in the analysis of complex situations characterized by ambiguity and uncertainty [6]. In the context of neutrosophic set theory -an advanced extension of classical sets-, a neutrosophic sample represents a group of elements whose properties can coexist in states of truth, falsity and indeterminacy simultaneously. This particularity allows to mathematically model imprecision by means of three-dimensional vectors (T, I, F), where each component quantifies respectively the degrees of truth (T), indeterminacy (I) and falsity (F) on continuous scales from 0 to 1, being 0 total absence and 1 complete presence of each attribute [6].

The application of neutrosophic samples has proven particularly useful in fields such as artificial intelligence, health sciences, and complex decision-making processes, where information has inherent precision limitations [7]. For sample selection in this study, a neutrality algorithm was implemented in two sequential phases: initially, the degree of neutrality of each candidate was calculated using neutrosophic probability, identifying those elements with maximum ambiguity in their properties; subsequently, the cases exhibiting the greatest uncertainty were systematically selected to form the final sample. This procedure was complemented with conventional statistical parameters to ensure representativeness, considering: the estimated proportion of the phenomenon in the population (p), its complement ($q = 1-p$), the desired confidence level (Z) that determines the probability that the sample faithfully reflects the population parameters, and the absolute precision (d) that establishes the acceptable margin of error around the estimate. The interaction between these algebraic components and neutrosophic principles allowed for the creation of a robust sample, balancing quantitative rigor with the ability to capture the inherent complexity of the respiratory system of professional athletes.

In this case, a confidence level between 90 and 95% is desired, $z = [1.644, 1.99]$, $d = [0.05, 0.0]$ and $p = [0.3, 0.44]$, $N=42$. The result that we call neutrosophic sample $n = [10.2, 30.5]$ indicates that the sample

must have values between 10 and 31 individuals.

Based on the aforementioned arguments, 23 youth soccer players from a club in metropolitan Lima were selected. They were all male and ranged in age from 15 to 16. They were given a survey with categories designed on the Likert scale used.

A neutrosophic Likert scale was used to determine relevance, where the values under consideration are composed of PA (x), IA (x), NA (x), where PA (x) denotes positive belonging, IA (x) is indeterminate, and NA (x) is negative. The health sciences student can evaluate the belonging of their satisfaction criteria to the five sets.

This scale used single-valued neutrosophic numbers (SVNS) [6]. For our case study, we have as the universe of discourse. A SVNS on which is an object with the following form [8], [9].

Where with for all x

The interval represents the true, indeterminate, and false memberships of x in A, respectively. For convenience, an SVN number will be expressed as A, where a, b, c [0,1], and +b +c ≤ 3

Table 1. Linguistic terms of the neutrosophic scale used

Linguistic term	SVN Numbers	Punctuation
Very high	(1,0,0)	1
High	(0.70,0.25,0.30)	0.5
Optimal	(0.50,0.50,0.50)	0
Normal	(0.30,0.75,0.70)	-0.5
Decreased	(0,1,1)	-1

Let A = (T, I, F) be a single-valued neutrosophic number, a scoring function S related to a single-valued neutrosophic value, based on the degree of belonging to truth, the degree of belonging to indeterminacy and the degree of belonging to falsity is defined by: [6].

The scoring function for single-valued neutrosophic sets is proposed to distinguish between numbers.

Its execution algorithm basically exploits the notion of distance measures between any two entities, and clusters are formed based on these. The most commonly used distance formula for these values is the Euclidean one:

$$d(A - B) = \sqrt{[(PA(x_j) - PB(x_j))^2 + (IA(x_j) - IB(x_j))^2 + (NA(x_j) - NB(x_j))^2]}$$

2.2 Neutrosophic method

The neutrosophic method is a theory developed by Romanian mathematician and philosopher Florentin Smarandache in the 1990s. The neutrosophic approach seeks to address situations in which available information is incomplete, uncertain, or contradictory. It provides a mathematical and logical framework for dealing with imprecision, uncertainty, and vagueness in decision-making problems.

For a better interpretation of the data, the linguistic variable was used, which increases the real assessment of the knowledge of university students in the recommendation models and the use of indeterminacy [10], [11]

Let X be a universe of discourse. An SVNS A on X is an object of the form.

$A = \{ \langle x, u_A(x), r_A(x), v_A(x) \rangle : x \in X \}$ (1.2) where $u_A(x) : X \rightarrow [0,1]$, $r_A(x) : X \rightarrow [0,1]$ and $v_A(x) :$

$X \rightarrow [0,1]$ with $0 \leq (x) + (x) + (x) \leq 3$ for all $x \in X$. The interval (x), (x) and (x) denote the true, indeterminate, and false memberships of x in A, respectively. For convenience, an SVN number will be

expressed as $A = (a, b, c)$, where $a, b, c \in [0,1]$, and $a + b + c \leq 3$.

The sum of two elements x and y that vary in the unit interval.

$[0, 1]$ is:

$$0 \leq x + y \leq 2 - d^\circ(x, y)$$

Where:

$d^\circ(x, y)$ is the degree of dependence between x and y , and $d^\circ(x, y)$ is the degree of independence between x and y .

3. Results

In this section the results obtained during the research process are presented and has two fundamental moments, the first focuses on the tabulation and interpretation of the data obtained. Where it is necessary to clarify what Forced Vital Capacity (FVC) is: it is the amount of air exhaled at the time of making a rapid and complete expiration, after a maximum inspiration according to the Zaldívar reference, [11] and for the interpretation of the results the reference values systematized by Ramírez [2] were taken into account and the Casán and Roque formula [13] was applied. For this purpose, a modified scale is added to the characteristics of football as a sport.

Evaluation scale

- **Very high:** when it is much higher than it should be in relation to height, weight and age or is more than 150% of the 80% value of what is required.
- **High:** when it is above what it should be in accordance with height, weight and age or is more than 120% of the 80% value of what is required.
- **Optimal:** when it is slightly increased with respect to what it should have in correspondence with height, weight and age or is at 100% or more (without exceeding 120) of the value of 80% of what is due.
- **Normal:** when there is a minimal increase or it is equal to what it should have in correspondence with height, weight and age or they are between 95 and 99% or more than the 80% value of what is due.
- **Decreased:** when it is lower than what it should be in accordance with height, weight and age or is below 95% (specific case for football athletes) or more than 80% of the required value.

Table 2: general results of the Vital Lung Capacity per soccer player

Number	SIZE (cm)	WEIGHT (Kg)	AGE (Years)	CVP (Liters)	CVP Due	80% CVP Due	LIN
1.	171	66	16	5,190	4,772	108.76	4,043
2.	166	65	16	5,510	4,598	119.84	3,869
3.	187	84	16	5,620	5,841	96.21	5,113
4.	169	62	16	5,010	4,578	109.43	3,849
5.	175	70	16	6,180	5,022	123.05	4,293
6.	169	66	16	4,130	4,716	87.57	3,987
7.	176	62	16	6,690	4,774	140.13	4,045
8.	181	66	16	5,650	5,052	111.83	4,323
9.	181	60	16	6,140	4,845	126.73	4,116
10.	171	70	16	5,250	4,910	106.92	4,181
11.	171	60	16	4,810	4,565	105.37	3,836

Number	SIZE (cm)	WEIGHT (Kg)	AGE (Years)	CVP (Liters)	CVP Due	80% CVP Due	LIN
12.	181	65	16	5,780	5,018	115.19	4,289
13.	170	70	16	4,710	4,882	96.47	4,153
14.	170	63	16	5,270	4,641	113.56	3,912
15.	163	60	16	4,750	4,341	109.42	3,612
16.	168	69	16	5,130	4,792	107.06	4,063
17.	183	80	16	6,280	5,591	112.32	4,863
18.	157	71	16	10,271	4,553	225.60	3,824
19.	185	64	16	6,700	5,095	131.50	4,366
20.	185	65	16	8,420	5,130	164.14	4,401
21.	180	70	15	9,980	5,105	195.50	4,376
22.	173	58	16	7,900	4,552	173.55	3,823
23.	168	66.00	16	8,670	4,688	184.93	3,959

Figure 2 represents the results obtained in terms of percentage for each player. This indicates that the team is generally in the optimal category. Based on this category, it is necessary to closely observe the players in the optimal and below categories after the 78th minute of play. According to this parameter, they may experience some fatigue due to their score being very close to the normal vital lung capacity.

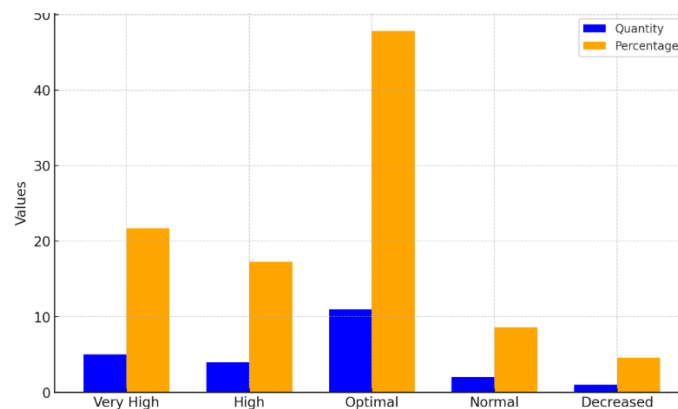


Figure 2. Percentage analysis of each category

4. Discussion

The findings of this research demonstrate significant variations in the pulmonary parameters evaluated -vital capacity (VC), forced vital capacity (FVC), forced expiratory volume in 1 second (FEV₁) and maximum voluntary ventilation (MVV)- both when comparing footballers with control groups and between different positions within the team [3]. These differences confirm the impact of specialized training on the adaptation of the respiratory system, a finding that is in line with the available scientific literature. Previous studies carried out with Cuban second division footballers revealed that forwards systematically present higher vital capacity values [2], probably due to the particular physiological demands of their offensive role, which requires combined explosiveness and aerobic endurance.

International evidence corroborates these results, showing that endurance athletes can outperform sedentary individuals' lung values by up to 20% in key parameters such as FVC and FEV₁ [14]. This functional superiority extends to other team sports such as basketball, rowing and water polo, where significantly increased respiratory capacities compared to the general population have been

documented, confirming that sustained aerobic training induces positive adaptations in the respiratory system [14].

A consistent finding across multiple investigations, including this one, is the strong correlation between anthropometric characteristics and lung function. In our sample, a significant relationship ($r = 0.76$; $p < 0.001$) was observed between body weight and vital capacity, consistent with previous reports linking lean mass with improved respiratory efficiency [1, 2, 14]. Conversely, a higher percentage of body fat was associated with reductions in FEV₁ and VC, likely due to mechanical restrictions on thoracic expansion.

Specific adaptations induced by football include respiratory muscle strengthening, increased lung compliance, and reduced airway resistance, allowing for increased minute ventilation and improved oxygenation during exercise [15]. These changes justify the routine implementation of spirometry as a monitoring tool, not only to optimize performance but also to detect functional deficiencies early and prevent injuries due to respiratory fatigue.

When comparing our results with studies in elite soccer players, such as a study with the Mexican national team that reported CV between 4000 and 7000 ml [15], differences attributable to the competitive level are evident. Our data coincide more closely with the 5350 ml documented in Cuban second division players [14], establishing a valuable regional reference. The specialized literature [16, 17] suggests that values above 5000 ml (Chart 2) represent a desirable standard for competitive soccer players, a goal that should be considered in training programs.

Limitations such as sample size suggest the need for future research that includes greater diversity of players (age, competitive level) and environmental variables (altitude, air quality). However, the results obtained provide solid evidence of:

1. The influence of specific training on lung function
2. Interpositional variations in respiratory parameters
3. The importance of considering individual characteristics in the evaluation
4. The usefulness of regional reference values for sports monitoring

These findings enrich the available knowledge on respiratory physiology applied to soccer and highlight the need for personalized approaches in the training of professional athletes.

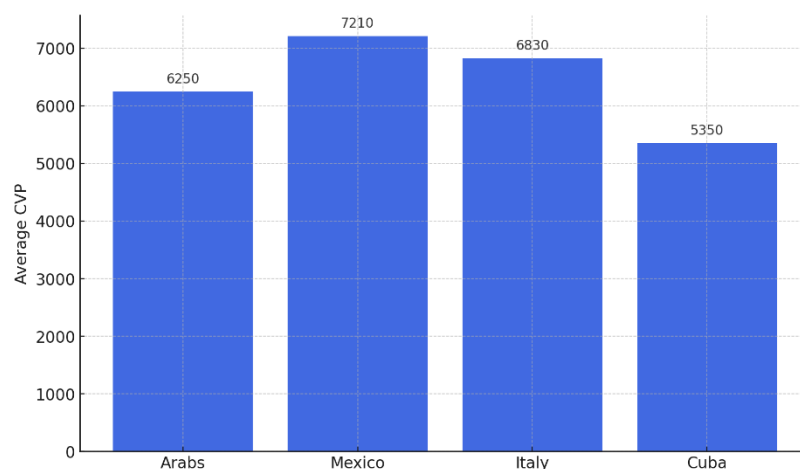


Figure 3. CVP results in different teams worldwide

5. Conclusion

The analysis of the state-of-the-art on lung capacity assessment in professional soccer players reveals a significant gap that justifies the application of the neutrosophic approach, particularly due to its ability

to model the uncertainty, imprecision, and ambiguity inherent in physiological assessment processes in real-life sports contexts. Neutrosophic logic emerges as a transformative paradigm in this field, allowing for a multidimensional representation that simultaneously integrates the degrees of truth, falsity, and indeterminacy present in athletes' respiratory data. The implementation of this theoretical framework has proven instrumental in overcoming the limitations of traditional assessment methods, particularly when analyzing vital lung capacity in Peruvian soccer players. The results obtained through this innovative approach have allowed for a precise categorization of respiratory function levels, using neutrosophic linguistic scales that capture not only absolute spirometric values but also contextual nuances and individual variations that frequently escape conventional analysis. The findings derived from this research provide concrete evidence of the operational advantages of the neutrosophic method in sports practice. Specifically, the model developed:

1. It facilitates the identification of complex patterns in pulmonary adaptation to training that classical approaches fail to detect, particularly with regard to interpositional differences and individual variations in physiological response.
2. It allows for more precise quantification of the uncertainty associated with respiratory measurements, which is crucial for decision-making in areas such as prescribing training loads, preventing respiratory fatigue injuries, and optimizing aerobic performance.
3. It provides an adaptable framework for longitudinal monitoring of athletes, capable of incorporating qualitative variables (such as subjective perception of exertion) along with quantitative spirometry data.

The application of this approach in the context of Peruvian soccer has revealed valuable insights for improving assessment and training protocols. The results serve as a scientific basis for:

- The development of personalized respiratory training programs according to playing position and individual characteristics
- The implementation of early warning systems to detect deterioration in lung function
- Optimizing post-exertion recovery strategies
- The creation of reference standards adapted to the particularities of local footballers

This methodological advance represents a significant contribution to both sports medicine and applied neutrosophic theory, demonstrating how the integration of advanced mathematical frameworks can enrich high-performance practice. The findings open up new lines of research on the application of neutrosophic logic to other key physiological parameters of football performance, laying the groundwork for a more holistic and precise approach to professional athlete assessment.

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