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Study of the impact of cardiovascular exercises and their functional responses on diabetic peripheral neuropathy using neutrosophic statistics

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Abstract. The main purpose of this paper is to determine cardiovascular exercise strategies that improve functional responses in patients with diabetic peripheral neuropathy. The methodology used is the 6-minute walk test (6MWT) which is recognized in the field of treatment of health problems associated with diabetes. The sample included 34 patients of different ages. One of the difficulties we encounter in the study of these diseases is the indeterminacy and uncertainty of the diagnosis of the disease and the treatment. They are complex diseases that require family, institutional, and medical support, in addition to the patient's total cooperation. The processed data corresponds to laboratory tests that must be evaluated with an interpretation of normal or non-normal depending on values given in an interval form instead of a crisp value. That is why the authors of the article decided to process the data using Neutrosophic Statistics, where traditional methods are extended to the framework of intervals instead of crisp numbers. Finally, we obtained a linear equation in interval form to link the measurement of "dyspnea" with the "distance of meters traveled."

Keywords: neuropathy peripheral diabetic, diabetes mellitus, neutrosophic numbers, neutrosophic statistics, t-test, neutrosophic least square method.

1 Introduction

Today there are approximately 382 million people who have diabetes mellitus (DM) worldwide and the projection towards 2030 is not encouraging at all, since the WHO considers that this disease will become in the leading cause of death worldwide, which indicates a complex health panorama shortly, furthermore that at least 10% of diabetic patients present diabetic peripheral neuropathy, a figure that reaches up to 50% in patients who have had the disease for at least 10 years, and at least 75% develops a very high risk of amputations.

In Ecuador the prevalence is very high since it is estimated that at ages between 20-79 years old, it reaches up to 8.5% of the population; It is even shortly proposed that diabetes and associated neuropathies would be the second cause of deaths in general.

Diabetic peripheral neuropathy is a very common complication of type II diabetes mellitus. It is usually characterized by significant deficits in tactile sensitivity, the sense of vibration, and proprioception of the lower extremities. Performing cardiovascular exercises is one of the most effective and beneficial strategies to reduce the symptoms of diabetic peripheral neuropathy.

So, the main objective of this research is to develop cardiovascular exercise strategies that allow improving functional responses in patients with diabetic peripheral neuropathy; to verify its effectiveness. The procedure begins with a 6-minute walk test called 6MWT, to answer the question posed in this work: whether the development of strategies based on cardiovascular exercises can improve functional responses in patients with diabetic peripheral neuropathy.

For the study, we decided to use neutrosophic models since the clinical problems and treatment of diseases such as diabetes and its complications can only be studied if the uncertainty and indeterminacy of both the diagnosis and the treatment are taken into account. In this type of disease converge a series of biological, as well as sociological and psychological factors. The patient must be educated to live with his (or her) illness and avoid complications. In addition, health parameters do not correspond to a single value, but to a range of values.

Due to the aforementioned, Neutrosophic Statistics is the tool that we proposed to apply in the study of the strategies to follow in the improvement of patients who suffer from diabetic peripheral neuropathy, since Neutrosophic Statistics is the generalization of classical statistics to situations where data or parameters exist in the form of intervals, also where the size of the population cannot be precisely defined [1-3]. In our case, due to the nature of the problem that we set out to study, where an exact normal value of heart rate or laboratory test results cannot be determined, it is, therefore, necessary to use values in the form of interval or neutrosophic numbers. In this way, a greater number of measurement situations for each individual are taken into account, beyond the specific situation in which the study is carried out, which increases the reliability of the experiment. In addition, we obtained an equation to determine the number of meters that the patient can travel concerning their state of dyspnea. For this end, we use the neutrosophic least square method ([4]). In this way, the patient can determine his (her) physical condition for walking by measuring the state of his dyspnea. This can be extended to other variables.

This paper is divided into a preliminary section, where we present the main concepts of neutrosophic numbers and Neutrosophic Statistics. Section 3 contains the results of the study carried out. The last section is to give the conclusions.

2 Preliminaries

This section contains the fundamental concepts about neutrosophic numbers and neutrosophic statistics.

Neutrosophic statistics refers to a set of data, such that the data or a part of it is indeterminate to some degree, and to the methods used to analyze these data ([1]).

In classical statistics all data are determined, this is the distinction between neutrosophic statistics and classical statistics. In many cases, when the indeterminacy is zero, the neutrosophic statistics coincide with the classical statistics. The neutrosophic measurement can be used to measure indeterminate data. Neutrosophic statistical methods will allow us to interpret and organize neutrosophic data (data that may have some indeterminacies) to reveal underlying patterns. Many approaches can be used in neutrosophic statistics.

In *neutrosophic probability*, indeterminacy is different from randomness. While classical statistics refers only to randomness, neutrosophic statistics refers to both randomness and especially indeterminacy.

Neutrosophic descriptive statistics is composed of all techniques for summarizing and describing the characteristics of neutrosophic numerical data. Since neutrosophic numerical data contain indeterminacies, *neutrosophic line graphs* and *neutrosophic histograms* are represented in 3D spaces, rather than 2D spaces as in classical statistics. The third dimension, in addition to the Cartesian system XOY, is that of indeterminacy (I). From unclear graphic data, we can extract neutrosophic (unclear) information.

Neutrosophic inferential statistics consist of methods that allow the generalization of neutrosophic sampling to a population from which the sample was selected.

Neutrosophic data are data that contain some indeterminacy. In a similar way to classical statistics, it can be classified as:

- *Discrete neutrosophic data*, if the values are isolated points; for example: $7 + i_1$, where $i_1 \in [0,1]$, 2, $38 + i_2$, where $i_2 \in [10,12]$;

- and *Continuous neutrosophic data*, if the values form one or more intervals, for example [0.05, 0.1] or [0.9, 1.0] (i.e., not sure which one).

Other classification:

- *Quantitative* (*numerical*) *neutrosophic data*;

For example: a number in the interval [3, 8] (we do not know exactly), or; 50, 53, 58, or 61 (we do not know exactly);

- and *Qualitative* (*categorical*) *neutrosophic data*; for example: blue or red (we do not know exactly), white, black or green or yellow (we do not know exactly). Additionally, we can have:

- *Neutrosophic data univariate*, i.e. neutrosophic data consisting of observations on a single neutrosophic attribute;

- and *Multivariate neutrosophic data*, that is neutrosophic data consisting of observations on two or more attributes. In particular cases, we mention the *bivariate neutrosophic data* and the *trivariate neutrosophic data*.

A *neutrosophic statistical number* N has the following form:

$N = a + bI$, where a is the determinate (known) part of N, and bI is the indeterminate (unknown) part of N ([1]).

The arithmetic operations between these numbers are summarized below ([5-8]):

Given $N_1 = a_1 + b_1 I$ and $N_2 = a_2 + b_2 I$ two neutrosophic numbers, some operations between them are defined as follows:

- $N_1 + N_2 = a_1 + a_2 + (b_1 + b_2)I$ (Addition);
- $N_1 - N_2 = a_1 - a_2 + (b_1 - b_2)I$ (Difference),
- $N_1 \times N_2 = a_1 a_2 + (a_1 b_2 + b_1 a_2 + b_1 b_2)I$ (Product),
- $\frac{N_1}{N_2} = \frac{a_1 + b_1 I}{a_2 + b_2 I} = \frac{a_1}{a_2} + \frac{a_2 b_1 - a_1 b_2}{a_2(a_2 + b_2)} I$ (Division).

For example, $a = 4 + I$, where $I \in [0, 0.5]$, is equivalent to $a \in [4, 4.5]$, so for sure $a \geq 4$ (meaning that the determinate part of a is 4), while the indeterminate part $i \in [0, 0.5]$ means the possibility that the number a is a little greater than 4. For example, if we have the following neutrosophic data: $3 + I_1$ with $I_1 \in (0, 0.1)$; $5 + I_2$ with $I_2 \in [4, 6]$; $5 + I_3$, with $I_3 \in [0,1]$; $10 + I_4$, with $I_4 \in [1.1, 1.5)$; $9 + I_1$.

A *neutrosophic sample* is a selected subset of a population, a subset that contains some indeterminacy: either concerning several of its individuals (who may not belong to the population we study or may only partially belong to it) or concerning the subset as a whole.

While classical samples provide precise information, neutrosophic samples provide vague or incomplete information. By abuse of language, it can be said that any sample is a neutrosophic sample since its determination can be considered equal to zero.

The results of the *neutrosophic survey* are survey results that contain some indeterminacy. A *neutrosophic population* is a population that is not well determined at the level of membership (i.e., it is not certain whether some individuals belong or do not belong to the population). For example, as in the neutrosophic set, a generic $x(t, i, f) \in M$ element i% the belonging of x to M is indeterminate (unknown, unclear, neutral: neither in the population nor outside).

A *simple random neutrosophic sample* of size N from a classical or neutrosophic population is a sample of N individuals such that at least one of them has some indeterminacy.

A *neutrosophic normal distribution* of a continuous variable σ^2, for example, μ, or σ, or both can be set with two or more elements. The most common distributions are when μ, σ, or both are intervals.

The formula for the *neutrosophic frequency function* is the same, except replaced μ_N by μ and σ_N by σ:

$X_N \sim N_N(\mu_N, \sigma_N^2) = \frac{1}{\sigma_N \sqrt{2\pi}} \exp(-\frac{(x - \mu_N)^2}{2\sigma_N^2})$, where X_N means $N_N(\cdot,\cdot)$ that instead of one bell-shaped curve for X, we can have two or more bell-shaped curves that have common and uncommon regions between them and are above the x-axis. Each of them is symmetrical concerning the vertical line passing through the mean ($x = \mu$).

Let us illustrate this with a neutrosophic example for the normal distribution, let us consider a normal distribution with $\mu = 0$ and $\sigma = [1, 2]$. Therefore, the standard deviation is indeterminate.

"Within one standard deviation of the mean" is translated in this example by $\mu \pm \sigma = 10 \pm [2, 3] = [10 - 3, 10 + 3] = [7, 13]$, or approximately 68% of the values are in $x \in [7, 13]$.

"Within two times the standard deviations of the mean" translates to $\mu \pm 2\sigma = 10 \pm 2 \cdot [2, 3] = 10 \pm [4, 6] = [10 - 6, 10 + 6] = [4, 16]$, or approximately 95.4% of the values are in $x \in [4,16]$. We could also calculate the last interval as: $[7, 13] \pm \sigma = [7, 13] \pm [2, 3] = [7 - 3, 13 + 3] = [4, 16]$.

Similar to classical statistics, a *neutrosophic null hypothesis*, denoted by NH_0, is the statement that is initially assumed to be true. The *alternative neutrosophic hypothesis*, denoted by NH_a, is the other hypothesis.

When carrying out a test of NH_0 versus NH_a there are two possible conclusions: to reject NH_0 (if the sample evidence strongly suggests that NH_0 is false) or do not reject NH_0 (if the sample does not support evidence against NH_0).

Examples:

$NH_0 : \mu \in [90,100]$ $NH_a : \mu < 90$,

$NH_a: \mu > 100$, $NH_a: \mu \notin [90, 100]$, where μ represents the classical average Intelligence Quotient of all children born since January 1, 2001.

For reading applications of Neutrosophic Statistics, see [9-14].

3 Results

The study was carried out in the province of Tungurahua, Canton of Ambato–Cevallos, Ecuador. With a group of patients suffering from diabetic peripheral neuropathy. Table 1 contains a summary of the distribution in terms of gender, age, and obesity, among other characteristics of the subjects studied.

		% of the Total number of board
Age	Elderly	70.6%
	Adults	29.4%
Sex	Male	32.4%
	Female	67.6%
Index of massbodily	Low weight	2.9%
	Normal	32.4%
	Overweight	26.5
	Obesity	29.4

Table 1. Distribution of the patients under study according to their age, gender, and body mass index.

For a patient to be included in the study, the following inclusion criteria were used:

- Patients from Atahualpa and Cevallos who present diabetic peripheral neuropathy, to whom fractional exercises will be applied, during the period from April to September 2022.
- Patients with ages ranging from 30 to 80 years old who present diabetic peripheral neuropathy.
- Patients who freely express their participation in the study by signing the informed consent.

The exclusion criteria used were the following:

- Patients who present pathologies other than diabetic peripheral neuropathy.
- Patients with recent surgeries.
- Patients who, due to associated comorbidities, cannot comply with the protocol in its entirety.
- Patients with severe cardiovascular disease.

To determine the sample, probabilistic sampling was selected, a method that is characterized by seeking with great dedication to obtain qualitatively representative samples, through the inclusion of apparently typical groups, that is, they meet characteristics of interest to the researcher with patients who are located in Atahualpa and Cevallos, who present diabetic peripheral neuropathy, to whom intense cardiovascular exercises 70% to 80% will be applied, during the period October 2022-January 2023, after evaluation and from whom the data and information required to the development of the study.

In the study, an initial and final evaluation was developed with the implementation of an accessible cardiovascular exercise protocol for patients with diabetic peripheral neuropathy, 15-minute cardiovascular exercises were selected. A form was used to record the information on the 6-minute walk test data for each patient who applied the test and completed it in its entirety.

The 6-minute walk test is a variety of the Cooper test, which aims to measure the maximum distance that a person can walk for 6 minutes. The speed at which the patient walks will determine the distance in meters, that is, a test that evaluates, in an integrated manner, the response of the respiratory, cardiovascular, metabolic, skeletal muscle, and neurosensory systems that the individual develops during exercise.

The 6-minute test is a valid and reliable method to evaluate functional capacity in a population with cardiovascular problems in phase II/III. This test is very valuable for smaller healthcare facilities that wish to document functional improvements but do not have access to conventional treadmill testing.

Table 2 shows a summary of the other diseases associated with the patients under study.

Background Pathological Personal		
Disease	**Frequency**	**Percentage**
None	6	35.3
Hypertension	2	11.8
Hypothyroidism	6	35.3
Respiratory	3	17.6

Table 2. Percentage of person pathological history with diseases not directly related to diabetes and its complications.

To perform numerical calculations we use neutrosophic numbers to represent the collected data. For each aspect to be measured, the symbolic value I represents the normal range of what is measured, and in numerical calculations it is replaced by the equivalent range. For example, for oxygen saturation the normal range is between 95-100% resting, which is why we take $I = [95, 100]$, this guarantees that if a patient has a resting saturation equal to 96 before the study and after the study he (she) has 98%, then the difference is 0. In this case, a reference is obtained from what is normal to what is not normal. Although this means loss of precision, in reality, it is quite the opposite, since at the time of the study the patient may have a certain saturation that may vary at another time, for example, upon awakening and when the interval I is considered instead of a specific value is taking into account, then more situations are studied than the only one in which the experiment is carried out, and in this way the dynamic behavior of these indicators is more accurately reflected.

Before performing the statistical t Test, we checked that the data satisfied the normality condition; in this case, it was a non-parametric test of normality with the help of the Kolmogorov-Smirnov test adapted to data in the form of intervals. Although the test resulted in the data not being distributed normally, as the sample is large enough $n = 34 \geq 30$, it is well known that the t-test is robust enough to give reliable results in the case of large samples, greater than 30 [15,16].

Table 3 shows the results obtained for heart rate, it reflects the average of the initial evaluation and the final evaluation, after having the training with the exercises.

	Average initial evaluation	**Average final evaluation**	**Difference average**	**p**
Frequency cardiac resting	$-5.1 + I$	$-4.6 + I$	0.76	0.683
Frequency cardiac 3min	$-0.34 + I$	$2.41 + I$	2.75	0.561
Frequency cardiac 6min	$-0.12 + I$	$1.41 + I$	1.53	0.644

Table 3. Results regarding average heart rate.

The following table (Table 4) shows the results regarding the saturation levels during the initial and final evaluation process regarding the execution of the exercises.

	Average initial evaluation	**Average final evaluation**	**Difference average**	**p**
Saturation resting	$-1.81 + I$	$-1.53 + I$	0.28	0.988
Saturation 3 min	$-2.59 + I$	$-1.24 + I$	1.35	0.921
Saturation 6 min	$-0.76 + Yo$	$0.41 + Yo$	1.17	0.371

Table 4. Levels of average saturation.

Table 5 shows the difference in the degree of fatigue between the execution of exercises between the initial evaluation and the final evaluation.

	Average initial evaluation	**Average final evaluation**	**Difference average**	**p**
Fatigue resting	$0.02 + I$	$-0.1 + I$	-0.12	0.253
Fatigue 3 min	$2.78 + I$	$2.25 + I$	-0.53	0.253
Fatigue 6 min	$5.66 + I$	$4.78 + I$	-0.88	0.121

Table 5. Fatigue average.

Table 6 below shows the results regarding dyspnea between the initial and final evaluation regarding the execution of the exercise.

	Average initial evaluation	**Average final evaluation**	**Difference average**	**p**
Dyspnea resting	$0.02 + I$	$-0.1 + I$	-0.12	0.09
Dyspnea 3 min	$0.31 + I$	$-0.1 + I$	-0.41	0.14
Dyspnea 6 min	$0.84 + I$	$0.66 + I$	-0.18	0.34

Table 6. Dyspnea average.

Table 7 summarizes the results regarding blood pressure.

	Average initial evaluation	**Average final evaluation**	**Difference average**	**p**
Pressure arterial systolic resting	$7.35 + I$	$10.12 + I$	2.77	0.002

Pressure arterial diastolic resting	$-0.24 + I$	$0.12 + I$	2.36	0.013
Pressure arterial systolic 6 min	$16.18 + I$	$16.41 + I$	0.23	0.010
Pressure arterial diastolic 6 min	$2.88 + I$	$2.76 + I$	-0.12	0.501

Table 7. Arterial Pressure average.

Table 8 shows the final results regarding the distance traveled in meters and the volume of oxygen used. In the results of the table, we do not consider neutrosophic numbers, since the measured parameters have no limits of what is a normal parameter.

	Average initial evaluation	**Average final evaluation**	**Difference average**	**p**
Meters traveled	325.71	336.18	10.47	0.00
VO2 max	22.89	23.55	0.66	0.00

Table 8. Distance traveled and average VO2.

Finally, in the following, we consider the neutrosophic method least squares that appear in ([4]). This is an extension of the well-known statistical method. The objective is to link the variable dyspnea as a dependent variable with the variable meters traveled as an independent variable. To do this, we carry out a statistical approximation using a linear function. The Equations are the following represented by intervals.

First, we wish to obtain the coefficients of the following linear equation:

$$\hat{y}_N = a_N + b_N x_N \qquad (1)$$

Where $\hat{y}_N$ is the approximation in interval form (or its equivalent in neutrosophic number) of the dependent variable, $a_N, and\ b_N$ are the coefficients in numbers within intervals of the linear equation, while x_N is the data of the independent variable given in the form of intervals/neutrosophic numbers.

The approximation of the first coefficient is obtained from Equation 2.

$$\bar{a}_N = \bar{y}_N - b_N \bar{x}_N \qquad (2)$$

Where $\bar{a}_N \in [\bar{a}_L, \bar{a}_U]$ and for the approximation of b_N Equation 3 is used.

$$\bar{b}_N = \frac{n_N(\sum x_N y_N) - (\sum x_N)(\sum y_N)}{n_N(\sum x_N^2)(\sum x_N)^2} \qquad (3)$$

$\bar{b}_N \in [\bar{b}_L, \bar{b}_U]$ and n_N is the number of elements in the sample.

In this way, we obtained the equation $I_{dist} = 338.601 - 77.0 I_{dys}$.

Conclusion

In this article, we carry out a study of the effectiveness of applying the 6-minute walk test (6MWT) in patients suffering from diabetic peripheral neuropathy in Ecuador. The study was carried out with 34 patients who suffer from this complication due to diabetes. Measurements were made of the results of different medical indicators applied before and after the training of the patients with the 6MWT, they are namely, "heart rate", "oxygen saturation", "fatigue", "dyspnea", "blood pressure", "distance traveled" and "condition physical cardiorespiratory (VO2max)". Within the study, we realized that the data collected are crisp and respond to the patient's state at a precise moment of measurement, although these parameters change over time and moment, it is for this reason that we converted the data from crisp to neutrosophic numbers and we apply neutrosophic statistics methods. Additionally, we found a statistical relationship between dyspnea and the number of meters traveled by patients with diabetic peripheral neuropathy, based on the neutrosophic least square method.

Specifically, about the results of the method, we conclude the following:

- It is concluded that from the state of health and physical condition of diabetic patients, the vast majority suffer from high blood pressure that affects their health condition and is a critical factor in diabetic patients if it is not adequately controlled.
- At the end of the application of the accessible cardiovascular exercise protocol for patients with diabetic peripheral neuropathy, which was designed with information from the initial diagnosis of the patient's clinical histories that allowed us to know the patient's pathologies, it was determined that the test of the 6 minutes is effective to evaluate the maximum travel distance and VO2 level in the effort between

distance and walking, to apply 15-minute cardiovascular exercises working at an intense intensity of 70% to 80% that were carried out in 8 weeks.

- At the end of the intervention, the results in older adults with diabetic peripheral neuropathy after having trained in cardiovascular exercises established that the development of the intervention favors systolic blood pressure resting and during the 6-minute exercise because it adapts the need and physical activity favors the health of patients when it is developed in a planned manner and based on their needs, regular exercise can contribute to diabetic patients by improving their quality of life.

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