Neutrosophic Sets and Systems, {Special Issue: Artificial Intelligence, Neutrosophy, and Latin American Worldviews: Toward a Sustainable Future (Workshop – March 18–21, 2025, Universidad Tecnológica de El Salvador, San Salvador, El Salvador)}, Vol. 84, 2025

University of New Mexico

Results of a physical exercise program with music therapy in Ecuadorian patients affected by type 2 Diabetes Mellitus to increase muscle strength in upper limbs from a Neutrosophic Evidence Theory perspective

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Abstract. This research, conducted at the Technical University of Ambato in Ecuador, addresses the impact of an innovative therapeutic plan that combines upper limb muscle strength exercises with music therapy in patients with type 2 diabetes mellitus (T2DM). This multidimensional approach seeks to improve the quality of life and functionality of patients through an accessible treatment tailored to their needs. The primary purpose of the study is to implement and evaluate a therapeutic plan designed to improve upper limb muscle strength in 28 older adults diagnosed with T2DM. The program included specific exercises and music therapy, structured in 48 sessions for 24 weeks. The music selected, based on the participants' preferences, sought to enhance the physical and emotional benefits of the treatment. The methodology included initial and final tests using manual dynamometry to measure muscle strength, and the results were analyzed with non-classical statistical tools. The findings revealed significant improvements in participants' muscle strength, with an average increase of 3 to 4 kg in the capacity for key movements such as shoulder flexion, extension, abduction, and adduction, as well as elbow flexion and extension. This study not only validates the use of music therapy as a complement to physiotherapy programs but also provides a replicable model for future interventions in the management of T2DM, highlighting the importance of integrative approaches in the treatment of chronic diseases. We used a Neutrosophic Evidence Theory method to process the collected data, according to which data are divided into a truthfulness component, an indeterminacy component, and a falseness component. Patient's performance is assessed using neutrosophic measures corresponding to the generalization of the Dempster-Shafer theory to the neutrosophic framework. In this way, we incorporate indeterminacy into the calculations. In addition, the Dempster-Shafer theory allows us to work with subjective probabilities. Specifically, we use the calculation of a probability estimation method appearing in the literature.

Keywords: Physical activity, type 2 diabetes mellitus, combination therapy, Neutrosophic Evidence Theory.

1 Introduction

Diabetes is known as an endocrine and metabolic disease characterized by high blood glucose levels (hyperglycemia). This condition can be determined by the genetic code, but it can also be present throughout life due to a sedentary lifestyle or an unhealthy diet. This condition is also characterized by a total or partial deficiency in insulin secretion.

This condition presents several types of diabetes, but there are two that are the most relevant, namely, Type 1 Diabetes Mellitus (T1DM) and Type 2 Diabetes Mellitus (T2DM). The World Health Organization (WHO) estimates the prevalence of Diabetes Mellitus at more than 347 million people worldwide, with T2DM accounting for 90-95% of cases and T1DM for 5-10% of cases.

In Ecuador, T1DM is a rare disease, thus it is not very common, so it is difficult to find concrete data on this condition. Despite this, in 2017 the Ministry of Health reported that provinces such as Guayas, Santa Elena, Pichincha, and Manabí reported a higher number of care visits for these patients. Fifty percent of people with T1DM are diagnosed during the first years of life.

T2DM is defined as a progressive disease characterized by insulin resistance and pancreatic cell failure, leading to chronic hyperglycemia. It has been classified as a silent but worrying pandemic because it increases the risk of acute and chronic complications. It not only directly affects the patient's health but also their quality of life and represents an economic burden on the healthcare system. It is important to note that, as mentioned above, it is progressive, so arteriosclerotic damage can accumulate years before diagnosis, with blood glucose levels above the maximum acceptable for health. This is stated by the Epidemiological Association of High Cardiovascular Risk.

There is also diabetes gestational that is characterized for the intolerance to the carbohydrates, giving way to hyperglycemia. Its severity can be variable; it starts and is recognized during the pregnancy. It is present approximately in a 7% of pregnant women. Gestational diabetes is associated with complications for the mother during pregnancy and the future human being. This diagnosis is important and would avoid future complications for the fetus and the mother.

Epidemiologically, T2DM is a disease that affects 10.5% of the world's population. The majority of patients are over 55 years of age (men) and 65 years of age (women). In countries with high economic resources (the United States, the United Kingdom, Spain, etc.), there is a downward trend in mortality among diabetic patients. This condition presents a high number of comorbidities that are directly associated with diabetes, complicating the progression and treatment of the individual suffering from it.

The nature of this condition tends to become metabolically chronic and can affect different organs and tissues, including the musculoskeletal system. High glucose levels can alter connective tissue components, causing chronic damage to this system. The common rheumatic conditions in these patients may occur due to direct damage to joint or periarticular tissues, or indirectly due to vascular or neurological complications.

In patients with T2DM, significant age-related changes occur, with visceral fat increasing and muscle and bone mass decreasing. This condition generates several alterations in the body, such as basal inflammation, oxidative stress, malnutrition, and energy imbalances. All of this causes frailty in diabetics, affecting and complicating their functionality and quality of life. This group can present two distinct manifestations: malnutrition and obesity.

One of the treatments increasingly used in patients with T2DM is strength training. This training has various effects, including decreasing blood glucose levels and increasing muscle mass, which is associated with increased basal and total metabolic rate. Strength training increases fast-twitch type 2b fibers, which are high-powered and have a low fatigue resistance.

To increase muscle mass and strength, training must be intensely stimulated (greater than daily activities) to produce muscular adaptation (overload principle). To continue progressing, the training stimulus must be increased (progression principle). If training is stopped, there will be a partial regression of the adaptations achieved (regression principle).

Specifically, we are interested in implementing an exercise plan to increase muscle strength in a group of 28 elderly patients with T2DM at the Senior Recreation Center of the Atahualpa Parish Regional Government. We include music therapy in the exercise plan as a way to make physical exercise more enjoyable and bearable. This way, the patients will feel more motivated and the results will be better.

The use of classical statistics does not allow for dealing with the indeterminacy that is inherent in any evaluation in decision-making. One option is the use of Neutrosophic Statistics that generalizes classical statistics for data or parameters in the form of intervals, or when the sample or population size is not precisely determined [1-4]. The other is the use of Plithogenic Statistics, which extends multivariate statistics to any type of indeterminacy in the data [5]. However, we prefer to use the Dempster-Shafer theory [6-13].

A generalization of subjective probability calculation is the Dempster-Shafer theory of evidence [6-

16]. In the case we are investigating, we want to conduct a more exhaustive investigation incorporating the characteristics of Neutrosophy, which is the use of imprecise and uncertain data. For this reason, we apply a probability estimate based on Neutrosophic Evidence Theory, according to the method that appears in [17]. This method generalizes another that was developed based on the Intuitionistic Fuzzy Evidence Theory [18], however, the latter one does not explicitly take indeterminacy into account.

To do this, we employ experts who assess patients' muscle strength before and after treatment. These specialists perform these assessments based on subjective probabilities. It is well known that humans make probabilistic calculations based on subjective evaluations of events, yet the results are still accurate since frequentist objective probabilities are not always possible or convenient to perform.

The article is structured as follows: a section that reviews the basic concepts of Neutrosophic Evidence Theory. The following section contains the details of the study. The article finishes with its conclusions.

2 Basic Concepts on Probability Estimation According to Neutrosophic Evidence Theory

Definition 1 ([17, 18]). Let U be a space of points with a generic element $u \in U$. A neutrosophic set $A \subseteq U$ is characterized by a truth-membership function T_A, indeterminacy membership function I_A, and falsity membership function F_A. T_A, I_A, and F_A are real standard or non-standard subsets of $]0^-, 1^+[$. I.e.,

$T_A: U \to]0^-, 1^+[$,

$I_A: U \to]0^-, 1^+[$,

$F_A: U \to]0^-, 1^+[$.

Where, $\forall u$ we have $0^- \leq inf\, T_A(u) + inf\, I_A(u) + inf\, I_A(u) \leq sup\, T_A(u) + sup\, I_A(u) + sup\, F_A(u) \leq 3^+$.

However, the Single-Valued Neutrosophic Sets are generally used.

Definition 2 ([17]). Let U be a space of points with a generic element $u \in U$. A Single-Valued Neutrosophic Set $A \subseteq U$ is characterized by a truth-membership function T_A, indeterminacy membership function I_A, and falsity membership function F_A. T_A, I_A, and F_A are elements of $[0, 1]$. I.e.,

$T_A: U \to [0, 1]$,

$I_A: U \to [0, 1]$,

$F_A: U \to [0, 1]$.

Where $\forall u$ we have $0 \leq T_A(u) + I_A(u) + I_A(u) \leq 3$.

According to the Dempster-Shafer theory of evidence, there is a finite set of mutually exclusive elements called the frame of discernment denoted by Ω. The power set of Ω contains all possible unions of the sets in Ω. The singleton sets in the frame of discernment are called atomic sets because they do not contain non-empty subsets.

Definition 3 ([17]). Let $\Omega = \{A_1, A_2, \cdots, A_n\}$ be a frame of discernment. A Basic Probability Assignment (BPA) is a function $m: \mathcal{P}(\Omega) \to [0, 1]$, satisfying the two following conditions:

1. $m(\emptyset) = 0$,
2. $\sum_{A \subseteq \Omega} m(A) = 1$.

Where $\emptyset$ is the empty set, $\mathcal{P}(\Omega)$ is the power set of Ω, and A is any subset of Ω.

Definition 4 ([17]). A subset A of Ω is called the focal element of a belief function m if $m(A) > 0$.

Definition 5 ([17]). Let $U = \{u_1, u_2, \cdots, u_n\}$ be a universe of discourse and $NS(U)$ is the set of all neutrosophic sets in U. A Neutrosophic Belief Function μ is defined as $\{\langle A_i, m(A_i), T_{A_i}(u_j), I_{A_i}(u_j), F_{A_i}(u_j)\rangle\}$, where $A_i \in NS(U)$, $T_{A_i}(u_j)$ is the truth-membership function, $I_{A_i}(u_j)$ is the indeterminacy-membership function, and $F_{A_i}(u_j)$ is the false-membership function of the neutrosophic set A_i and $m(A_i)$ is the BPA of A_i.

Definition 6 ([17]). Let $P(u_j)$ ($j = 1,2,\dots,n$) be the probability of each element in U. The Basic Probability Assignment (BPA) of a Neutrosophic Event $A_i = \{\langle u_j, T_{A_i}(u_j), I_{A_i}(u_j), F_{A_i}(u_j)\rangle : u_j \in U\}$ is an interval value defined as: $m(A_i) = [m_{min}(A_i), m_{max}(A_i)]$.

Where $m_{min}(A_i)$ is the minimal BPA of A_i and $m_{max}(A_i)$ is the maximal BPA of A_i. They are defined as follows:

Given,

$m_T(A_i) = \sum_{j=1}^{n} P(u_j)\, T_{A_i}(u_j)$,

$m_I(A_i) = \sum_{j=1}^{n} P(u_j)\left(1 - I_{A_i}(u_j)\right)$,

$m_F(A_i) = \sum_{j=1}^{n} P(u_j)\left(1 - F_{A_i}(u_j)\right)$,

We have,

$m_{min}(A_i) = min\left(m_T(A_i), m_I(A_i), m_F(A_i)\right)$,

$m_{max}(A_i) = max\left(m_T(A_i), m_I(A_i), m_F(A_i)\right)$.

Definition 7 ([17]). Let $U = \{u_1, u_2, \cdots, u_n\}$ be a universe of discourse and $\mathbb{F}$ is the set of all focal elements. A Normalized Neutrosophic Belief Function μ is given as:

$\{\langle A_i, m(A_i), T_{A_i}(u_j), I_{A_i}(u_j), F_{A_i}(u_j)\rangle\}$, $A_i \in \mathbb{F}$, $u_j \in U$.

So, the probability of u_j ($j = 1,2,\dots,n$) can be estimated as $\tilde{P}(u_j) = [\tilde{a}_j, \tilde{b}_j]$, where $\tilde{a}_j$ and $\tilde{b}_j$ are defined as:

$\tilde{a}_j = min\{\tilde{T}_{A_i}(u_j), \tilde{I}_{A_i}(u_j), \tilde{F}_{A_i}(u_j)\}$,

$\tilde{b}_j = max\{\tilde{T}_{A_i}(u_j), \tilde{I}_{A_i}(u_j), \tilde{F}_{A_i}(u_j)\}$,

Such that:

$$\tilde{T}_{A_i}(u_j) = \sum_{A_i \in \mathbb{F}} \frac{m(A_i) T_{A_i}(u_j)}{\sum_{j=1}^{n}\left(1 - I_{A_i}(u_j)\right) + \sum_{j=1}^{n}\left(1 - F_{A_i}(u_j)\right)},$$

$$\tilde{I}_{A_i}(u_j) = \sum_{A_i \in \mathbb{F}} \frac{m(A_i) I_{A_i}(u_j)}{\sum_{j=1}^{n}\left(T_{A_i}(u_j)\right) + \sum_{j=1}^{n}\left(1 - F_{A_i}(u_j)\right)},$$

$$\tilde{F}_{A_i}(u_j) = \sum_{A_i \in \mathbb{F}} \frac{m(A_i) F_{A_i}(u_j)}{\sum_{j=1}^{n}\left(T_{A_i}(u_j)\right) + \sum_{j=1}^{n}\left(1 - I_{A_i}(u_j)\right)}.$$

3 Study Details

The study population consisted of 28 older adults from the Atahualpa Parish Regional Government of the Elderly Recreation Center. A non-probability convenience sampling design was used. Due to the population size, the study will be conducted with the entire population that meets the inclusion and exclusion criteria, which are listed below:

Inclusion criteria

- People diagnosed with T2DM,
- People from 45 to 85 years old,
- Sex Male/Female,
- People who sign the informed consent,

Exclusion criteria

- People with uncontrolled high blood pressure,
- People who present chronic pain in the upper limb without a precise diagnosis,
- People with upper limb musculoskeletal injuries in the last 3 months,
- People with upper limb surgery in the last 3 months,
- People who are absent from the treatment plan for more than 3 consecutive sessions,

- People with pacemakers,
- People with metal implants or prostheses.

The research was carried out in 6 phases:

1. **Documentary:** Authorization was requested from the Atahualpa Parish to work with the group of diabetic older adults at the Senior Citizen Recreational Center, and proceed with the selection of the population. Then, the informed consent was designed, through which the older adults authorized their participation in the project and the use of the personal data necessary for the development of the project through their signature. At the same time, a systematic review of information on physical activity and muscle strengthening for diabetic patients and older adults was carried out in different databases such as PubMed, Scielo, ScienceDirect, Scopus, Taylor & Francis, and Google Scholar; for analysis. This process was developed through the document analysis research technique.
2. **Diagnosis:** After signing the informed consent, a medical history form was structured to identify the risk history, age, and living conditions of the elderly diabetics in the study group, and the following tests were applied:
   - **Dynamometry:** Measurement of muscle strength through a sustained maximum isometric contraction using a portable device. The device used is a Hydraulic Hand Dynamometer, which allows us to determine the amount of resistance or repetitions for the activity or exercises planned for the exercise plan.
   - Body Mass Index (BMI): The BMI is a widely used indicator of body weight in population studies and is easy to calculate. The BMI was obtained from anthropometric measurements of weight and height.
3. **Selective:** Once all the patient data has been obtained and reviewed, the strengthening exercise to be applied, the frequency of training, the number of sets and repetitions, and the tempo of the music to be used to work together with this type of patient are determined.
4. **Application:** A 24-week exercise plan was implemented, with a frequency of twice a week and an approximate duration of 45 minutes per session. The exercise tolerance of the older adults was monitored using the Borg scale during each activity or exercise, which indicated the intensity and difficulty of the exercise.
5. **Evaluative:** Periodic evaluations will be conducted every 8 weeks; once the strengthening plan is completed, each participant will be assessed using the initial body mass index and dynamometry tests. Data will be collected using the initial registration form. A comparison will then be made with the initial pre-strengthening and post-strengthening states, where changes will be determined based on the results obtained.
6. **Comparison:** Once the results are obtained with each of the patients, they have been compared and determined, a meeting is held with the participants to explain and report on the results by each of them, about the changes they presented if applicable, and recommendations are given so that the results or changes can be prolonged for a longer period of time.

The first result is related to the sociodemographic data collected, which are summarized in Table 1.

Table 1. Data on the sociodemographic characteristics of the patients studied.

Sociodemographic Data	Frequency		Percentage
Sex	Female	18	64.3
	Male	10	35.7
	Single	5	17.9
Sociodemographic Data	**Frequency**		**Percentage**

Marital status	Married	14	50.0
	Widower	5	17.9
	Divorced	4	14.3
Occupation	Active	6	21.4
	Retired	22	78.6
	Average		71.43
Age	Minimum		56.00
	Maximum		89.00
	Total	28	

The proposed exercises correspond to the movements that we will summarize below in Table 2 for the joints of the upper limbs.

The procedure followed in the evaluations is shown below according to the following steps:

1. A study is conducted before performing the training exercises. The experts are asked to agree on the weight in kilograms they believe the patient can carry. The universe of discourse is the weight in kilograms, which depends on the joint in question. In the case of shoulder flexion, this is considered, $U_1 = \{3.0, 4.0, \ldots, 18.0\}$, and in the case of right elbow extension, it is $U_{11} = \{4.0, \ldots, 27.0\}$.

   Table 2 summarizes the amount of weight in kilograms that is considered minimum and maximum within the experiment for each of the movements.

Table 2. Initial assessment of upper limb strength. The minimum and maximum strengths required for each of the twelve movements are shown.

#	**Motion**	**Lower limit (kg)**	**Upper limit (kg)**
1	Right shoulder flexion	3.00	18.00
2	Left shoulder flexion	3.00	18.00
3	Right shoulder extension	2.00	22.00
4	Left shoulder extension	3.00	24.00
5	Right shoulder abduction	3.00	18.00
6	Left shoulder abduction	2.00	22.00
7	Right shoulder adduction	2.00	17.00
8	Left shoulder adduction	2.00	17.00
9	Right elbow flexion	3.00	30.00
10	Left elbow flexion	4.00	29.00
11	Right elbow extension	4.00	27.00
12	Left elbow extension	5.00	26.00

2. The experts were asked to establish a minimum weight at which the exercise was considered adequate, and they all agreed that halfway between the minimum and maximum weights was sufficient to consider the patient successfully passing the test. For example, for right shoulder flexion, $\frac{18+3}{2} = 10.5$ kg is considered the threshold for passing the test; let us round this to 10 kg.

   To measure all the joints to the same scale, each of the above values is converted to a percentage between 0 and 100 using the formula shown below:

   $\bar{u}_j = 100 \times round\left(\frac{u_j - u_{min}}{u_{max} - u_{min}}\right)$

Where,

$\bar{u}_j$: is the new element of the universe of discourse, now denoted by $\bar{U}$,

u_j: is the element belonging to the old universe of discourse U,

u_{min}: is the smallest element of U,

u_{max}: is the maximum element of U,

$round(.)$: is the rounding function.

So, all universes of discourse are normalized to $\bar{U} = \{0,10,20,\dots,100\}$ percentages.

In this way, the event "passing the test successfully" would be considered as follows:

$$A = \left\{ \begin{matrix} \langle 0,0,0,1\rangle, \langle 10,0.1,0.5,0.9\rangle, \langle 20,0.2,0.4,0.8\rangle, \langle 30,0.3,0.3,0.7\rangle, \langle 40,0.4,0.2,0.6\rangle, \langle 50,0.5,0.1,0.5\rangle, \langle 60,0.6,0,0.4\rangle, \\ \langle 70,0.7,0,0.3\rangle, \langle 80,0.8,0,0.2\rangle, \langle 90,0.9,0,0.1\rangle, \langle 100,1,0,0\rangle \end{matrix} \right\}$$

An alternative is an event "passing the test unsatisfactorily", where the following is calculated:

$$B = \left\{ \begin{matrix} \langle 0,1,0,0\rangle, \langle 10,0.9,0.5,0.1\rangle, \langle 20,0.8,0.4,0.2\rangle, \langle 30,0.7,0.3,0.3\rangle, \langle 40,0.6,0.2,0.4\rangle, \langle 50,0.5,0.1,0.5\rangle, \langle 60,0.4,0,0.6\rangle, \\ \langle 70,0.3,0,0.7\rangle, \langle 80,0.2,0,0.8\rangle, \langle 90,0.1,0,0.9\rangle, \langle 100,0,0,1\rangle \end{matrix} \right\}$$

3. Each of the 28 patients is assigned a probability p_{ij} for each of the exercises for event A with $i = 1, 2, \dots, 28$ and $j = 1, 2, \dots, 12$, where i is the patient index and j is the exercise index according to Table 2. The probability for event B is $q_{ij} = 1 - p_{ij}$.

   The joint probability for all patients is calculated as:

   $$m_j(A) = \prod_{i=1}^{j} (0.5p_{ij} + 0.5\mathrm{C}) \quad (1)$$

   Where C is a value representing a fixed probability. Let us take $\mathrm{C} = 0.5$, as a neutral probability, neither high nor low.

   Equivalently, the joint probability for the event B is calculated as follows:

   $$m_j(B) = \prod_{i=1}^{j} (0.5q_{ij} + 0.5\mathrm{C}) \quad (2)$$

   With these two elements and the interval probabilities appearing in Definition 7, the desired results are calculated.

4. The procedures in step 3 are repeated for the results obtained in patients when they complete the treatment with muscle exercises.

5. The results before and after treatment are compared.

The results of applying Equation 1 were as follows:

Table 3. Joint evaluations $m_j(A)$ were obtained for each exercise, before and after training.

#	Motion	Expert evaluation before	Expert evaluation after
1	Right shoulder flexion	0.35	0.55
2	Left shoulder flexion	0.33	0.55
3	Right shoulder extension	0.38	0.51
4	Left shoulder extension	0.28	0.42
5	Right shoulder abduction	0.25	0.53

#	Motion	Expert evaluation before	Expert evaluation after
6	Left shoulder abduction	0.29	0.47
7	Right shoulder adduction	0.37	0.61
8	Left shoulder adduction	0.36	0.60
9	Right elbow flexion	0.36	0.56
10	Left elbow flexion	0.39	0.55
11	Right elbow extension	0.36	0.55
12	Left elbow extension	0.33	0.56

The approximate probabilities obtained before and after training are shown in Table 4, applying the Equations of Definition 7. Note that for simplicity we write down the absolute minimum and maximum for all possible values, instead of each patient individually.

Table 4. Joint approximate probabilities of event *A* before and after passing the training.

#	Motion	Expert evaluation before	Expert evaluation after
1	Right shoulder flexion	[0.023, 0.091]	[0.0294, 0.091]
2	Left shoulder flexion	[0.0215, 0.091]	[0.0294, 0.091]
3	Right shoulder extension	[0.0248, 0.091]	[0.032, 0.091]
4	Left shoulder extension	[0.0183, 0.091]	[0.0275, 0.091]
5	Right shoulder abduction	[0.0163, 0.091]	[0.0307, 0.091]
6	Left shoulder abduction	[0.0189, 0.091]	[0.0307, 0.091]
7	Right shoulder adduction	[0.0241, 0.091]	[0.0255, 0.091]
8	Left shoulder adduction	[0.0235, 0.091]	[0.0261, 0.091]
9	Right elbow flexion	[0.0235, 0.091]	[0.0288, 0.091]
10	Left elbow flexion	[0.0254, 0.091]	[0.0294, 0.091]
11	Right elbow extension	[0.0235, 0.091]	[0.0294, 0.091]
12	Left elbow extension	[0.0216, 0.091]	[0.0288, 0.091]

As can be seen for all the movements studied, there is a higher estimated probability post-training with respect to pre-training.

4. Conclusion

The loss of muscle strength in patients suffering from type 2 diabetes mellitus is an effect of this disease. One of the reasons for alleviating this situation is the incorporation of strength training exercises. When music therapy is added to this, the results are improved because it contributes to patient motivation. This paper studies the effectiveness of a muscle strength training exercise in older diabetic patients with the inclusion of music therapy. Specifically, the study was conducted on 28 diabetics belonging to the Senior Adult Recreation Center of the Atahualpa Parish in Ecuador. Since measurements were based on expert judgment, where uncertainty and indeterminacy exist, a method for approximate probability calculation based on Neutrosophic Evidence Theory was preferred. When comparing the results obtained by the patients before and after treatment, there was an increase in muscle strength across all the twelve movements. This means that muscle function was restored, both through anatomical development and increased functionality.

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Received: December 23, 2024. Accepted: April 4, 2025.