Spth-FCM: decision support tool for speech therapist based on fuzzy cognitive mapping

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ABSTRACT

The development and integration of medical information systems into a unified information space is a significant focus in the field of information technologies. It is essential to develop decision support systems (DSS) to enhance the effectiveness of medical and diagnostic procedures. This article presents a novel decision support tool for speech therapists, which is based on fuzzy cognitive maps (FCM). The latter is a method of modeling complex systems using knowledge of human existence and experience. The proposed tool is composed of three phases. The first phase focuses on entering patient information into the graphical interface developed in JAVA based on the most precise observations. An FCM will be automatically constructed, describing the type of disorder and the patient's case during the second phase. Finally, in the third phase, FCM-based scenarios were built during the execution of the inference process under FCM expert. The system is presented and demonstrated using a real cases study for eight weeks. The results show that the tool makes it possible to display, guide, assist, and confirm the medical decision of the speech therapist for an appropriate diagnosis and treatment.

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1. INTRODUCTION

The area of decision support systems (DSS) has a lengthy track record of research and advancement. Recently, traditional standalone DSSs have encountered new challenges [1]. To enhance DSS performance in meeting these challenges, numerous studies have been actively pursued to create new DSS. Developing DSS for medical applications is a very complex and difficult task. Especially the diversity and increasing number of diseases make the process of medical decision-making more complexes. For this, DSS have been developed since the 1970s to help solve semi-structured and unstructured decision problems [2].

The medical decision support system (MDSS) is a computer system designed to assist physicians and other healthcare professionals in making clinical decisions. MDSS helps decision-makers by increasing their capacity and does not replace their judgments [3]. Nowadays, MDSSs are being used in various fields, including speech therapy. Clinical decision-making is a vital skill in medical practice [1] and involves a cycle of perceptual activities, encompassing what is perceived through the senses and the cognitive activities linked to the intellectual processing of information. The speech therapist is a health professional who performs tasks according to a medical prescription. First, they conduct a speech therapy assessment to evaluate disorders and present a speech therapy diagnosis, and, if necessary, a rehabilitation project [4]. The practice of speech therapy involves promoting health, preventing speech disorders, and assessing language and mathematical cognition. The speech therapist provides care to patients of all ages with congenital, developmental, or acquired disorders. Speech therapy contributes to the development and maintenance of the patient's autonomy and quality of life [3].

There have been many publications in the literature aimed at helping speech therapists in their work. These tools usually include tests and databases [4]-[11]. However, most of these tools do not use reasoning to help speech therapists make decisions. In our work, we have created a comprehensive support tool for speech therapists that combines existing tools with the qualitative reasoning of fuzzy cognitive maps (FCMs). Our tool's goal is to help and guide speech therapists in making the most appropriate diagnoses.

FCMs are modeling techniques that rely on experience and knowledge. They were developed based on theories of fuzzy logic, neural networks, and evolutionary computing, which are generally classified as soft computing and computational intelligence techniques [12]. FCM is a soft computing method that offers a flexible and robust framework for knowledge representation and reasoning, making it a useful tool for dynamic system modeling [13].

The basic idea of this work is to take advantage of the integration of FCMs in the speech therapist's diagnosis. The use of FCMs helps improve diagnostic accuracy through modeling the complexity of symptoms and clinical conditions in a more realistic and nuanced manner. Fuzzy logic, in FCMs, is particularly useful for managing imprecise and ambiguous information common in speech therapy. This allows speech-language pathologists to more effectively navigate clinical situations where data is partial or the diagnosis is ambiguous. The use of FCMs also makes it possible to ensure the consistency of partial decisions taken throughout the treatment. It also helps to explain the past decision by causal relationships. It makes it possible to predict the future states of the patient from previous data, improve the knowledge base of the speech therapist, and facilitate the proposal of the methodology to follow for appropriate treatment of the patient. In this work, the diagnosis is presented formally in graph form (FCM), which makes the results more readable. Speech therapists usually try to minimize the time required to monitor the condition of their patients, and our proposition of using FCMs makes it possible to achieve this goal.

The main objective of this paper is to present a decision support tool for speech therapists (Spth-FCM) that presents a new and alternative approach. In section 2, we present a brief overview of the basic concept that is FCM. Then, in section 3, we explain in detail the proposed approach. In section 4, we show the results and comparison part. Finally, section 5 concludes this work and offers some perspectives.

2. A BRIEF OVERVIEW OF FUZZY COGNITIVE MAPPING (FCM)

Various decision support tools have been suggested in research, with some being qualitative and others quantitative. The FCM is a promising tool for modeling and controlling complex systems, and it has emerged as a new approach for expressing and assessing the behavior of a system [14]. Predicting the outcome by enabling the several concerns to interact is the main goal of developing an FCM. This method may be applied to ascertain if a conclusion is consistent with all of the stated causal statements in the collection [15].

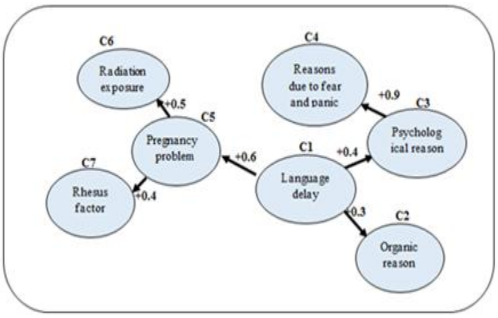
Formalization of fuzzy cognitive maps: Fuzzy logic and neural networks are two soft computing approaches combined into one tool called FCM. It belongs to the class of cognitive networks, which are created by professionals through an interactive process of knowledge acquisition [16]-[19]. Unlike traditional expert systems that rely on "IF/THEN" rules, FCM provides a more flexible and powerful way to represent human knowledge and reasoning [20], [21].

An FCM is a graphical model used for representing and reasoning about causal knowledge. It may express information at various granularities as well as the causal links between ideas. Concepts (nodes) and the connections between them (edges) make up an FCM. The following is the mathematical model of FCM [21], [22]:

$$Vcj(t+1) = f\left(\sum_{i=1}^{N} Vci\,(t)wij\right) \quad (1)$$

where wij is the weight of the causal link from concept Ci to concept Cj, f (x) is the threshold function of concept Cj, and Vci and Vcj are the state values of the cause concept Ci and the effect concept Cj, respectively.

Figure 1 shows a real example of an FCM performed by a speech therapist (domain expert) associated with a patient state, where Ci is a concept with a state value. The existential degree of a concept can be represented by a fuzzy value in the interval [0, 1], or its open/closed state can be represented by a bivalent logic in the interval {0, 1}. The graphical representation of the proposed FCM in Figure 1(a). This FCM is composed of seven concepts (C1: Language delay, C2: Organic reason, C3: Psychological reason, C4: Reasons due to fear and panic, C5: Pregnancy problem, C6: Radiation exposure, C7: Rhesus factor) and six edges. The weight wij of a connection, can either be a trivalent logic in {-1, 0, 1} or a fuzzy value in [-1, 1], signifies the level of influence from cause concept Ci to effect concept Cj. If the weight is negative, a decrease/increase in the state value of concept Ci results in a decrease/increase in the state value of concept Cj. When the weight is negative, changing the state value of concept Ci will also lead to a change in the state value of concept Cj in the opposite direction. Figure 1(b) displays the adjacency matrix for the proposed FCM.



(a)

Concepts	C1	C2	C3	C4	C5	C6	C7
C1	+0.3	+0.4	0	+0.6	0	0	0
C2	0	0	0	0	0	0	0
C3	0	0	0	+0.9	0	0	0
C4	0	0	0	0	0	0	0
C5	0	0	0	0	0	+0.5	+0.4
C6	0	0	0	0	0	0	0
C7	0	0	0	0	0	0	0

(b)

Figure 1. A FCM proposed by a speech therapist (a) graphical representation of the proposed FCM and (b) its matrix d'adjacency

The function f () is used in the first rule listed above to restrict each concept's activation value to a particular interval. This function can be bivalent, trivalent, hyperbolic tangent, sigmoid, or any other sort of function that is monotonically non-decreasing. These functions are all specified in scholarly sources like [18], [23], [24].

The sigmoid function's convergence degree is determined by the value of "α".

$$f_{sign}(x) = \begin{cases} 0 & x \le 0 \\ 1 & x > 0 \end{cases} \quad (2)$$

$$f_{tri}(x) = \begin{cases} -1 & x \le -0.5 \\ 0 & -0.5 < x < 0.5 \\ +1 & x \ge 0.5 \end{cases} \quad (3)$$

$$f(x) = \tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \quad (4)$$

$$f(x) = \frac{1}{1+e^{-\alpha x}} \qquad \alpha \ge 0 \quad (5)$$

The situations and results of the simulation are directly affected by the type of threshold function used. Discrete-output functions, such as in (2) or (3), influence the simulation to either form a hidden pattern or a fixed-point attractor. The former phrase describes a scenario where the state vector stabilizes after a certain number of iterations. The latter describes a situation where the system continuously switches between a certain number of states. A chaotic attractor may arise when the transformation function is of the continuous-output type, like in (5). This implies that for each subsequent cycle, the system produces a new state vector [12]. Most of these features are found in the decision support system that was created.

3. METHOD

The process of making decisions can be quite complicated, but decision support tools can make it easier to study. Speech therapy is an area where it can be challenging to make the right diagnosis, as speech therapists need to closely monitor their patients to determine the best course of therapeutic action.

In the speech-language pathology field, speech therapists must manage a rising volume of information related to medical knowledge, pathophysiological data, and diagnostic and therapeutic techniques to effectively care for their patients. Speech therapists have to make a variety of decisions in order to accurately diagnose a patient during treatment. Our proposed work aims to utilize FCMs, which are DSS, to simulate medical reasoning for modeling medical practices. To achieve this, we need to closely observe the approach of speech therapists toward their patients and analyze their medical decisions. In other words, we need to study the reasoning path and the conditions that lead to medical decisions.

According to the domain specialists and some medical references [4], [5], [8]-[10], [25], [26], speech therapists first interview their patients, and in the case of children, their families as well. During this interview, the speech therapist will ask various questions about the patient's life, development, and concerns to gather their medical history. Utilizing the feedback received, the speech therapist will choose the most suitable assessments and procedures to identify any potential speech or language impairments. These assessments will examine the patient's ability in both spoken and written language, as well as cognitive functions including memory, attention, and time perception. After finishing the evaluation, the speech therapist will provide a diagnosis and suggest further testing if needed.

In our approach, we will translate the work of the speech therapist to the software based on FCM (the speech therapy assessment) passing through the main steps as shown in Figure 2.

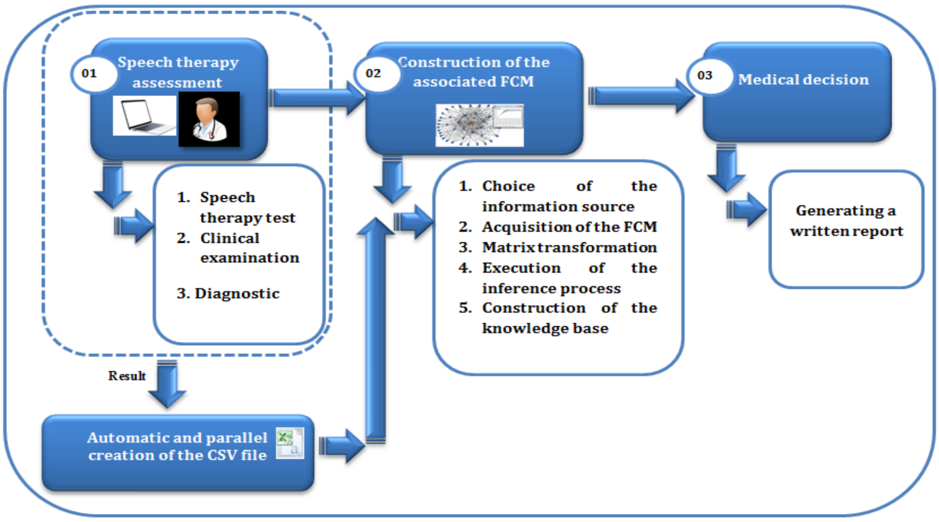


Figure 2. Global architecture of the proposed approach

The proposed approach consists of three main steps that run simultaneously. Firstly, the speech therapist will input the patient's information into our graphical interface based on the most accurate observations. Secondly, an FCM will be automatically constructed, describing the type of disorder and the patient's case. Finally, after the FCM inference, our tool will display the medical decision to confirm the speech-language pathologist's reasoning. The details of each of these steps and their implementation are explained in the following subsections.

3.1. Speech therapy assessment

The starting point of our approach is the arrival of the patient to be treated. The purpose is to find anappropriate care. Our tool has two cases for patients:

- If the patient is new, a new file will be automatically generated which will contain the patient's information, associated FCM, and a CSV-type file.
- If the patient already exists, meaning they already have a file in the patient database, the tool will recognize this and open the existing file.

A speech therapy assessment's goal is to pinpoint the precise type of a patient's communication impairments so that the best course of action may be decided. It can only be conducted with a medical prescription and must be performed by a qualified speech therapist. In this approach, the assessment is crucial to identify the root cause of the patient's difficulties before any rehabilitation can be initiated. This allows the speech therapist to target the precise origin of the patient's communication concerns. The process involved in the speech therapy diagnosis is described in detail below.

3.1.1. Speech therapy test

After receiving all the necessary information, the speech-language pathologist will speak to the child privately. Parents may be present only if the patient is too young to understand what the professional is trying to convey. Depending on the complaints and other factors, such as the age and education level of the patient, the speech-language pathologist will suggest a series of tests to evaluate the patient's language modalities and components. The speech therapist uses several tests to classify and differentiate the disorder to be studied and treated. These tests consist of games and various exercises that focus on both expression and comprehension, for example: language sample review, contextual verification, speech examination, oral and facial examination, reading test, syllable testing, and language comprehension test.

Our tool is designed to help SLPs choose the appropriate tests based on the patient's condition. Whereas there are several online tools available, our approach focuses on making the SLP's job easier, reducing treatment time, and monitoring the progress of therapy. Our aim is not to create new tests, as this problem has already been solved [4]-[11]. Instead, we aim to determine the type and severity of language disorders and evaluate the success of therapy. So, the results of the tests will either be positive or negative.

3.1.2. Clinical examination

After conducting tests, the speech therapist will ascertain whether there is a flaw in the patient's speech and then recommend them to a specialist for necessary interventions. The speech therapist may seek help from experts like a neurologist, psychologist, or dentist to assist the patient in overcoming the issue. After the specialist has chosen the correct course of action, the outcome is relayed back to the speech therapist for finalization of the process. The outcome can be either favorable or unfavorable.

3.1.3. Diagnostic

In the proposed work, the language disorders to be treated are selected according to a detailed study on the speech therapy field [4], [5], [8]-[10], [25], [26] and also the views of domain experts. The most known disorders are shown in Table 1.

Table 1. Disorder list

Disordertype	Definition
Aphasia (or mutism)	Loss of the ability to speak or understand language, written or spoken
Dysphasia	A disorder of language development in children, both written and spoken
Dysarthria	Articulation disorder due to brain damage or damage to the various speech organs
Stuttering	Speech flow disorder (repetitions and blockages, often on the first syllable of words)
Oral-facial apraxia	A disorder of the mobility of the mouth, tongue and muscles that allows one to not speak clearly
Dyslexia	Written language disorder
Spasmodic dysphonia	Voice alteration caused by vocal cord spasms (laryngeal dystonia)
Dysphonia	Voice problems (hoarseness and inappropriate voice pitch or intensity)

Our study has revealed that each language disorder has its own set of causes. To facilitate our work, we use an FCM. This is a graph that is labeled and directed, with each node representing a concept (that is a cause of the disorder), and the arcs depicting the causal relationships between them. At present, these causal relationships have unknown values, which are determined by the speech therapist based on their specialist knowledge, as well as the results of tests performed. Using the FCM, our tool launches an inference process to determine the best course of action for treating the disorder. This involves identifying the patient's specific disorder based on the tests conducted, and the decisions made using the FCM. We will delve into this further in the following sub-sections.

In reality, during a speech therapy assessment, the patient's condition is evaluated to determine whether it is a developmental disorder, a learning disorder, or an acquired disorder. In our tool, we have implemented a graphical interface (as shown in Figure 3) implemented in Java.

The proposed interface presenting the developed tool (Figure 3) called "decision support tool for speech therapists based on fuzzy cognitive mapping" (Spth-FCM) consists of four parts. The first part constitutes the interview part in which the speech therapist will enter information concerning the patient to be treated. This information is stored in a database used for storing patient records and crucial information for the patients' evaluation. The second part presents the different tests to be done. According to SLPs, there are three types of tests: oral language, written language, and cognitive skills. As mentioned earlier, the purpose of this work is not to develop tests but to assist the SLP in making medical decisions. Therefore, in this part, the SLP has the right to choose his tools for testing. Otherwise, it is possible to guide him by using online tools. For example, TalkTime, Tiger's Tale, Speech Therapy for Apraxia, Articulation Station (Pro), and Comunica. The third part is devoted to the results obtained from the clinical examination. If there is a problem either organic, psychic, or otherwise, the speech therapist will seek the advice of other specialists (neurologist, psychologist, dentist, and ENT), to help the patient overcome the detected problem. The deduced diagnosis is shown in the last part.

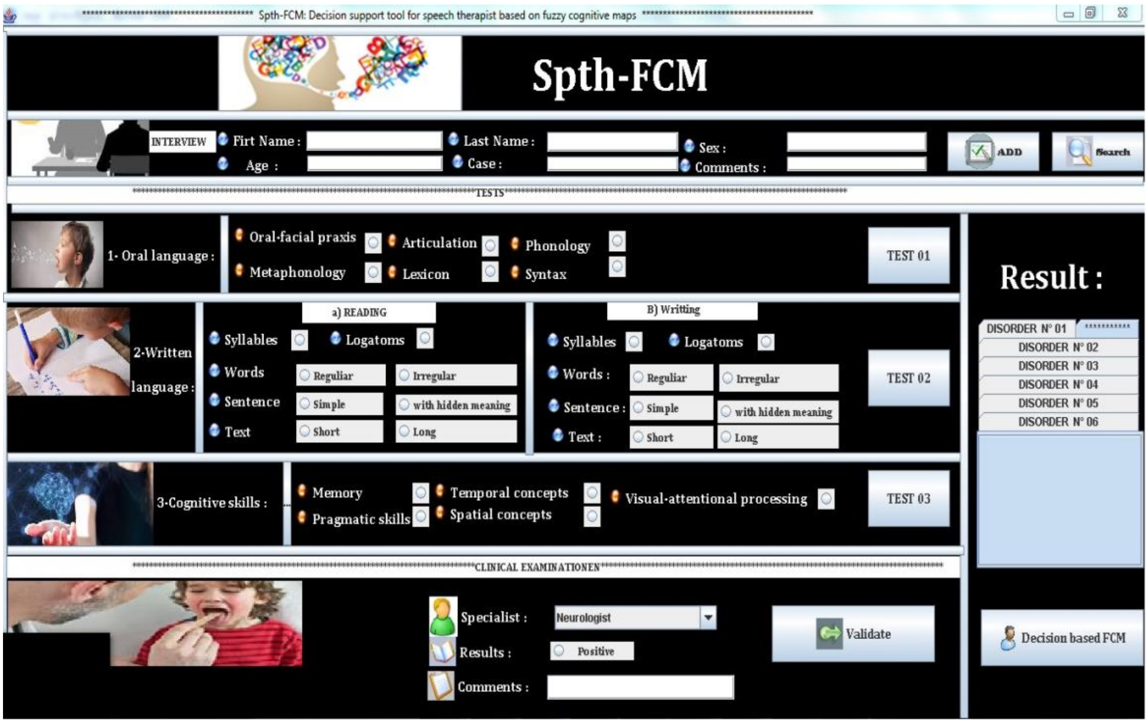


Figure 3. User interface of the proposed Spth-FCM

While conducting the speech therapy assessment, a CSV file (see Figure 4) is automatically created in parallel. This file includes an adjacency matrix linked to the FCM of the patient's state that needs to be treated. The purpose of this file is to connect our computer tool with the FCM Expert tool.

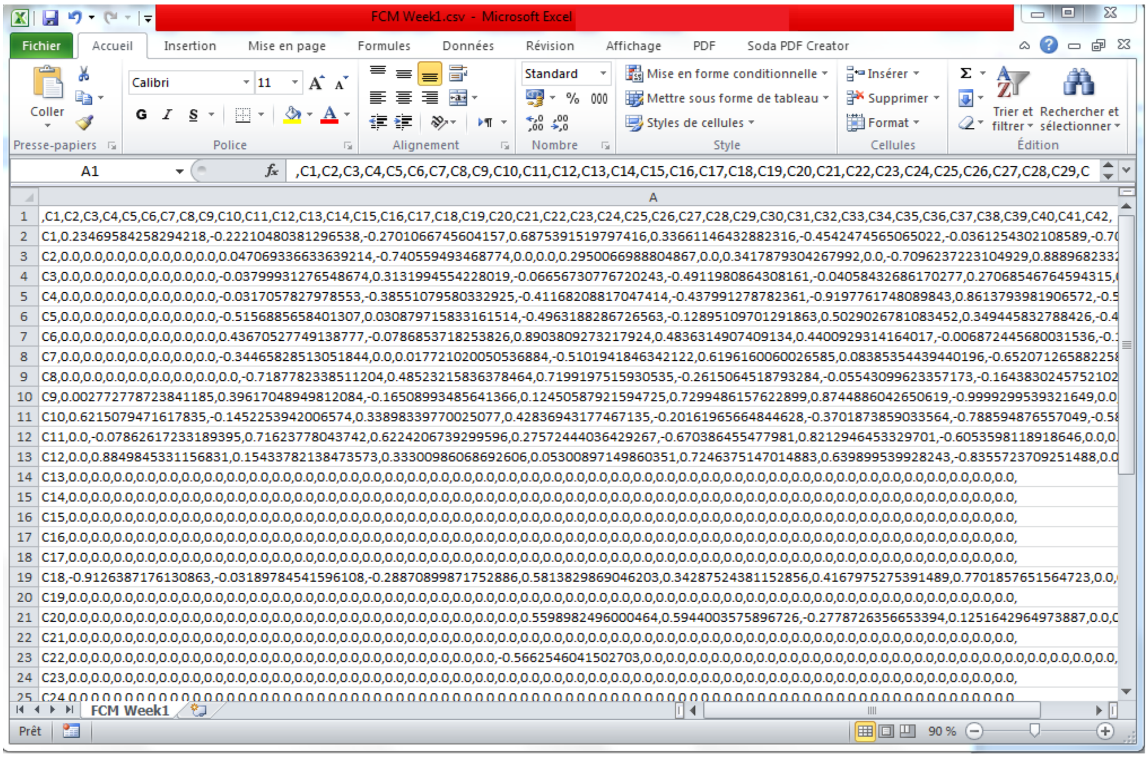


Figure 4. CSV file associated to the deducted FCM

3.2. Construction of the associated FCM

In this section, we will present in detail the construction process of the FCM associated with the patient's state to be treated. Firstly, a global FCM is used to describe the main causes that exist in the literature. Subsequently, according to this global FCM and according to the patient's state, the speech therapist will indirectly activate the concepts through our graphic interface.

3.2.1. Choice of the information source

Regarding the information source in our work, it is based on the perspectives of domain experts, who in our case are speech therapists. Additionally, we utilized information from certain papers in the field of speech therapy [4], [5], [8]-[10], [25], [26]. Therefore, expert panel and medical references were utilized to construct the initial FCM in our tool.

3.2.2. Acquisition of the FCM

For this particular step, we enlisted the help of some SLPs to generate a comprehensive list of all the relevant concepts related to the speech therapy domain that we will be analyzing. By involving domain experts, we can narrow down the list of concepts by evaluating their importance, selecting arcs, and determining their weights (causal relationships). According to the chosen speech therapists and the papers used, the list of concepts is shown in Table 2. So, according to the SLPs, we have almost 42 concepts. The FCM proposed by the domain experts is the basis for the decisions made by our tool.

Table 2. Concepts list

Notation	Concept	Notation	Concept
C1	Language disorder	C22	Polyp
C2	Aphasia	C23	Atrophy
C3	Dysphasia	C24	Paralysis
C4	Dysarthria	C25	Psychological reason
C5	Stuttering	C26	Psychological trauma
C6	Buccofacial apraxia	C27	Panic and fear
C7	Dyslexia	C28	Development disorder
C8	Spasmodic dysphonia	C29	Autism
C9	Functional reason	C30	Hyperactivity
C10	Reduced lexical abilities	C31	Intellectual disability
C11	Problems in syntax	C32	Tourette's syndrome
C12	Problems in grammatical morphology	C33	Pregnancy problems
C13	Impaired or limited phonological development	C34	Synopsis
C14	Impaired use of pragmatics	C35	Radiation exposure
C15	Reading difficulties	C36	Rhesus factor
C16	Problems in writing and spelling	C37	Health problem
C17	Reduced ability of verbal language comprehension	C38	Head trauma
C18	Impaired sociability	C39	Traumatic brain injury
C19	Organic reason	C40	Epilepsy
C20	Speech organ disorder	C41	Multiple sclerosis
C21	Pronunciation limb injury	C42	Heredity

3.2.3. Matrix transformation

The graphical form of the FCM makes it easy to design and understand. However, to utilize it, it needs to be transformed into a matrix form. All inference mechanisms are based on the matrix representation. In our work, it automatically generates a CSV file that contains the adjacency matrix linked to the FCM. This file acts as a bridge between the developed graphical interface and the FCM Expert tool used.

3.2.4. Execution of the inference process

An FCM uses algebraic operations to evaluate the effects of a given system state. These effects are then represented as another state of the system. Essentially, an FCM is a dynamic system that generates new descriptive states of the system at every time step, starting from an initial state. The inference process carried out by these operations provides answers to questions of the form "What if ...?" for the system.

The inference process [16] in cognitive maps facilitates decision-making, forecasts future conditions, and explains previous behavior. The algorithm 1 below describes this process:

Algorithm 1. Inference process
```
Suppose we haveacognitivemapofnconcepts
1. ExtracttheadjacencymatrixMij.
2. Prepareexcitervectora1.
/*Initializetheexcitervectortozero (0).*/
```

```
    Fori=1tondo
    a1[i] □ 0;
    endFor
    /*Each valueirepresentsthestateofconcepti.*/
    -Setto1thedesiredconcepts.
    -Adda1toWorkingMemoryWM.i□1;
    3. Whilei<= n do
    ai+1=ai ×Mij;
    Ifai+1∈WMthenai+1istypicalbehavior.
    elseFori= 1to ndo
    Ifai+1[i]≥0.5thenai+1[i]□1,elseai+1[i]□0;
    endIf
    endFor
    addai+1inWM
    endIf
    i □i +1 ;
endWhile
```

FCMs enable feedback in their connections, allowing us to examine the dynamics of the system by describing the impact of specific changes across the entire causal network. Consequently, during the inference phase, the FCM employs the standard McCulloch-Pitts model [27], [28] to compute the activation value of all concepts at each discrete time step.

In (1) in section 2.1 formalizes Kosko's activation rule. At each step t, a new activation vector is calculated, and after a fixed number of iterations, the FCM will be in one of three states: equilibrium point, restricted cycle, or chaotic behavior [20]. The FCM is considered to have converged if it achieves a fixed-point attractor; if not, the updating process ends when it reaches a maximum of T iterations.

The outcome of executing the inference process in the obtained FCM is a collection of typical behaviors. These behaviors represent possible scenarios for the language disorder that can be treated by a logical interpretation of our tool. The inference process is similar to the one proposed in many works [29]-[33], except for the threshold function S(x). In our work, we can select one of the functions mentioned in section 2.

3.2.5. Construction of the knowledge base

Our tool's global knowledge base can be improved by inferring all possible scenarios. This means that we can see what will happen if any possible combination of concepts is activated. In our work, we activate the concepts that represent the reasons for the disorder. Once these concepts are activated, our system infers the possible scenarios. In other words, it displays the scenario inferred according to the inputs of the tool that correspond to the patient's state.

After constructing the FCM, it is important to validate and synthesize it. These two steps are critical to our tool. The validation process ensures that the information derived from the cognitive map is not ambiguous. Sometimes, when calculating the propagated influence of one concept on another, the influences propagated on different paths linking the two concepts may not have the same value. When these values are aggregated, it results in an undetermined aggregation that produces an ambiguous value, particularly when some values represent opposite concepts. Validation enables us to identify ambiguities and address them during the construction of the map. In our work, the SLP can correct their map to avoid ambiguity. Our tool validates the constructed FCM by highlighting any ambiguities.

Once the validation is complete, the FCM can be synthesized. This process is carried out when the patient has multiple treatment sessions. Our approach involves a mechanism based on a taxonomy of concepts that enables the expression of causal links between the different concepts used by the SLP. This taxonomy is provided to the SLP before constructing the map, so they can use it as a vocabulary. However, the SLP can always enrich it by adding new concepts and causal links, provided they agree on the modification. The construction is done step-by-step, with each step designed to meet the needs of the SLPs.

In our proposed approach, a new FCM is generated in each treatment session. This FCM describes the current state of the patient. At this step, our tool synthesizes the previous FCMs with the new FCM. The synthesis of all the FCMs aims to produce an FCM that synthesizes the different new information and presents the current state of the patient in a simple way, privileging certain information over others.

To build and manipulate FCMs, we used FCM expert [28]. It is a software tool for designing, learning, and simulating FCMs devoted to complex systems and pattern classification. To compute the weight matrix defining the FCM model, optimize the network topology without sacrificing pertinent information, and enhance network convergence, FCM Expert incorporates both supervised and unsupervised learning techniques. An FCM linked to the initial patient condition is depicted in Figure 5 based on the results of the tests that were run.

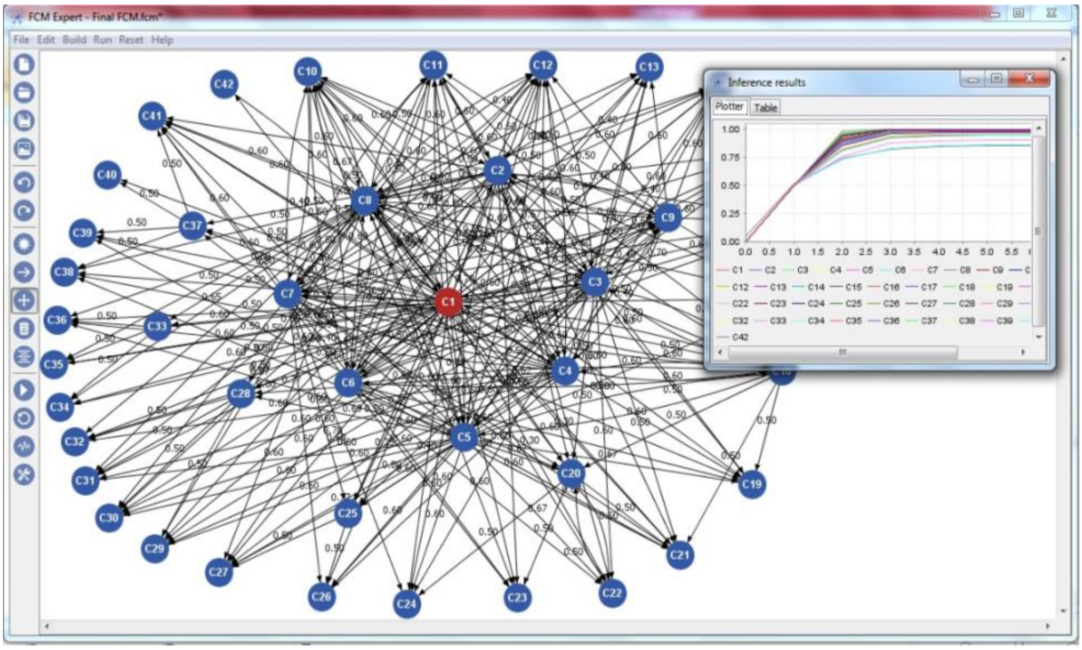


Figure 5. FCM example under FCMexpert tool

3.3. Medical decision

This is the last step in our approach, in which the speech therapist will decide according to the constructed FCM and according to the tests that have been performed:

- Patientstate,
- An appropriate diagnosis for the patient being treated,
- A rehabilitation project, if necessary,
- Sessions number to be performed during the treatment process.

Our diagnosis tool generates a written report in its final phase, which includes the medical decision. This decision is based on the tests conducted, the FCM results, and the opinion of the speech therapist to confirm the obtained outcomes.

4. RESULTS AND DISCUSSION

Computer DSS are applications designed to assist clinicians in making diagnostic and therapeutic decisions for patient care. Speech-language problems can now be diagnosed and treated using intelligent technologies, such as systems known by acronyms like computer speech training (CBST), computer-assisted methods for speech therapy (CAMST), computer-aided/assisted speech therapy (CAST), or computer-aided speech and language therapy (CASLT). Most of these systems consist of tests and exercises to address disorders. However, a comprehensive decision support system to monitor, assist, and guide speech therapists for improved diagnosis is currently lacking. This is the primary goal of our work.

The role of technology in speech therapy is becoming increasingly important as it improves the quality of treatment, the efficiency with which time is spent in the speech therapy office, and the speed with which the client may access remedial exercises. The success of computer-assisted speech therapy software is notable in tasks such as phonemic insertion, phonemic practice, phonemic correction, and phonemic automation, and less so in language problem diagnosis [8], [34]. In our work, we based on these works and the FCMs to develop the proposed tool.

FCMs have been effectively used for modeling and decision making in a number of scientific domains, including electrical circuits [35], political developments [36], organizational behavior and job satisfaction [37], virtual sea world featuring dolphins, sharks and fish [19], economic demographics of world countries [38], and medicine [39].

The majority of the tools in the field of speech therapy come in the form of databases that hold standard patient data, including visits, observations, and test results. However, our proposal goes beyond this and offers a decision support tool that utilizes FCMs for qualitative reasoning. This unique property enables the tool to guide speech therapists in determining the type and severity of language disorders in their patients, as well as monitor their progress during treatment.

4.1. Experiments and results

In this work, we relied on a panel of experts and some medical references [4], [5], [8]-[10], [25], [26] to create the initial FCM. This card will describe all the disorders that exist in the field of speech therapy. According to Table 2, we have 42 key concepts representing the different causes of various disorders. Therefore, we have 2^{42} possible scenarios, amounting to more than four billion possible scenarios. The large number of possible scenarios makes our system richer in terms of possible solutions to help and guide the speech therapist.

To demonstrate the importance of our proposed approach and apply the developed tool, we chose to illustrate, analyze, and explain various scenarios of a patient's treatment. Patient-specific data were recorded over eight weeks. With the help of the developed tool (Spth-FCM), the initial outcome based on the patient's condition indicates dyslexia, confirmed by the speech therapist.

In parallel, under the FCM expert tool, the concepts (C9, C10, C11, C12, C13, C14, C15, C17, C19, C20, C21, C25, and C27) are activated (Figure 6), corresponding respectively to functional reason, reduced lexical abilities, problems in syntax, problems in grammatical morphology, impaired or limited phonological development, impaired use of pragmatics, reading difficulties, reduced ability of verbal language comprehension, organic reason, speech organ disorder, pronunciation limb injury, psychological reason, panic, and fear.

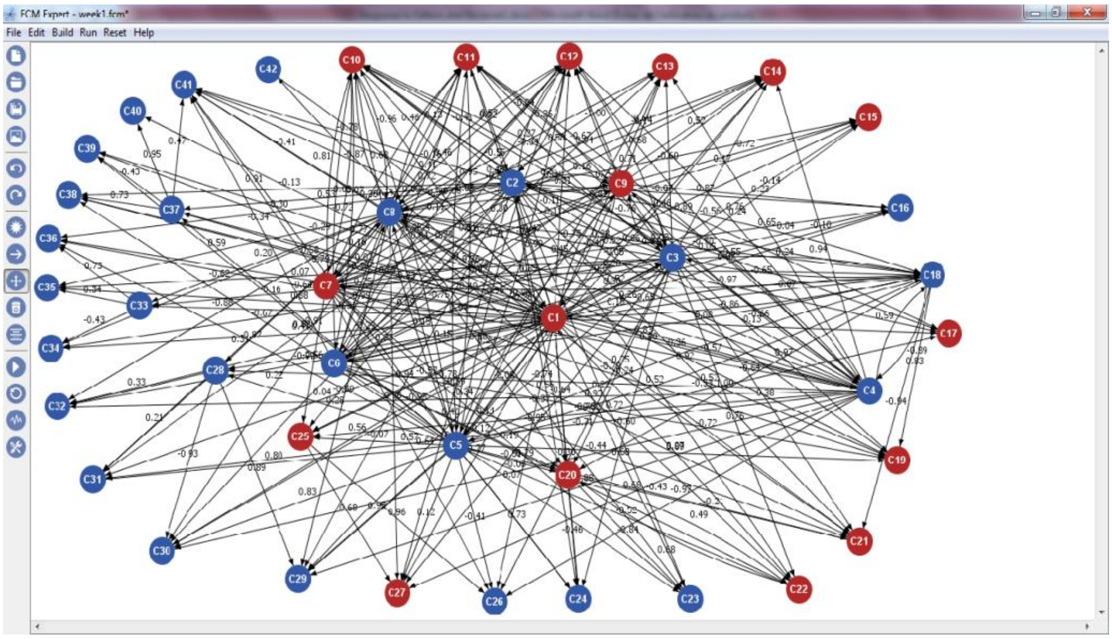


Figure 6. Associated FCM to the patient

Based on the information provided by the speech therapist, which includes the patient's condition, certain tests, and the opinion of a neurologist, our tool has interpreted the results as follows: "The patient is suffering from a disorder that has some identifiable reasons or activated concepts. These reasons include functional, organic, and psychological factors".

When creating the FCM linked to the patient's condition, the inference process is carried out automatically. For each treatment session, a new inference process is initiated to describe the patient's current state. Figure 7 illustrates the results of this process over the first three weeks, divided into four parts: Figure 7(a) displays the results before diagnosis, Figure 7(b) those of the first week, Figure 7(c) those of the second week, and Figure 7(d) those of the third week.

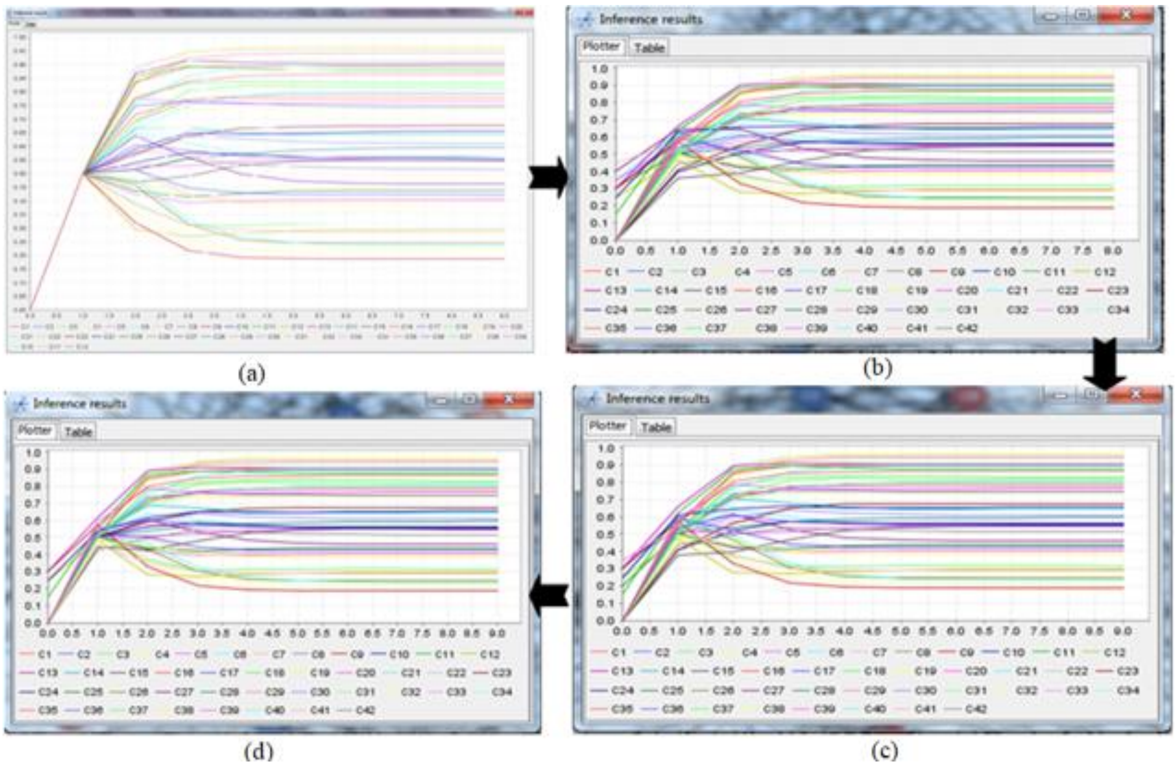


Figure 7. Inference process during the first three weeks: (a) inference process before diagnostic, (b) inference process in the first week, (c) inference process in the second week, and (d) and inference process in the third week

After the inference process, the resulting activated concept is concept C7, which refers to the disorder known as dyslexia. Therefore, based on the obtained results and a logical interpretation of our tool, it can be concluded that the patient has dyslexia. The results (Figure 7) show that the activation of key concepts representing the causes of the disorder decreased over time, suggesting an improvement in the patient’s condition. This was confirmed by the speech therapist, as well as other doctors.

During the eight-week follow-up period, we had weekly appointments to check the patient’s condition. From the second session onwards, we used our tool to validate the FCM data we had collected, ensuring that it was clear and accurate. The data obtained were synthesized to create a single FCM that accurately described the patient’s condition during the mentioned period.

To provide clarity on the patient’s condition, Figure 8 displays the activation levels of selected concepts over a two-month period. The speech therapist has observed significant improvements during the treatment period, supported by the results. Our tool uses FCMs to create treatment recommendations for patients in the speech therapy field. These recommendations are generated by running the inference process on the FCM linked to the diagnosed disorder.

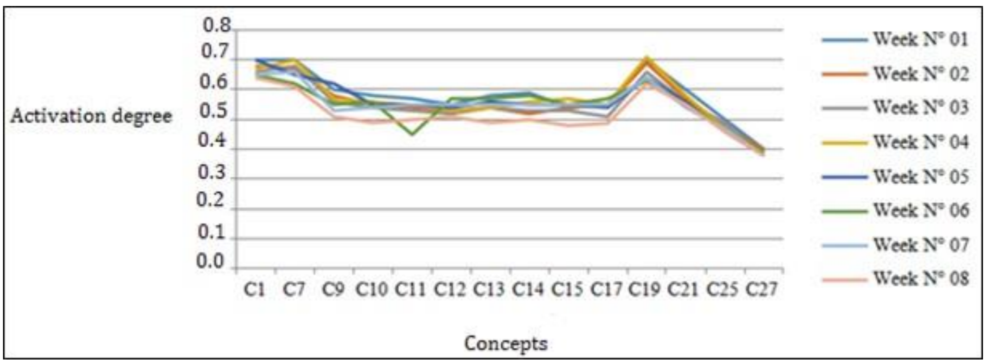


Figure 8. The activation degree of the concepts chosen during two months

4.2. Comparison

The following Table 3 presents a comparison of the developed tool with other decision-support tools in the field of speech therapy and similar systems in other areas. According to Table 3, the first tool (LingWare/STACH) is a multimedia program created in 1985. This program was created to be used in conjunction with regular speech therapy, not as a stand-alone treatment. The second tool was a unified interface for signal collecting, data analysis, treatment design, and speech therapy monitoring. The third tool is a program for the Analysis and evaluation of all kinds of speech disorders [7]. Another system, known as Telelogos, consists of a collection of tests available only to special education specialists and aimed to detect a wide spectrum of linguistic problems as well as learning difficulties [5], [40]. The WEANE is an online multimedia language assistant to support speech therapy in the logopaedic cabinet as well as at home throughout the therapy period. In 2014, “Pre-Lingua”, “Vocaliza”, and “Cuéntame”, are three speech therapy tools aimed at assisting people to improve their communication capacities in terms of phonology, articulation, descriptive and comprehensive language, respectively [43]. In 2020, CHOCSLAT was developed. It is a set of Chinese healthcare-oriented computerized speech and language assessment tools [44]. In 2022, authors have presented a method for using feature engineering and machine learning to assist in the screening of children with speech disorders [45].

The various computer programs cited above in speech therapy generally focus on providing exercises to patients, while the speech therapist assesses the accuracy of their pronunciation. These programs provide a variety of activities and engaging graphic interfaces to capture the subject’s attention. However, they have a significant drawback in that they cannot detect the kind and degree of language disorder, nor can they monitor therapeutic progress and make automatic adjustments to practice sessions based on a subject’s phonological feedback. As a result, the success of the treatment is mostly dependent on the therapist’s direct skill, which includes factors like the therapist’s agenda, professional experience, and intervention time for each patient, therapy group size, and session frequency. To address this deficiency, the proposed work uses the FCM. At each step of the SLP diagnostic process, an FCM associated with the patient to be treated will be automatically generated in parallel, describing his or her condition.

Creating a decision-support tool for speech therapists using FCM has many advantages. It can improve decision-making, customize treatment plans, and enhance the overall quality of care in speech therapy. This tool uses advanced modeling techniques to address the complex nature of speech disorders and therapy outcomes, with the ultimate goal of optimizing patient care and therapeutic results.

The limitations of the proposed approach are directly linked to the limitations of FCMs. For instance, FCMs heavily depend on expert knowledge to build network structures and assign weights to connections. This can restrict their applicability when specialized knowledge is scarce or impossible. In our study, it was very challenging to access information about real patients’ disorders, as the doctors considered it highly confidential.

Table 3. Comparison with other decision-support tools

Authors	Year	Tool name or decision support system	Tool type	Patients age	Methods and models used
Griessl and Stachowiak [6]	1985	LingWare/STACH	Multimedia program	Not specific	Graphics, written, and spoken text
TurkandArslan [10]	2005	CATSEAR	Unified interface	Patients with speech/language disorders and voice quality problems	Automatic assessment techniques using pattern recognition algorithms
Mayer *et al.* [7]	2009	PEAKS	Program	All Kinds of speech disorders	Web technologies
Glykas and Chytas [5], [40]	2005	Telelogos	Collection of tests	Not specific	Use of editors such as configuration and vocabulary
Ma *et al.* [41], [42]	2008-2009	W2ANE	Online multimedia language assistant	Individuals with aphasia	Multimedia Language
Drigas and Petrova [43]	2014	“Preingua”, “Vocaliza”, and “Cuéntame”	Three speech therapy tools	Not specific	Tests
Towey *et al.* [44]	2020	CHOCSLAT	Set of tools	Children	Not specific
Suthar *et al.* [45]	2022	No name	Not specific	Children	Utilization of Landmark (LM) analysis for automatic speech disorder detection
Maziz and Taouche	2024	Stph-FCM	Graphic interface	All ages	Qualitative reasoning of FCMs

Our approach shows that the developed tool is crucial for supporting the decision-making process of speech therapists. In the future, using a database that reflects real patient conditions could enhance the benefits of our tool by integrating existing learning algorithms in FCMs. Considering the program's widespread acceptance by patients and therapists, as well as the consistency of medical decisions with specialists' opinions in the field over eight weeks, the results show promise.

5. CONCLUSION

The article introduces Spth-FCM, a novel decision-support tool for speech therapists based on FCMs, which combine fuzzy logic and cognitive mapping to model complex speech therapy cases. The tool assists professionals in diagnosing disorders, suggesting treatment strategies, and negotiating between clinical observations and computational results. It operates through three simultaneous steps: conducting a speech therapy assessment, constructing an FCM to represent the patient's condition, and generating a medical decision based on FCM dynamics. Developed in JAVA, Spth-FCM enables visualization and storage of patient data, improving diagnostic accuracy and treatment planning. Initial tests on real cases demonstrated 99% alignment with expert opinions, validating its reliability and usability.

Spth-FCM enhances clinical decision-making by leveraging fuzzy logic to handle uncertainty in speech disorders, offering personalized treatment recommendations. Its user-friendly interface facilitates adoption, while its ability to graphically represent patient conditions improves interpretability. Additionally, the tool serves as an educational resource, integrating current research and best practices to guide therapy adjustments. By combining FCMs with fuzzy inference, Spth-FCM provides a sophisticated approach to managing diagnostic and therapeutic challenges, ultimately supporting more informed clinical decisions.

Future improvements aim to expand Spth-FCM's capabilities by incorporating FCM learning algorithms for better prediction accuracy, as well as intelligent interfaces, agents, and distance-learning technologies. The authors also propose transforming the tool into a web application to enhance accessibility, enabling remote testing and feedback collection from speech therapists. These advancements would further solidify Spth-FCM's role as an innovative and practical solution in speech therapy practice.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

The datasets used and analyzed during the current study are available from the corresponding author.

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