



A YinYang bipolar fuzzy cognitive TOPSIS method to bipolar disorder diagnosis



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ABSTRACT

Background and Objective: Bipolar disorder is often mis-diagnosed as unipolar depression in the clinical diagnosis. The main reason is that, different from other diseases, bipolarity is the norm rather than exception in bipolar disorder diagnosis. YinYang bipolar fuzzy set captures bipolarity and has been successfully used to construct a unified inference mathematical modeling method to bipolar disorder clinical diagnosis. Nevertheless, symptoms and their interrelationships are not considered in the existing method, circumventing its ability to describe complexity of bipolar disorder. Thus, in this paper, a YinYang bipolar fuzzy multi-criteria group decision making method to bipolar disorder clinical diagnosis is developed.

Methods: Comparing with the existing method, the new one is more comprehensive. The merits of the new method are listed as follows: First of all, multi-criteria group decision making method is introduced into bipolar disorder diagnosis for considering different symptoms and multiple doctors' opinions. Secondly, the discreet diagnosis principle is adopted by the revised TOPSIS method. Last but not the least, YinYang bipolar fuzzy cognitive map is provided for the understanding of interrelations among symptoms.

Results: The illustrated case demonstrates the feasibility, validity, and necessity of the theoretical results obtained. Moreover, the comparison analysis demonstrates that the diagnosis result is more accurate, when interrelations about symptoms are considered in the proposed method.

Conclusions: In a conclusion, the main contribution of this paper is to provide a comprehensive mathematical approach to improve the accuracy of bipolar disorder clinical diagnosis, in which both bipolarity and complexity are considered.

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1. Introduction

In WHO's World Mental Health surveys, bipolar disorder has been ranked as the illness with the second greatest cause of inability to work [3]. Since there are currently no valid biomarkers for bipolar disorder, the role of clinical assessment of bipolar disorder remains key. Unfortunately, statistics shows that only 20% of patients with bipolar disorder having a depressive episode are diagnosed with bipolar disorder within the first year of seeking treatment, since they look similar to the ones with unipolar depression [10]. In fact, bipolar disorder formerly known as manic-depressive illness, is a psychiatric condition in which patients experience drastic mood shifts. Only when mania and depression both reach some extent, i.e. *bipolarity* occurs, the patient can be

diagnosed as suffering bipolar disorder. Although *bipolarity* may be exist in other disease diagnosis, in bipolar disorder diagnosis, it is the norm rather than exception. In [31], Zhang et al. pointed out that bipolar disorder can be characterized as loss of harmony of the two sides of an equilibrium.

Considering the unique characteristic of *bipolarity* and the inevitable fuzziness characteristic, the primary mission of bipolar disorder diagnosis is to find a suitable fuzzy mathematical tool to model equilibrium *bipolarity*. Although there are some fuzzy models have been successfully applied to medical diagnosis, among which only the YinYang bipolar fuzzy set has been proven to be suitable to model bipolar disorder diagnosis [31]. In the same paper, the mathematical characterizations of the intrinsic of bipolar disorder diagnosis were presented and a unified inference method was proposed for diverse types of bipolar disorder. Furthermore, focusing on the balance of two poles of mental equilibrium, bipolar database integration and bipolar data virtualization are discussed

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in [32]. The method proposed by Zhang is undoubtedly an improvement, since *bipolarity* between mania and depression is considered. On the other hand, different experts' opinions and different symptoms with their interrelations are neglected in Zhang's method, resulting inaccuracy in the real world clinical diagnosis. Thus, we develop Zhang's method to propose a novel YinYang bipolar fuzzy multi-criteria decision making method to bipolar disorder diagnosis. By analyzing characteristics of bipolar disorder diagnosis, a hybrid multi-criteria group decision making method to bipolar disorder diagnosis is proposed. The new method is based on fuzzy cognitive map (FCM) and revised TOPSIS under the YinYang bipolar fuzzy environment. Comparing with Zhang's method, the new one is more comprehensive. The merits of the new method are listed as follows:

First of all, multi-criteria group decision making method is introduced into bipolar disorder diagnosis for considering different symptoms and multiple doctors' opinions.

Secondly, the discreet diagnosis principle is adopted by the revised TOPSIS method.

Last but not the least, YinYang bipolar fuzzy cognitive map (YBFCM) is provided for the understanding of interrelations among symptoms.

The main originalities of this paper are listed as follows:

(1) In theory, a series of aggregation operators and metrics about YinYang bipolar fuzzy information are presented. Furthermore, YBFCM is discussed by introducing bipolarity into FCM theory.

(2) In Methodology, a hybrid fuzzy decision making method to bipolar disorder diagnosis is proposed, in which multiple doctors' opinions, different symptoms and interrelations among symptoms all considered.

The rest of the paper is structured as follows. In Section 2, firstly, by analyzing the characteristics of bipolar disorder diagnosis, the motivation to introduce the new method is proposed. Secondly, some new concepts and theories about YinYang bipolar fuzzy information are presented. Aggregation operators, metrics and FCM about YinYang fuzzy bipolarity information are proposed. Lastly, a hybrid multi-criteria group decision making method to bipolar disorder diagnosis is proposed, based on FCM and revised TOPSIS under the YinYang bipolar fuzzy environment. In Section 3, the illustrated case is presented. In Section 4, comparison analysis and discussion are included to highlight the feasibility, validity, and necessity of the theoretical results obtained. Finally, the paper is concluded in Section 5.

2. Proposed method

In this section, firstly, by analyzing the characteristics of the bipolar disorder diagnosis, the motivation of the new method is presented. Secondly, related theory to the new method to bipolar disorder diagnosis, such as aggregation operator, metric and FCM under the YinYang bipolar fuzzy environment are proposed. Finally, based on the analysis and the new theory, a YinYang bipolar fuzzy cognitive TOPSIS method to bipolar disorder diagnosis is proposed.

2.1. Bipolar disorder diagnosis problem analysis

Mathematical modeling and diagnostic analysis of psychiatric disorders bear great significance in biomedical engineering and clinical psychopharmacology [25]. To find a suitable mathematical model, in this subsection, the characteristics of the bipolar disorder diagnosis are analyzed, and the corresponding mathematical models to handle it are addressed as follows:

1° As we mentioned in Introduction, *bipolarity* is the unique characteristic of bipolar disorder diagnosis. Meanwhile, uncertainty

or fuzziness is undoubtedly a characteristic of bipolar disorder diagnosis, just as other diseases. Thus, we need to find a suitable fuzzy model, which can capture not only fuzziness but also bipolarity in bipolar disorder diagnosis.

From the angle of bipolarity semantics, the interval-valued fuzzy set [29] is truth-based but not bipolar equilibrium-based, though it is more complicated than fuzzy set [28] in fuzziness. Atanassov's intuitionistic fuzzy set [4] perfectly reflects *indeterminacy* but not *bipolarity*. Montero et al. pointed that neutrosophic set [22] is equivalent to the YinYang bipolar fuzzy set in syntax [17]. While, in semantics, the YinYang bipolar fuzzy set suggests *equilibrium*, and neutrosophic set suggests a general *neutrality*. Although, neutrosophic set has been successfully applied to medical diagnosis [9,27], from above analysis and the conclusion in [31], we see that YinYang bipolar fuzzy set is obvious the suitable model to bipolar disorder diagnosis and will be adopted in this paper.

Denote $I^P = [0, 1]$ and $I^N = [-1, 0]$, and $L = \{\tilde{\alpha} = (\tilde{\alpha}^P, \tilde{\alpha}^N) \mid \tilde{\alpha}^P \in I^P, \tilde{\alpha}^N \in I^N\}$, then $\tilde{\alpha}$ is called YinYang bipolar fuzzy number.

(YinYang bipolar fuzzy set) [30] $X = \{x_1, \dots, x_n\}$ represents the finite discourse. YinYang bipolar fuzzy set in X is defined by the mapping $\tilde{A}: X \rightarrow L, x \mapsto (\tilde{A}^P(x), \tilde{A}^N(x)), \forall x \in X$. Where the functions $\tilde{A}^P: X \rightarrow I^P, x \mapsto \tilde{A}^P(x) \in I^P$ and $\tilde{A}^N: X \rightarrow I^N, x \mapsto \tilde{A}^N(x) \in I^N$ define the satisfaction degree of the element $x \in X$ to the property, and the implicit counter-property to the YinYang bipolar fuzzy set $\tilde{A}$ in X , respectively. All of the YinYang bipolar fuzzy sets in X is denoted by $\tilde{F}(X)$.

Remark 1. In fact, for any $\tilde{\alpha}, \tilde{\beta} \in L$, there are two order relations have been defined in L :

One is the "YinYang order relation" $\leq_Y$ defined in [30]: $\tilde{\alpha} \leq_Y \tilde{\beta}$ if and only if $\tilde{\alpha}^P \leq \tilde{\beta}^P, \tilde{\alpha}^N \geq \tilde{\beta}^N$. The "equilibrium" principle has played an essential role in the success of traditional Chinese medicine where symptoms are often diagnosed as the loss of balance and/or harmony of the two sides. That is the reason to introduce the YinYang order relation.

The other is the "preference" order relation $\leq_C$ defined in [13]: $\tilde{\alpha} \leq_C \tilde{\beta}$ if and only if $\tilde{\alpha}^P \leq \tilde{\beta}^P, \tilde{\alpha}^N \leq \tilde{\beta}^N$. There exists the "like-dislike" bipolar case which can be interpreted as "preferably positive pole" and meantime "non-preferably negative pole". It is obvious that the "like-dislike" bipolar case emphasizes "preference". That explains the meaning of "preference" order relation.

Bipolar disorder can be characterized as a biological and mood imbalance or loss of harmony of the two sides of an equilibrium. Thus, the "YinYang order relation" which emphasizes "equilibrium" of the two sides is adopted in this paper.

Remark 2. In the existing papers, YinYang bipolar fuzzy set also was called bipolar fuzzy set [5] and bipolar-valued fuzzy set [13,16].

On one hand, Atanassov's intuitionistic fuzzy set sometimes is also called bipolar fuzzy set [7], it follows that the name of bipolar fuzzy set may cause confusion.

On the other hand, as discussed in Remark 1, "YinYang order relation" should be adopted in this paper. Thus, we see that the name of YinYang bipolar fuzzy set is appropriate to bipolar disorder diagnosis and adopted in this paper.

Note that I^N is introduced in the YinYang bipolar fuzzy set theory. Although, a mathematical equivalence between $I^P \times I^N$ and $I^P \times I^P$ exists, from the semantics aspect, $I^P \times I^N$ is more suitable to human thinking than $I^P \times I^P$ to express bipolarity [11–13]. The reason is that a mathematical equivalence is one thing, and what a particular mathematical concept or property may model (its semantics) is the other thing, clearly the latter is what matters more for applications [7].

2° To make the accurate diagnosis, multiple symptoms should be considered. Meanwhile, considering complexity of bipolar dis-

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