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Fuzzy Modeling of Perceived Stress, And Cortisol Responses to Awakening Using Distance for Fuzzy Sets

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Abstract- In this paper, fuzzy modeling of distance between Intuitionistic fuzzy sets (four inputs–one output and two inputs–one output) were developed to test the hypothesis that high job demands and low job control (job strain) are associated with elevated free cortisol levels early in the working day and with reduced variability across the day and to evaluate the contribution of anger expression to this pattern. The models were derived from multiple data sources including One hundred five school teachers (41 men and 64 women) classified 12 months earlier as high (N = 48) or low (N = 57) in job strain according to the demand/control model sampled saliva at 2-hour intervals from 8:00 to 8:30 hours to 22:00 to 22:30 hours on a working day. Comparison of the models show that the four input model exhibited less entropy than the two input model using distance between Intuitionistic fuzzy sets.

Index Terms- Cortisol, Euclidean distance, Intuitionistic fuzzy set, Job strain, Hamming distance, Normalized Euclidean distance, Normalized Hamming distance, Work stress

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I. Introduction

Fuzzy set was proposed by Zadeh in 1965 as a frame work to encounter uncertainly, vagueness and partial truth, represents a degree of membership for each member of the universe of discourse to a subset of it. Intuitionistic fuzzy set was proposed by Attanassov, [1], [2] in 1986 which looks more accurate to uncertainty quantification and provided the opportunity to precisely model the problem based on the existing knowledge and observations. The Intuitionistic fuzzy set theory has been studied and applied in different areas.

Using the concept of an intuitionistic fuzzy set that makes it possible to express many new aspects of imperfect information. For instance, in many cases information obtained cannot be classified due to lack of knowledge, discriminating power of measuring tools, etc. In such a case the use of a degree of membership and non-membership can be an adequate knowledge representation solution. Work stress has emerged as a major psychosocial influence on physical and mental health over recent decades. Fuzzy model has proved valuable in understanding the work characteristics associated with coronary heart disease risk, hypertension, mental health, quality of life, and other outcomes. This model proposes that people working in highly demanding jobs who also have low control and limited opportunities to use skills will experience high job strain. The HPA axis is one of the principal pathways activated as part of the physiological stress response. It is puzzling, therefore, that clear links between cortisol and work stress has not been established. This study used serial sampling over the working day to determine whether salivary cortisol was predicted by measures of job strain taken 1 year earlier in men and women working in a single occupation.
The purpose of this study was to develop generalized rule based fuzzy models from multiple knowledge sources to test the hypothesis that high job demands and low job control (job strain) are associated with elevated free cortisol levels early in the working day and with reduced variability across the day and to evaluate the contribution of anger expression to this pattern and subsequently test its performance by comparing defuzzified outputs to actual values from test data and comparing predicted and actual fuzzy classifications.

A popular area-based defuzzification procedure is the centroid method. As the term implies, the point of the output membership function that splits the area in half is selected as the crisp value (Figure 1C). This method however does not work when the output membership function has non-convex properties. Depending on the shape of the membership function of the output, defuzzification routines may not produce effective values for the predicted output. However, the defuzzified value using the mean-max membership principle that does not convey the ambiguity. The centroid method has drawbacks when the output membership function is non-convex (Figure 1B). The defuzzified value is at a point that has low membership. In an effort to compensate for these drawbacks, an alternative approach to model validation is proposed that uses a distance measure to compare actual and predicted fuzzy classifications consisting of three point ordinal sets.

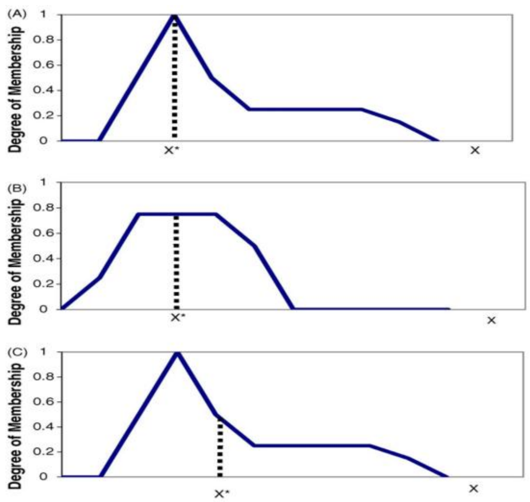

Figure 1. Different defuzzification methods: (A) max-membership principle; (B) mean-max membership principle; (C) centroid principle. Note: *x is the defuzzified value.**

II. DISTANCE MEASURES BETWEEN FUZZY SETS

For two fuzzy sets A and B in the same universe, the Hamming distance [3] is an ordinal measure of dissimilarity.
The Hamming distance (HD) is defined as:

$$\mathrm{HD(A,B)} = \sum_{i=1}^{n} \left| \mu_A(x_i) - \mu_B(x_i) \right|$$

where n is the number of points that define the fuzzy sets A and B, $\mu_A(x_i)$ the membership of point x_i in A and $\mu_B(x_i)$ is the membership of point x_i in B. The Hamming distance is smaller for fuzzy sets that are more alike than those that are less similar.

2.1 ENTROPY OF A FUZZY SET

Entropy is a measure of fuzziness associated with a fuzzy set. The degree of fuzziness can be described in terms of a lack of distinction between a fuzzy set and its complement. For a fuzzy set A, entropy [4] is calculated as:

$$\mathrm{E(A)} = 1 - \frac{1}{n} \sum_{i=1}^{n} \left| 2\mu_A(x_i) - 1 \right| \qquad \text{………………(1)}$$

where n is the number of points that define A, and $\mu_A(x_i)$ is the membership of point x_i in A. In this study, the concept of entropy was used to quantify the ambiguity associated with the predicted fuzzy outputs. In the absence of actual values, entropy values are essentially a measure of confidence in outputs predicted by a fuzzy model.

2.2 PROPOSED DISTANCE MEASURE

As indicated in the theory section, a modified form of the Hamming distance is proposed which enables better distinction between different levels of classification (see Table1 and 2).
The proposed distance measure D(A, P) is defined as:

$$\mathrm{D(A,B)} = \frac{1}{4}\left(\sum_{i=1}^{n} \left| \mu_A(x_i) - \mu_B(x_i) \right| + \sum_{i,k=1 (i \neq k)}^{n} (2(2|i-k|-1)\mu_A(x_i)\mu_P(x_k))\right) \qquad \text{……(2)}$$

where A is the actual fuzzy classification, P the predicted fuzzy classification, n the number of classes that define A and P, $\mu_A(x_i)$ is the membership of point x_i in A and $\mu_P(x_k)$ is the membership of point x_k in P.

2.3 COMPARING FUZZY CLASSIFICATIONS

The two output membership functions created in both models are categorized as low and high. The actual value from the test data was evaluated using the parameters of these membership functions to produce a fuzzy set represented by two points (high and low). This fuzzy set represents the degree of belongingness (μ) to each of the two categories (low and high). The predicted output from the Mamdani model is a fuzzy set represented by the given points. Based on the relative contributions from each output membership function, the predicted fuzzy set of given points was reduced to a fuzzy set of three points. The relative contributions from each output membership function were estimated by integrating the predicted fuzzy set over the range of the membership function. Equations (3) were used to develop the predicted fuzzy classification:

$$\mu_P(x) = \frac{\int f(x).\mu_i(x)dx}{\int \mu_i(x)dx} \qquad \text{…………(3)}$$

For each test case, an actual fuzzy classification and a predicted fuzzy classification were obtained. The modified Hamming distance measure (3) was used to determine the similarity between the two fuzzy sets. Apart from a comparison to actual values, the ambiguity associated with each predicted value was quantified using an entropy measure (1) as defined in the theory section.

2.4 DEFUZZIFYING THE PREDICTED OUTPUT

The centroid method was used to defuzzify the output of the Mamdani models. The crisp predictions were compared to the actual values from the test data and entropy value was calculated. This is a common form of comparison utilized for most modeling strategies. However, defuzzifying the output results in a loss of information regarding the ambiguity of the prediction. In the absence of actual values, the confidence in the prediction can be determined based on the degree of ambiguity.

2.5 INTUITIONISTIC FUZZY SETS

Intuitionistic fuzzy set was introduced first time by Atanassov, which is a generalization of an ordinary Zadeh fuzzy set. Let X be a fixed set. An intuitionistic fuzzy set A in X is an object having the form

$$A = \{(x, \mu_A(x), v_A(x)) \mid x \in X\}$$

where the functions $\mu_A(x), v_A(x) : X \to [0,1]$ are the degree of membership and the degree of non-membership of the element $x \in X$ to A, respectively; moreover, $0 \le \mu_A(x) + v_A(x) \le 1$ must hold.

Obviously, each fuzzy set may be represented by the following intuitionistic fuzzy set

$$A = \{(x, \mu_A(x), 1 - \mu_A(x) | x \in X\}$$

2.6 DISTANCE BETWEEN INTUITIONISTIC FUZZY SET

In Szmidt and Kacprzyk [5], [6], it is shown why in the calculation of distances between the intuitionistic fuzzy sets one should use all three terms describing them. Let A and B be two intuitionistic fuzzy set in $= \{x_1, x_2, \dots, x_n\}$. Then the distance between A and B while using the three term representation (Szmidt and Kacprzyk) may be as follows.

The Hamming distance:

$$d_{IFS}(A,B) = \frac{1}{2}\sum_{i=1}^{n}(|\mu_A(x_i)-\mu_B(x_i)| + |v_A(x_i)-v_B(x_i)|$$

The Euclidean distance:

$$e_{IFS}(A,B) = \sqrt{\frac{1}{2}\sum_{i=1}^{n}((\mu_A(x_i)-\mu_B(x_i))^2 + (v_A(x_i)-v_B(x_i))^2)}$$

The normalized Hamming distance:

$$l'_{IFS}(A,B) = \frac{1}{2n}\sum_{i=1}^{n}(|\mu_A(x_i) - \mu_B(x_i)| + |v_A(x_i) - v_B(x_i)|)$$

The normalized Euclidean distance:

$$q'_{IFS}(A,B) = \sqrt{\frac{1}{2n}\sum_{i=1}^{n}((\mu_A(x_i) - \mu_B(x_i))^2 + (v_A(x_i) - v_B(x_i))^2}$$

The Hamming distance is smaller for fuzzy sets that are more alike than those that are less similar. In our study, the model-testing phase involved comparison of low and high actual fuzzy classifications[7]. From the results in Table 1, the normalized Euclidean distance measure is better than the Hamming distance at distinguishing between different levels of classification. In cases e and f, the Hamming distance(HD) gave the same value for different the normalized hamming distance fuzzy classifications.

III. EXAMPLE

Data were collected at the 12-month follow-up phase of a study of job strain and cardiovascular risk, details of which have been published previously [13]. Participants in the original sample were 162 junior and high school teachers, selected on the basis of scores on a work stress measure (37) as having high (28 men and 52 women) or low (32 men and 50 women) job strain scores. Eighty-five (52.5%) were classroom teachers, and 77 (47.5%) had additional administrative roles. One hundred thirty-seven teachers took part in the 12-month phase (84.6%), which consisted of ambulatory blood pressure monitoring and a psychiatric interview (to be reported elsewhere) in addition to cortisol measurements. Of the 25 who did not participate at 12 months, 10 had left teaching or retired, 7 were seriously ill or pregnant, 1 experienced equipment failure, and 7 did not respond to our invitation. Comparisons between the 137 participants and 25 who dropped out of the study revealed no significant differences in gender, job strain scores, age, grade of employment, or scores on negative affect or anger expression. An additional 15 of the 137 individuals refused to sample saliva during the working day, mainly because they envisaged that data collection might be embarrassing or inconvenient at school. Statistical comparisons of these individuals with the remainder again identified no differences on demographic or psychological variables.

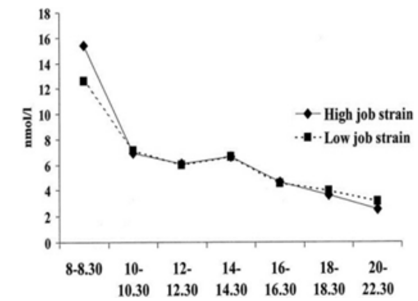

Figure 2. Mean concentration of saliva free cortisol in high and low job strain groups across the day and evening.

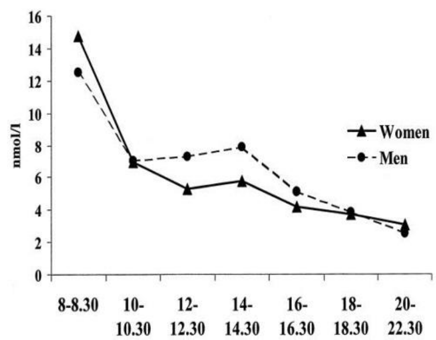

Figure 3. Mean concentration of saliva free cortisol in men and women across the day and evening.

Saliva sampling was conducted on a working day at schools. Participants were asked to take eight saliva samples at 2-hour intervals, and a 30-minute time window was allowed for each sample. Participants were asked to not consume any caffeine, citrus drinks, or food for at least 60 minutes before the saliva sample was taken. The schedule sampling sequence was therefore 8:00 to 8:30, 10:00 to 10:30, 12:00 to 12:30, 14:00 to 14:30, 16:00 to 16:30, 18:00 to 18:30, 20:00 to 20:30, and 22:00 to 22:30 hours. The first sample of the day was always obtained at schools after explanation of the procedure by the investigators. Saliva samples were collected in Salivettes, which were stored at −30°C until analysis. After defrosting, samples were spun at

3000 rpm for 5 minutes, and 100 µl of supernatant was used for duplicate analysis involving a time-resolved immunoassay with fluorescence detection.

Fuzzy function of the given figure 2 and 3 is defined as

$$f(x) = \begin{cases} -5x + 1.5, x \in [0,0.2] \\ 0.5, x \in [0.2,0.4] \\ -x + 0.9, x \in [0.4,0.7] \end{cases}$$

$$A_1(x) = \begin{cases} 5x, x \in [0,0.2] \\ 2 - 5x, x \in [0.2,0.4] \\ 0, otherwise \end{cases}$$

$$A_2(x) = \begin{cases} 5x - 1, x \in [0.2,0.4] \\ -3.33x + 0.33, x \in [0.4,0.7] \\ 0, otherwise \end{cases}$$

Corresponding Fuzzy diagram of given figure 3 and figure 5

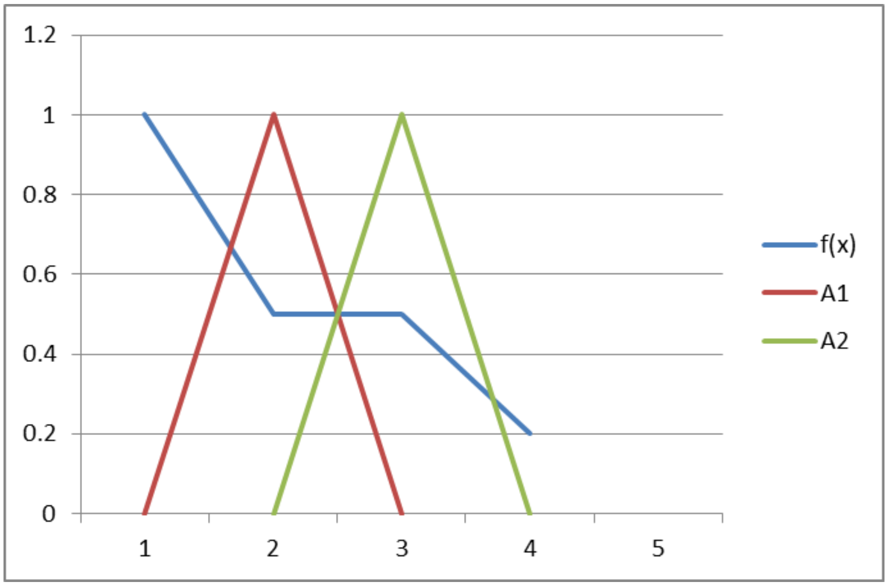

Figure 4. Fuzzy Mean concentration of saliva free cortisol in high and low job strain groups across the day and evening and Fuzzy Mean concentration of saliva free cortisol in men and women across the day and evening.

Case		Actual fuzzy classification		Predicted fuzzy classification		HD	Predicted Distance
	Time	High $\mu_A(x_i)$	Low $\mu_A(x_i)$	High $\mu_B(x_i)$	Low $\mu_B(x_i)$		
a	8 – 8.30	(1, 0)	(0.83, 0.17)	(0.9, 0.1)	(0.8, 0.2)	0.13	0.43
b	10 – 10.30	(0.45, 0.55)	(0.45, 0.55)	(0.8, 0.2)	(0.8, 0.2)	0.4	0.34
c	12 – 12.30	(0.39, 0.61)	(0.39, 0.61)	(0.5, 0.5)	(0.5, 0.5)	0.16	0.13
d	14 – 14.30	(0.44, 0.54)	(0.44, 0.54)	(0.4, 0.6)	(0.4, 0.6)	0.16	0.11
e	16 – 16.30	(0.31, 0.69)	(0.31, 0.69)	(0.5, 0.5)	(0.5, 0.5)	0.4	0.18
f	18 – 18.30	(0.24, 0.76)	(0.27, 0.73)	(0.4, 0.6)	(0.5, 0.5)	0.4	0.16
g	20 – 22.30	(0.17, 0.83)	(0.21, 0.79)	(0.4, 0.6)	(0.5, 0.5)	0.51	0.18
Entropy Value		(0.57, 0.43)	(0.64, 0.36)	(0.64, 0.36)	(0.8, 0.2)		
Various Distance Between Intuitionistic fuzzy set				Women	Men		
Hamming Distance				**0.54**	**0.55**		
Euclidean Distance				**0.39**	**0.49**		
Normalized Hamming Distance				**0.15**	**0.16**		
Normalized Euclidean Distance				**0.15**	**0.19**		

Table 1: Comparison of the various distances of Fuzzy Mean concentration of saliva free cortisol in high and low job strain groups across the day and evening

Case		Actual fuzzy classification		Predicted fuzzy classification		HD	Predicted Distance
	Time	Women $\mu_A(x_i)$	Men $\mu_A(x_i)$	Women $\mu_B(x_i)$	Men $\mu_B(x_i)$		
a	8 – 8.30	(1, 0)	(0.83, 0.17)	(0.9, 0.1)	(0.8, 0.2)	0.13	0.43
b	10 – 10.30	(0.6, 0.4)	(0.6, 0.4)	(0.8, 0.2)	(0.8, 0.2)	0.7	0.35
c	12 – 12.30	(0.34, 0.66)	(0.5, 0.5)	(0.5, 0.5)	(0.5, 0.5)	0.22	0.15
d	14 – 14.30	(0.37, 0.63)	(0.53, 0.47)	(0.4, 0.6)	(0.4, 0.6)	0.08	0.11
e	16 – 16.30	(0.27, 0.73)	(0.33, 0.67)	(0.5, 0.5)	(0.5, 0.5)	0.38	0.17
f	18 – 18.30	(0.25, 0.75)	(0.25, 0.75)	(0.4, 0.6)	(0.5, 0.5)	0.39	0.16
g	20 – 22.30	(0.2, 0.8)	(0.19, 0.81)	(0.4, 0.6)	(0.5, 0.5)	0.52	0.17
Entropy Value		(0.52, 0.48)	(0.66, 0.36)	(0.71, 0.29)	(0.8, 0.2)		
Various Distance Between Intuitionistic fuzzy set				Women	Men		
Hamming Distance				**0.59**	**0.62**		
Euclidean Distance				**0.51**	**0.56**		
Normalized Hamming Distance				**0.17**	**0.18**		
Normalized Euclidean Distance				**0.19**	**0.21**		

Table 2: Comparison of the Hamming various distances of Fuzzy Mean concentration of saliva free cortisol in men and women across the day and evening

IV. CONCLUSIONS

Job strain is associated with elevated free cortisol concentrations early in the working day but not with reduced cortisol variability. The interaction with outward anger expression suggests that individual characteristics modulate the impact of chronic work stress on the hypothalamic-pituitary-adrenocortical system. fuzzy modeling of distance between Intuitionistic fuzzy sets were developed to predict characteristics of the sample are summarized in table 1 and 2. The high and low job strain groups did not differ in gender distribution, age, occupational grade, or proportion of cigarette smokers. There were significant differences between groups in job strain and in its components job demands, job control, and skill utilization. The high job strain group reported greater demands, lower control, and less skill utilization than the low job strain group as inputs.

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