

Modelling Diagnostic Reasoning Based on Mental State Examination

Irosh Fernando and Frans A. Henskens

Abstract—Mental state examination is an important aspect of clinical assessment. Clinicians arrive at an overall subjective diagnostic judgment based on the findings of the mental state examination. It is largely an implicit process, which clinicians have learned through their experience, and is therefore, prone to inconsistencies. This paper presents a formal model for arriving at expert clinical judgment based on mental state examination findings, and monitoring the course of illness using parameters derived using the model. The proposed model has been implemented as a clinical tool, which is currently being evaluated in clinical practice. The model has the advantage of improving the reliability and validity of clinical assessment.

Index Terms—Diagnostic reasoning in psychiatry, modelling mental state examination in psychiatry, clinical reasoning in psychiatry, modelling diagnostic reasoning in psychiatry.

I. INTRODUCTION

Psychiatric disorders have been recognised as one of the most disabling group of illnesses [1]. However, because of the highly subjective nature of their symptoms, a reliable and valid assessment of psychiatric illnesses can be challenging, particularly for inexperienced clinicians. Complete diagnostic reasoning involves generating diagnostic hypotheses based on patients' historical data and their mental state features. The authors have previously introduced a theory for diagnostic reasoning based on patients' clinical histories, which include reported symptoms [2]. This paper complements the previous paper by providing a theory for diagnostic reasoning based on patients' mental state examinations. Mental state examination also plays a crucial role in monitoring the process of recovery from psychiatric illnesses, and in early recognition of relapse of psychiatric illnesses. Therefore a model that formalises the process of diagnostic reasoning based on mental state examination is important to improve the reliability and the validity of diagnostic reasoning, and to monitor the course of psychiatric illnesses.

There have been previous approaches to quantification of mental state examination findings [3], and there are different scales available for rating different subgroups of mental state features such as cognition [4], and psychotic features [5]. However, these scales cannot be considered as general

diagnostic tools that can be used to evaluate the likelihood of different diagnoses.

The next section of this paper describes the conceptual nature of mental state examination, and its challenges. Then, a formal model for mental state examination is developed, and is applied to mental state examination findings of four hypothetical patients having four different psychiatric diagnoses. Finally, implementation of the model as a clinical tool, which is currently being evaluated for its use in clinical practice, is presented.

General appearance
Behaviour
Activity level
Speech
Affect and mood
Thought form
Thought content
Perceptual disturbances
Level of insight
Cognitive functions

Fig. 1. Main general categories of mental state features.

II. MENTAL STATE EXAMINATION

Mental state examination is an important part of medical diagnostic reasoning, particularly in the branch of Psychiatry. It involves a cross sectional evaluation of a number of patient characteristics or features, which are observed by the clinician during clinical assessment [6]. A general list of categories of these features is given in Fig. 1. Certain features of mental state examination are more commonly observed in some diagnoses compared to others. For example, whilst a patient with depression may have slow speech, a patient with an anxiety disorder may have rapid speech. Also, whilst a patient with anxiety or depression may generally have demonstrated coherence in his/ her thought form, a patient with psychosis may have an illogical and incoherent thought form. Diagnostic reasoning based on mental state examination can be considered as a process of evaluating the set of features in mental state examination against a set of likely diagnoses, in which the state of each mental state feature has a different level of significance in relation to different diagnoses. Clinicians learn mental state examination through years of their clinical experience by observing patterns of mental state features that are observed in different patients. Unfortunately, there is no available

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formal theory that explains the diagnostic reasoning of psychiatric mental state examination. Clinicians use their previous clinical experience, and their clinical judgments, in an implicit process that arrives at diagnostic conclusions based on the features of mental state findings. This can potentially cause inconsistencies, and lack of agreement on the diagnostic conclusions arrived at by different clinicians.

III. FORMAL MODEL

Let us define a set of all possible diagnoses as $D = \{d_1, d_2, \dots, d_m\}$, and a set of all items (i.e. features) in mental state examination as $E = \{e_1, e_2, \dots, e_n\}$. Mental state examination involves assigning each item e_i a value according to the mental state of the patient. This will result in a vector $F(E) = (f_1(e_1), \dots, f_n(e_n))$. The function f_i assigns the corresponding entity e_i a value in the interval $[0..1]$. The function f_i can be approximated using the clinician's expert judgment.

Mental state examination needs to be interpreted in relation to the context of the diagnosis being considered. In other words, each entity $e_i \in E$ has a different level of importance in relation to each considered diagnosis $d_i \in D$. This can be represented as a vector of weights $W(d_i) = (w_{i1}, w_{i2}, \dots, w_{in})$ where $w_{ij} \in I$. We may define I as an interval $[0 \dots L]$, in which zero means there is no importance, and $L \in R$ is a real number representing the maximum possible level of importance.

Evaluation of mental state examination in relation to a diagnosis $d_i \in D$ can be approximated linearly as the multiplication of the vector $W(d_i)$ by the transpose of the vector $F(E)$ as follows:

$$W(d_i).F(E)^T = (w_{i1}, w_{i2}, \dots, w_{in}). \begin{pmatrix} f_1(e_1) \\ \vdots \\ f_n(e_n) \end{pmatrix} = \varphi_i \quad (1)$$

The maximum possible score a patient can get for a diagnosis d_i occurs when $Max(f_j(e_j)) = 1.0$ for all $j = 1, \dots, m$. Therefore,

$$Max(W(d_i).F(E)^T) = \sum_{j=1}^n w_{ij} \quad (2)$$

The overall clinical judgment can be described as a function $(F(E), W(d_i))$, which expresses the value calculated using equation (1) as a ratio to the maximum possible value calculated using the equation (2) as follows:

$$\begin{aligned} (F(E), W(d_i)) &= \frac{W(d_i).F(E)^T}{Max(W(d_i).F(E)^T)} \\ &= \varphi_i \left(\sum_{j=1}^n w_{ij} \right)^{-1} \end{aligned} \quad (3)$$

As this often involves evaluating more than one possible diagnosis, the corresponding vectors can be represented together as a matrix as follows,

$$W(D) = \begin{pmatrix} w_{11} & \dots & w_{1n} \\ \vdots & \ddots & \vdots \\ w_{m1} & \dots & w_{mn} \end{pmatrix}$$

Evaluation of mental state $F(E)$ against all the diagnoses included in $W(D)$ involves extending (1) as follows:

$$\begin{aligned} W(D).F(E)^T &= \begin{pmatrix} w_{11} & \dots & w_{1n} \\ \vdots & \ddots & \vdots \\ w_{m1} & \dots & w_{mn} \end{pmatrix} \cdot \begin{pmatrix} f_1(e_1) \\ \vdots \\ f_n(e_n) \end{pmatrix} \\ &= \begin{pmatrix} \varphi_1 \\ \vdots \\ \varphi_m \end{pmatrix} \end{aligned} \quad (4)$$

Then equation (3) can be extended as follows:

$$(F(E), W(D)) = \begin{pmatrix} \varphi_1 \left(\sum_{j=1}^n w_{1j} \right)^{-1} \\ \vdots \\ \varphi_m \left(\sum_{j=1}^n w_{mj} \right)^{-1} \end{pmatrix} \quad (5)$$

Each value $\varphi_i \left(\sum_{j=1}^n w_{ij} \right)^{-1}$ in (5) corresponds to diagnosis d_i , $i = 1 \dots m$, and the most likely diagnosis is d_i such that

$$\begin{aligned} Max \left(\varphi_1 \left(\sum_{j=1}^n w_{1j} \right)^{-1}, \dots, \varphi_m \left(\sum_{j=1}^n w_{mj} \right)^{-1} \right) \\ = \varphi_i \left(\sum_{j=1}^n w_{ij} \right)^{-1} \end{aligned} \quad (6)$$

Importantly, given that a patient has diagnosis d_i , its corresponding value $\varphi_i \left(\sum_{j=1}^n w_{ij} \right)^{-1}$ not only indicates the likelihood of the diagnosis, but also serves as a parameter that can be used to monitor the course of the illness. As the mental state examination of patients is carried out on a regular basis, a progressively increasing score of $\varphi_i \left(\sum_{j=1}^n w_{ij} \right)^{-1}$ indicates that the disease diagnosed as d_i is worsening. On the other hand, a progressively decreasing score indicates that patient is recovering from the disease. Therefore, $\varphi_i \left(\sum_{j=1}^n w_{ij} \right)^{-1}$ can be used as a useful indicator of response to treatment, and the level of recovery from the disease diagnosed as d_i . Due to the relapsing nature of most psychiatric illnesses, this parameter can also be used to recognise relapse of psychiatric illnesses at their early stages,

when they are often more easily treatable, through a process of regular mental state examination.

IV. AN EXAMPLE USING SAMPLE DATA

The model described above was simulated using four different psychiatric diagnostic categories in relation to four different hypothetical patients. The model parameter I (i.e. the range of values, $w_{ij} \in I$) was initialised arbitrarily as $I = [0 \dots 10]$. Thirty-four mental state features were selected for an initial evaluation based on their relative clinical importance, and a weight matrix was derived for the four different diagnostic categories using the clinician's subjective judgment. Mental state characteristics of these four patients were selected so that each patient represented a mental state finding predominantly indicative of only a one diagnostic category. The four diagnostic categories, and their weight matrix in relation to the thirty-four different mental state features, are shown in Fig. 2.

	Depression	Anxiety	Acute Psychosis	Mania
1 Poor self-care	9	3	6	3
2 Over familiarity	0	0	0	9
3 Slowing of motor activity	7	0	0	0
4 Distractibility	2	7	7	8
5 Agitation	5	8	5	8
6 Irritability	5	2	4	6
7 Lack of reactivity of affect	9	2	4	0
8 lability of affect	4	0	0	9
9 Level of anxiety	5	9	4	0
10 Level of depression	9	4	3	0
11 Lack of prosody in speech	9	2	0	0
12 Reduced volume in speech	9	0	0	0
13 Reduced flow of speech	9	0	0	0
14 Increased flow of speech	0	6	0	9
15 Tangential thought form	0	0	6	9
16 Lack of coherence in speech	0	1	8	8
17 Grandiosity	0	0	3	9
18 Guilt and self-blame	9	4	0	0
19 Low self-esteem and confidence	9	4	0	0
20 Increased self-esteem	0	0	0	9
21 Worrying thoughts	5	9	4	0
22 Pessimistic thoughts	9	4	0	0
23 Self-harm thoughts	8	0	0	0
24 Persecutory thoughts/delusions	4	0	9	0
25 Bizarre delusions	0	0	9	0
26 Non-bizarre mood congruent delusions	8	0	7	9
27 Auditory hallucinations (mood congruent)	9	0	7	9
28 Auditory hallucinations (mood incongrue)	0	0	9	0
29 Visual hallucinations	0	0	0	0
30 Lack of insight	1	0	8	9
31 Impaired concentration	5	9	7	8
32 Impaired registration	5	9	7	7
33 Impaired recall	6	9	7	7
34 Disorientation	0	0	0	0
Totals	160	92	124	136

Fig. 2. Diagnoses matrix

The data in Fig. 2 can be translated into the model as follows:

$$D = \{d_1, d_2, d_3, d_4\} \text{ where}$$

$d_1 = \text{Depression (Major Depressive Disorder)}$

$d_2 = \text{Anxiety (Generalised Anxiety disorder)}$

$d_3 = \text{Psychosis (Paranoid Schizophrenia)}$

$d_4 = \text{Mania (Manic Episode)}$

And,

$$W(d_1) = (9,0,7 \dots, 6,0)$$

$$W(d_2) = (3,0,0, \dots, 9,0)$$

$$W(d_3) = (6,0,0, \dots, 7,0),$$

$$W(d_4) = (3,9,0, \dots, 7,0)$$

Mental state examination findings of the four hypothetical patients are described in Fig. 3. These findings were made up in such a way that the patient-1 has features predominantly indicative of a depressive disorder, patient-2 has features predominantly indicative of anxiety disorder, patient-3 has

features predominantly indicative of acute psychosis, and patient-4 has features predominantly indicative of manic episode.

Mental State Features	Patient-1	Patient-2	Patient-3	Patient-4
Poor self-care	0.5	0	0.3	0
Over familiarity	0	0	0	0.4
Slowing of motor activity	0.6	0	0	0
Distractibility	0	0.7	0.5	0.6
Agitation	0	0.6	0.6	0.7
Irritability	0	0	0	0.5
Lack of reactivity of affect	0.6	0.2	0.3	0
lability of affect	0	0	0	0.5
Level of anxiety	0	0.8	0.4	0
Level of depression	0.7	0.3	0.3	0
Lack of prosody in speech	0.5	0	0	0
Reduced volume in speech	0.5	0	0	0
Reduced flow of speech	0.4	0	0	0
Increased flow of speech	0	0.5	0.3	0.7
Tangential thought form	0	0	0.5	0.8
Lack of coherence in speech	0	0.2	0.5	0.5
Grandiosity	0	0	0	0.7
Guilt and self-blame	0.6	0.2	0	0
Low self-esteem and confidence	0.5	0.2	0	0
Increased self-esteem	0	0	0	0.8
Worrying thoughts	0.1	0.6	0.5	0
Pessimistic thoughts	0.6	0.2	0	0
Self-harm thoughts	0.5	0.2	0	0
Persecutory thoughts/delusions	0	0	0.6	0.5
Bizarre delusions	0	0	0.4	0
Non-bizarre mood congruent delusions	0	0	0.4	0
Auditory hallucinations (mood congruent)	0	0	0	0
Auditory hallucinations (mood incongrue)	0	0	0.8	0
Visual hallucinations	0	0	0	0
Lack of insight	0	0	0.5	0
Impaired concentration	0.5	0.5	0.3	0.4
Impaired registration	0	0.4	0.3	0.2
Impaired recall	0.6	0.2	0.3	0.4
Disorientation	0	0	0	0

Fig. 3. Mental state findings of four patients

The data in Fig. 3 can be translated into the model as follows:

$$F(E_1)^T = \begin{pmatrix} 0.5 \\ 0 \\ 0.6 \\ \vdots \\ 0.6 \\ 0 \end{pmatrix}, F(E_2)^T = \begin{pmatrix} 0 \\ 0 \\ 0 \\ \vdots \\ 0.2 \\ 0 \end{pmatrix},$$

$$F(E_3)^T = \begin{pmatrix} 0.3 \\ 0 \\ 0 \\ \vdots \\ 0.3 \\ 0 \end{pmatrix}, F(E_4)^T = \begin{pmatrix} 0 \\ 0.4 \\ 0 \\ \vdots \\ 0.4 \\ 0 \end{pmatrix},$$

The resulting values, $W(d_i) \cdot F(E_j)^T, i = 1,2,3,4 j = 1, 2, 3, 4$ are shown in Fig. 4.

	Patient-1	Patient-2	Patient-3	Patient-4
Depression	58.9	28.6	27.5	16.6
Anxiety	24.1	39.4	29.5	24.5
Psychosis	15.6	24.5	50.3	32.1
Mania	9.7	24.7	35.6	59.9

Fig. 4. Mental state findings of four patients

The final results, $(F(E), W(D))$ as percentages are shown in Fig. 5. As indicated in (6) the diagnosis, which has the highest score is considered the most likely diagnosis. As expected, patient-1 scored highest for depression (36.815), patient-2 scored highest for anxiety (42.82609), patient-3 scored highest for psychosis (40.56452), and patient-4 scored highest for manic episode (44.0441) indicating their most likely diagnoses.

	Patient-1	Patient-2	Patient-3	Patient-4
Depression	36.8125	17.875	17.1875	10.375
Anxiety	26.19565	42.82609	32.06522	26.63043
Psychosis	12.58065	19.75806	40.56452	25.8871
Mania	7.132353	18.16176	26.17647	44.04412

Fig. 5. Mental state findings of four patients

V. MODEL IMPLEMENTATION

The model has been implemented as a web-based system, which is currently being evaluated in clinical practice. Once a patient's mental state is examined, the features are entered using the screen shown in Fig. 6 (which depicts the mental state features of patient-1 as shown in Fig. 3), and the overall score is derived using the weight matrix stored in the system. An output screen showing the result in relation to the four above-mentioned diagnoses is shown in Fig. 7.

Mental State Evaluator(MSE)
Enter Mental State Examination Findings

Mental State Feature	Score [0...1]
Poor self-care	0.5
Overfamiliarity	0.0
Slowing of motor activity	0.6
Distractibility	0.0
Agitation	0.0
Irritability	0.0
Lack of reactivity in affect	0.6
Lability of affect	0.0
Level of anxiety	0.0
Level of depression	0.7
Lack of prosody in speech	0.5
Reduced volume in speech	0.5
Reduced flow of speech	0.4
Increased flow of speech	0.0
Tangential thought form	0.0
Lack of coherence in speech	0.0
Grandiosity	0.0
Guilt and self-blame	0.6
Low self-esteem and confidence	0.5
Increased self-esteem	0.0
Worrying thoughts	0.1
Pessimistic thoughts	0.6
Self-harm thoughts	0.5
Persecutory thoughts/delusions	0.0
Bizarre delusions	0.0
Non-bizarre mood congruent delusions	0.0
Auditory hallucinations(mood incongruent)	0.0
Auditory hallucinations(mood congruent)	0.0
Visual hallucinations	0.0
Lack of insight	0.0
Impaired concentration	0.5
Impaired registration	0.0
Impaired recall	0.6
Disorientation	0.0

Fig. 6. Mental state findings of four hypothetical patients

Mental State Evaluator(MSE)
Mental State Evaluation Results

Diagnosis	Value	Percentage
Depression	59	37
Anxiety Disorder	24	26
Acute Psychosis	16	13
Manic Episode	9.7	7.1

Fig. 7. Mental state findings of four patients

VI. CONCLUSION

This paper introduced a model for diagnostic reasoning based on mental state examination features. The clinician's expert knowledge of how to interpret patients' mental state features in relation to different diagnoses is represented as a weight matrix. Using the presented model, a weight matrix was derived for four different diagnostic categories, with the individual weights representing approximations made using the clinician's subjective judgment. Using four different patient profiles, the way the proposed model arrives at the

expected diagnostic conclusions was demonstrated. The model not only differentiates diagnoses, but also provides a parameter that can be used to monitor the course of the patient's illness. The presented model is currently under evaluation, and will be further extended and refined as a result of that evaluation. It is expected that the proposed model will enhance the quality of clinical practice by formalising the process of clinical assessment, and monitoring of patients' response to treatment.

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