Original Research

Predictive Factors of Response to Mindfulness-Based Cognitive Therapy (Mbct) for Patients with Depressive Symptoms: The Machine Learning's Point of View

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Abstract

While there is abundant literature on the benefits of Mindfulness-Based Interventions (MBI), data about factors associated with their Efficiency are scarce. Our study attempts to determine the moderators of efficacy and adherence in Mindfulness-Based Cognitive Therapy (MBCT) with a machine learning analysis. Seventy-six psychiatric outpatients at "university hospital mental health service" had a prescription for MBCT from their referring psychiatrist.
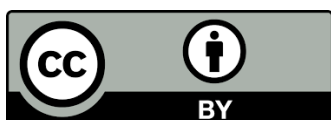
They suffer from various psychiatric illnesses with depressive symptoms. They completed a battery of clinical, mindfulness, and psychological functioning self-report questionnaires before and after the MBCT intervention of 8 sessions. Changes (after minus before) in scores were used for efficacy. Scores before MBCT were used to study the adherent profile (8 sessions of MBCT) versus non-adherent patients (stopping MBCT before the eight sessions). For efficacy and adherence profiles, machine learning analysis based on the support vector machine (SMV) method was applied to complement classical statistical analyses. Results: For efficacy factors, the SVM analysis finds a two-dimensional profile of patients. The patients for whom MBCT is most effective are patients with a high Beck score (>25) and high trait mindfulness (FFMQ >90). The percentage of misclassified validation examples is 24.6 (LOO = 75.4). The model's sensitivity is 79.3%, and the specificity is 71.9%. For adherence factors, a three-dimensional model is found. The patients who perform the 8 sessions of the MBCT have a profile with high or low trait mindfulness, high or low bodily dissociation, and low self-compassion. The percentage of misclassified validation examples is 37.3 (LOO = 62.7). The model's sensitivity is 48.4%, and the specificity is 71.9%. These results provide preliminary evidence that the predictive power of machine learning may allow the designing of standard patient profiles, which can contribute to 3 more personalized care for patients with symptoms of depression and anxiety. Also, including more psychoeducation in MBCT programs can maximize clinical benefits and adherence to this therapy. However, further studies are needed to explore this topic in more detail.

1. Introduction

Mindfulness meditation has attracted increasing interest in the Western world over the past 30 years with Jon Kabat-Zinn's work, to the point that it has become part of the third wave of Cognitive Behavioral Therapy (CBT). A consensual definition of mindfulness is "directing one's attention in a particular way, deliberately, in the present moment and without value judgment" [1]. It characterizes both a natural disposition existing to varying degrees in all individuals (trait mindfulness) [2, 3] and a practice aimed at developing these skills (presence, acceptance, non-judgment, non-reactivity) [4]. Trait mindfulness is associated with a lower vulnerability to stress [5-8] and more adaptive cognitive processes, including fewer ruminations and less avoidance when facing negative situations [9]. Such a functioning help to manage the patterns of thinking activated by stress and emotion that unavoidably occurs in daily life [10, 11]. It is, therefore, a protective factor against the risk of depression [12]. Mindfulness-based interventions (MBI) are validated for their beneficial effects on mental health [13]. Among them, Mindfulness-Based Cognitive Therapy (MBCT) [10] is a psychotherapy directly derived from Mindfulness-Based Stress Reduction (MBSR) with the addition of cognitive therapy elements. It was developed to prevent relapses in recurrent depressive syndrome, specifically for patients who have experienced three or more depressive

episodes in their lifetime [14]. It is effective in clinical distress [15, 16] and treatment of residual depression symptoms [17] in combination with pharmacological treatment.

MBCT's mechanisms [18] are effective (increased positive emotions, greater appreciation of these emotions, increased responsiveness to pleasant everyday activities) and cognitive. The cognitive mechanisms imply a reduction of ruminations [19] and an increase in trait mindfulness [20-22], particularly for patients with fewer than three depressive relapses [18].

Whether there is abundant literature on the benefits of MBI, data about individual moderators associated with efficiency are scarce. Therefore, there is a need to better determine the predictors of MBI efficiency to offer more personalized care to each patient and possibly act on modifiable factors. Efficiency involves factors predicting the effectiveness of the treatment itself and the retention in the prescribed treatment program They maintain in a program means not only patient attrition (number of patients leaving the study prior to completion) but also exercise compliance (ability to complete the prescribed number of exercise sessions) and exercise adherence (ability to complete the specific exercises as detailed in the exercise prescription). Indeed, MBCT mindfulness requires, like all cognitive-based therapy (CBTs), a significant commitment from patients. A recent meta-analysis [23] shows that the attrition rate in CBTs could rise to 26% during treatment. Attrition from MBI would average 16% [24], or up to 38% in patients experiencing a depressive episode during the intervention [25]. Attrition from pharmacological treatment of depression is similar to that observed in CBTs (27% at 12 weeks of treatment) [26].

To date, studies about predictors of mindfulness practice adherence are limited. About sociodemographic factors, only age seems to have a significant effect, with subjects dropping out earlier from MBCT being significantly younger [27]. Concerning clinical history, participants who had less than three depressive episodes in their lifetime [28], not take antidepressant medication [27] would be more likely to drop out of the MBCT program prematurely. For cognitive factors, a high level of ruminations [29], and increased cognitive reactivity to changes in the mood [27] would be correlated with earlier withdrawal from the program.

MBI holds promise as an evidence-based treatment for psychiatric disorders. A comprehensive meta-analysis of RCTs examined the effects of MBI on disorder-specific symptoms across psychiatric populations showing that IMB impacts clinical outcomes, especially depression, pain conditions, anxiety, smoking, and addictive disorders [30]. The effectiveness of MBCT is well documented for preventing depressive relapses. Although it is less so for current depression, a recent meta-analysis shows that MBCT does not differ from other active therapies after treatment and during the longest follow-up [11]. Furthermore, age appears to be an interesting moderator with an improvement in depressive symptoms in MBSR in significantly younger patients [31]. In two studies, women show better clinical improvement after MBCT and one year after MBCT [32, 33]. A study [34] about a subgroup of depressed diabetic patients found that patients without prior psychotherapeutic management had significantly greater clinical improvement than those with a history of psychotherapy immediately after MBCT. Two studies [33, 35] consider trait mindfulness during MBSR and MBCT and would show greater improvement in anxiety and depressive symptoms for patients with a high level of trait mindfulness. This is underpinned by the assumption that doing the meditation exercises would be easier or more comfortable for them. The issue of personality traits has been addressed in another study [36] which paradoxically suggests individuals with a high level of neuroticism (persistent tendency to experience negative emotions, significantly correlated with a low level of trait mindfulness) [37] could derive more benefit from a mindfulness-based

intervention. This would be explained by the margin of progression that would be greater for these patients and that meditation programs would support.

Altogether, these data highlighted factors including clinical severity, personality, and mindfulness functioning as key factors implied in efficiency. They were based on classical statistics. Complementing the established benefits of classical null hypothesis testing in medicine, machine learning offers a set of tools based on an algorithmic method to uncover general principles underlying a series of observations without explicit instructions [38, 39]. Machine learning methods are characterized by making few formal assumptions. They aim to offer the data to speak for themselves. Furthermore, they allow the ability to mine structured knowledge from extensive data. They appear to be predisposed to address many challenges in the upcoming era of precision psychiatry, especially in terms of predictive profiles of patients for a complementary understanding of efficacy and adherence.

The general objective of this pilot study is to study the contribution of machine learning analyses to better understand the psychological factors predicting the effectiveness of MBCT in a population of patients followed in ambulatory for various psychiatric sufferings, including symptoms of depression.

Our study will focus on answering two questions. The first focuses on determining the efficacy factors of MBCT on psychiatric symptoms in patients who complete the program. The second focuses on determining factors associated with adherence to MBCT, defined as participation in the full 8-week MBCT program. To address these objectives, machine learning techniques will be applied to find a model, if any, which could account for the response (efficacy and adherence) from the psychological variables (features).

2. Methodology

2.1 Participants

Our sample consisted of N = 76 patients receiving general psychiatric therapy at "Conception Psychiatric Pole" of the university hospital mental health service (Marseille, France), to whom their psychiatrist proposed to participate in an MBCT session organized within the service for dealing with their depressive symptoms. The university hospital mental health service provides specialized follow-up in psychiatry (depressive and anxiety disorders, schizophrenia, adult ADHD, resistant psychiatric disorders, HPI), addictology (tobacco, alcohol, pathological gambling, bulimia, etc.), and as sexology and gender dysphoria. Among the proposed therapies, the university hospital mental health service offers MBCT programs to patients throughout the year. The prescription is made by the patient's referring psychiatrist by the patient in an orientation visit.

The study was approved by the ethical committee of the La Conception Hospital with the agreement of the national commission for information and freedom (number 1223715 in 2016). The inclusion criteria were the prescription by the patient's referring psychiatrist. The non-inclusion criteria were (a) the inability to understand or read English or French, (b) the inability to personally express consent, including adults under legal protection or deprived of their liberty by judicial or administrative decision, or hospitalized urgently or involuntarily committed. The exclusion criteria were (a) a history of participation in an MBCT program and (b) regular meditation practice.

During an informal visit, participants were presented with a complete description of this low-risk study, and written informed consent was obtained.

2.2 Protocol

The study protocol included five groups of patients enrolled for MBCT between 2016 and 2017. It included 2 psychometric assessment sessions: before and after the MBCT program. The duration of each collection session was approximately 25 minutes.

Just before the first MBCT intervention, patients were included in the protocol. The battery of self-report questionnaires was completed. The second session was held at the end of the last session of MBCT (Session 8; post-MBCT session). The battery included the same questionnaires as the battery of the first session, except sociodemographic data.

For each session, the general instructions for filling out the questionnaires were specified: read the instructions in the header of each questionnaire, be spontaneous, answer all the items, and choose the answer closest to the situation when the subject did not quite know how to answer.

For both sessions, an investigator was present throughout the session to answer any questions from participants.

2.3 Intervention

The program is carried out by two psychologists certified in MBCT. Our training protocol was based on the MBCT format for patients with recurrent depression [14]. The MBCT course consisted of eight weekly 2-hour sessions of formal meditation exercises such as the body scan, sitting meditation, walking meditation, and mindful movement. The themes of each of the eight sessions were identical to the themes in the MBCT protocol for recurrent depression, and the homework exercises were also the same as those in the original MBCT protocol. Participants were given homework training to cultivate awareness of everyday activities, such as eating or taking a shower. Participants were provided exercises and audio recordings to practice at home for 45 min a day, six days a week.

During the information visit and before the first session of the MBCT training, the relevance of presenting to the entire program, that is, eight sessions, were explained to the patients. After each MBCT session, the availability of patients for the next session was checked. We consider adherence to the program to be participation in all eight sessions.

2.4 Measures

2.4.1 Clinical Questionnaires

Beck Depressive Inventory 13 items (BDI-13 items) [40, 41]. The measurement of depressive symptoms was performed using the abbreviated version of the Beck Depressive Inventory-II, consisting of 13 questions referring to the presence of depressive symptoms in the two weeks preceding the questionnaire. Answers are scored on a 3-level Likert scale (example 0 = I do not feel sad at 3 = I'm so sad that I cannot stand it). In the general population, a score between 0 and 4 indicates minimal depression, between 4 and 7 mild depression, between 8 and 15 moderate depression, and a score greater than 15 means severe depression.

Medical Outcome Study (SF-36) [42]. An abbreviated 36-item (SF-36) form of this quality-of-life scale was developed for the Medical Outcomes Study to allow its use in clinical practice and research. This scale classifies health into eight sub-groups: 1) physical functioning, 2) social functioning, 3) role limitation due to physical health problems, 4) bodily pain, 5) mental health (psychological distress and well-being), 6) role limitation due to emotional problems, 7) vitality (energy and fatigue) 8) general health.

The recommended scoring system for the SF-36 is a weighted Likert system for each item. The items in the subscales are summed to obtain a score for each subscale.

2.4.2 Mindfulness Functioning Questionnaires

Freiburg Mindfulness Inventory (FMI) [43, 44]. This 14-item scale measures dispositional mindfulness. It takes into account two dimensions: presence and acceptance. Answers are scored on a 4-level Likert scale (1 = rarely at 4 = almost always). The higher the total score, the more the subject is considered "mindful." In the general population, a total score greater than 37 means that the participant has an average level of mindfulness.

Five Facet Mindfulness Questionnaire (FFMQ) [45, 46]. This questionnaire measures the 5 facets that, according to Baer et al. [46], would be constitutive of mindfulness: Description: talk about the experience using words, aware actions: make actions with active attention at every step, non-judgmental inner experience: no positive or negative comments about the thoughts and emotions experienced, non-reactivity: let thoughts and emotions exist without answering them automatically, and observation: stay conscious and focused on the experience even when it is aversive or painful.

An overall score of "mindfulness" is obtained by adding the scores of the 5 facets. The items are evaluated on a 5-level Likert scale ranging from 1 = never or very rarely true to 5 = very often or always true (5). Facet scores are obtained by adding item scores, considering the inverted items. The higher the score (minimum 40, maximum 200), the more the experiences of the person are lived in a "mindful" way.

Ruminative responses scale (RRS) [47]. This is a sub-questionnaire of the Response style questionnaire developed by Nolen-Hoeksema. It consists of 22 items where the participant rates proposals on a 4-level Likert scale (1 = never, 2 = sometimes, 3 = often, or 4 = always). The higher the score, the more the subject uses ruminative cognitive responses (on him, symptoms, causes, and consequences of symptoms) when depressed. Women would average a score of 42 and men 39.6.

The scale of Body Connection (SBC) [48]. Body awareness involves the ability to identify and feel the body's inner sensations and global emotional/physiological state, as well as the perception of body information in response to events in everyday life. Bodily dissociation is an experience characterized by the avoidance of internal feelings. The SBC scale consists of 20 items divided into two subcategories: body awareness (12 items) and bodily dissociation (8 items). The items are scored on a 5-level Likert scale (0 = not at all and 4 = all the time). The higher the score, the higher the body awareness.

Self-Compassion Scale (SCS) [49, 50]. It measures the degree of self-compassion of the participant. The scale is composed of six subscales: "self-kindness", "self-judgment", "common humanity", "isolation", "mindfulness", and "over-identification" (excessive identification). The abbreviated version consists of 12 items to which the participant responds on a Likert scale ranging from 1 (rarely) to 5 (almost always). The higher score the participant gets, the more he or she has a strong compassion for him/herself.

2.4.3 Psychological Functioning Questionnaires

Rosenberg Self-Esteem Scale (RSES) [51] is a self-inventory measuring participants' self-esteem by studying both positive and negative thoughts about oneself. It includes ten items rated on a 4-level Likert scale (1 = strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree). The higher the score, the higher the patient's self-esteem, and a score below 15 is associated with low self-esteem.

State Anxiety Inventory (STAI) [52]. This self-questionnaire is one of the first to simultaneously assess anxiety as a "state" and a " trait." Each type of anxiety has its scale of 20 questions; scores range from 20 to 80, with higher scores correlated with higher anxiety. Only the first 20 proposals about anxiety as a state were used in our study. A score above 40 is associated with clinically significant anxiety. The proposals are rated on a 4-level Likert scale (1 = not at all, 2 = sometimes, 3 = moderately, 4 = a lot).

2.5 Statistical Analysis

Data processing was performed using Statistica (Stat Soft France, Maison Alfort, v7.1) software and Matlab 2018b (The Mathworks®), including the Statistics and Machine Learning toolbox, the Deep Learning toolbox, and custom scripts.

For each of the scales, the internal consistency was acceptable (Cronbach alpha between 0.67 and 0.9), except for the FFMQ (Cronbach alpha = 0.98)

Data were compared using the Chi-square test or Fisher's exact test when Chi-square's conditions were not met. Intention-to-treat that includes all patients as originally enrolled, and per protocol, that includes only those patients who completed the treatment as prescribed, analyses were applied for the evaluation of MBCT efficacy on depressive symptoms using Student's paired t-test (pre-MBCT and post-MBCT), when the variables were normally distributed. Otherwise, the Wilcoxon signed-rank test was used.

In addition to classical statistical approaches, we used Machine Learning (ML) analyses as an innovative way to explore the relationship between Efficiency and psychological factors. As supervised features selection, the Orthogonal Forward Regression (OFR) algorithm was applied for the efficacy and the adherence separately [53] with two steps: (1) all features are ranked according to their correlations to the response variable, namely the squared cosine of the angle between the feature and the response variable; the most correlated feature (with the maximum squared cosine) is ranked first; (2) all remaining features and the response variable are orthogonalized on the best feature, in order to eliminate the contribution of the best feature to the output; then, the best psychological feature is stored and removed from the set, and the algorithm iterates on the remaining orthogonalized features until all features are ranked. Performances of the model were evaluated using the sensitivity index (*i.e.,* the proportion of examples from the adherent class (or

patients with a decrease in depression) that are correctly classified) and the specificity index (*i.e.,* the proportion of examples from the non-adherent class (or patients without a decrease in depression) that are correctly identified). The best model was selected using a global method that consisted in estimating the generalization error: Leave-One-Out (LOO). The LOO method aims to evaluate the ability of the model to generalize prediction [54].

For the decision criterion, in all cases, we considered that a difference was significant as soon as $p < 0.05$. A trend toward significance was considered when $0.05 < p \leq 0.1$.

3. Results

3.1 Participants

Seventy-six patients were included in the study in five successive groups corresponding to their MBCT session. There were 18 patients in group 1 (23.6%), 22 patients in group 2 (25%), 13 patients in group 3 (17.1%), and 14 patients in group 4 (18.4%). %) and 9 patients in group 5 (11.8%).

At the socio-demographic level, our sample consisted of at least 56.5% women and at least 34.2% men (7 missing values). The average age was 48 years (standard deviation 12.83). Regarding marital status, 36.8% of participants lived alone, 23.6% lived in a family, and 26.3% lived with a partner (10 missing values). 11.8% of participants weren't educated, 10.5% had a "bac + 2" degree, and 64.4% had a higher education (10 missing values). Of the participants, 39.4% had a profession, and 43.4% did not work (10 missing values). 52.6% of participants had already worked in their lifetime. The remaining 36 patients did not provide an answer or an applicable answer to the question. There is no sociodemographic difference between the 5 MBCT groups.

The primary diagnosis of the study participants from the shared hospital file was a unipolar mood disorder for 40 of them (52.63%) and a bipolar mood disorder for 12 (15.78%) of them. Six of them (7.89%) were diagnosed with comorbid anxiety spectrum disorder (generalized anxiety disorder, phobic disorder), 5 of them (6.57%) had another somatic or psychiatric comorbidity (chronic pain syndrome 2, acute psychotic disorder 1, eating disorder 1, alcohol dependence 1).

The depressive disease was diagnosed on average 16 years ago (standard deviation 12.62), and participants had been on medication for an average of 13 years (standard deviation 11.52) at the pre-MBCT session. The Beck Depressive Inventory severity score (BDI, Table 1) of the participants before MBCT averaged 10.51 (standard deviation 7.3), corresponding to a moderate depressive episode on this scale. At the pre-MBCT session, 12 participants were under the cut-off of depression (15.79%). Fifteen participants (19.73%) had a mild depressive episode, 25 participants (32.90%) had a moderate depressive episode, and 18 participants (23.68%) had a severe depressive episode. Six patients (7.89%) did not provide an answer or an applicable answer to the question.

Table 1 Questionnaire results at pre-MBCT session (before treatment). S = size; M = mean; SD = standard deviation BDI = Beck Depressive Inventory. RSES = Rosenberg Self-Esteem Scale. FFMQ = Five Facet Mindfulness Questionnaire. RRS = Ruminative Response Scale. FMI: Freiburg Mindfulness Inventory. SCS = Self-Compassion Scale. SBC = Scale of Body Connection. STAI = State Trait Anxiety Inventory. SF-36 = Medical Outcome Study.

		N	M	Median	Min	Max	SD
Clinical questionnaires							
BDI		70	10,51	10	0	41	7,31
	Physical functioning	60	77,33	85	30	100	22,14
	Role limitation due to physical health problem	60	45,42	37,5	0	100	42,56
	Bodily pain	60	38,71	42,5	0	90	26,61
	General health	60	57,15	56,25	33,33	79,17	8,23
SF36	Vitality	60	51,67	55	20	85	14,98
	Social functioning	60	47,29	50	12,5	75	10,06
	Role limitation due to emotional health problem	60	38,33	33,33	0	100	40,63
	Mental health	60	53,20	52	20	80	11,77
	Total	60	47,62	45,39	23,75	76,25	13,97
Mindfulness questionnaires							
	Total	71	30,197	30	19	51	7,22
FMI	Presence	71	13,9	13	6	23	3,65
	Acceptance	71	16,63	16	9	28	4,09
	Observation	71	25,50	26	10	36	5,59
	Description	71	24,29	24	12	37	5,75
FFMQ	Aware actions	71	22,85	23	10	38	5,75
	Non-reactivity	71	17,09	17	7	28	4,57
	Non-judgmental inner experience	71	22,05	22	9	37	6,60
	Total	71	111,77	111	76	163	16,28
RRS		74	56,09	55,5	25	88	13,51
SBC	Body awareness	69	20,33	21	6,4	32	5,72
	Bodily dissociation	69	13,73	14,2	2	22	4,27
SCS		73	29,06	29	15	49	7,34
Psychological functioning questionnaires							
RSES		68	24,07	24,5	14	36	4,88
STAI		71	49,46	51	25	75	13,93

The average number of depressive episodes for participants was 4 (standard deviation 3.66). On average, 7.8% of participants experienced two depressive episodes during their lifetime, 31.5% of participants experienced three depressive episodes, and 25% experienced more than 5 depressive episodes during their lifetime. The remaining patients did not provide an answer or an applicable answer to the question.

All subjects have, or had, psychotherapeutic care, including psychodynamic or cognitive and behavioral therapy. Concerning medication, 11 subjects did not answer (14.47%), and 10 subjects reported having no medication (13.76%). For those reporting medication, 30 subjects have antidepressants (39.47%), 18 neuroleptics (23.7%), six anxiolytics (7.9%), 6 sleeping pills (7.9%), 5 pain killers (6.6%) and 3 lithium (3.9%). Among them, 10 subjects (13.76%) have at least two medications, mainly antidepressant and neuroleptic.

Psychological scores at the pre-MBCT session are presented in Table 1.

3.2 Efficiency of the MBCT Program

3.2.1 Patient's Adherence Dynamics

Figure 1 describes the flow of subjects at different times of the study. In post-MBCT, 38 out of 76 patients (50%) were lost to follow-up.
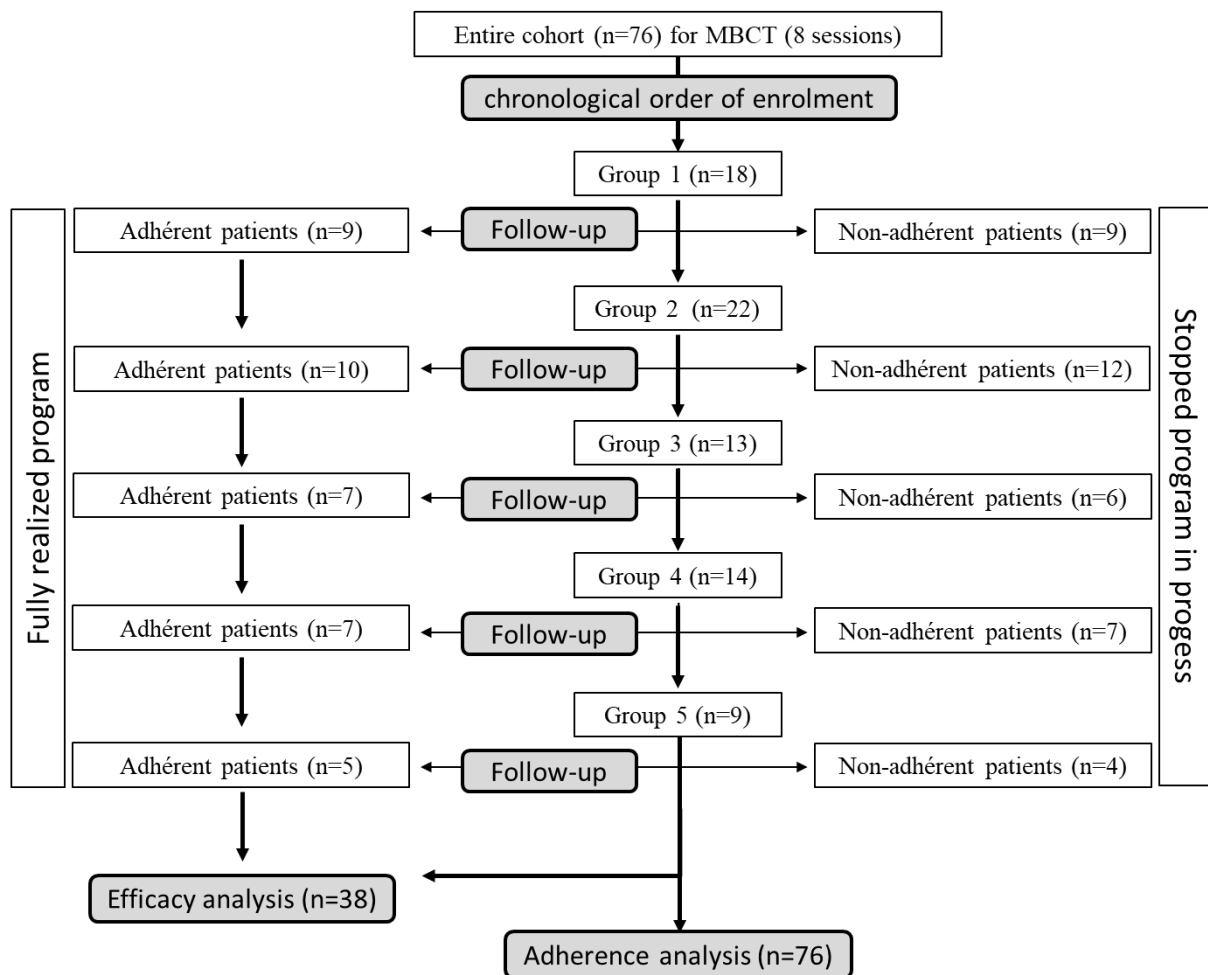

Figure 1 Flowchart of included participants.

3.2.2 Pre-Post MBCT Evolution

The intention-to-treat analysis results show a significant decrease in Beck's score at the end of the program (t = 3.99, p < 0.01). Beck's average pre-MBCT score is 10.56 (standard deviation 7.26), and Beck's average post-MBCT score is 8.88 (standard deviation 7.34), which means a decrease in

depression score of 1.68. There is no difference between the 5 MBCT groups for the decrease in the Beck score.

The results of per-protocol analysis show a significant decrease in the Beck score at the end of the program (t = 4.3, p < 0.01). The average pre-MBCT Beck score is 9.84 (standard deviation 5.59), and the average post-MBCT Beck score is 6.57 (standard deviation 4.82), which means a decrease in depression score of 3.27. There is no difference between the five MBCT groups for the decrease in the Beck score.

Of the 38 patients who fully realized the MBCT program, 8 (20.5%) experienced no depressive episode, 17 experienced a mild depressive episode (22.37%), 12 experienced a moderate depressive episode (15.79%), and one a severe depressive episode (1.31%). There is a significant difference in the distribution of the number of subjects by severity category at the end of the program (Chi-square = 24.34, p = 0.004). The changes in categories mainly concern patients classified as "moderate" and "severe" pre-MBCT depression who move to a less clinically severe category. Among the 12 subjects with moderate depression at inclusion, 3 exhibited no symptoms after the MBCT program and four mild symptoms, whereas five patients remained in the moderate depression range. The patient with severe depressive symptoms at inclusion exhibited mild depression symptoms after the MBCT program.

3.3 Characterization of Groups by Machine Learning Approach

3.3.1 Characterization of the Population Responding to the MBCT Program

At the end of the SVM analysis (Orthogonal Forward Regression), only two factors are selected to characterize patients who improved after the MBCT program. The first is the Beck score higher than 25 at inclusion, which signifies severe depression, and the second is an average FFMQ score, indicating a mindfulness level of over 90 for a population with a score between 76 and 163 and a median of 111 (Figure 2).
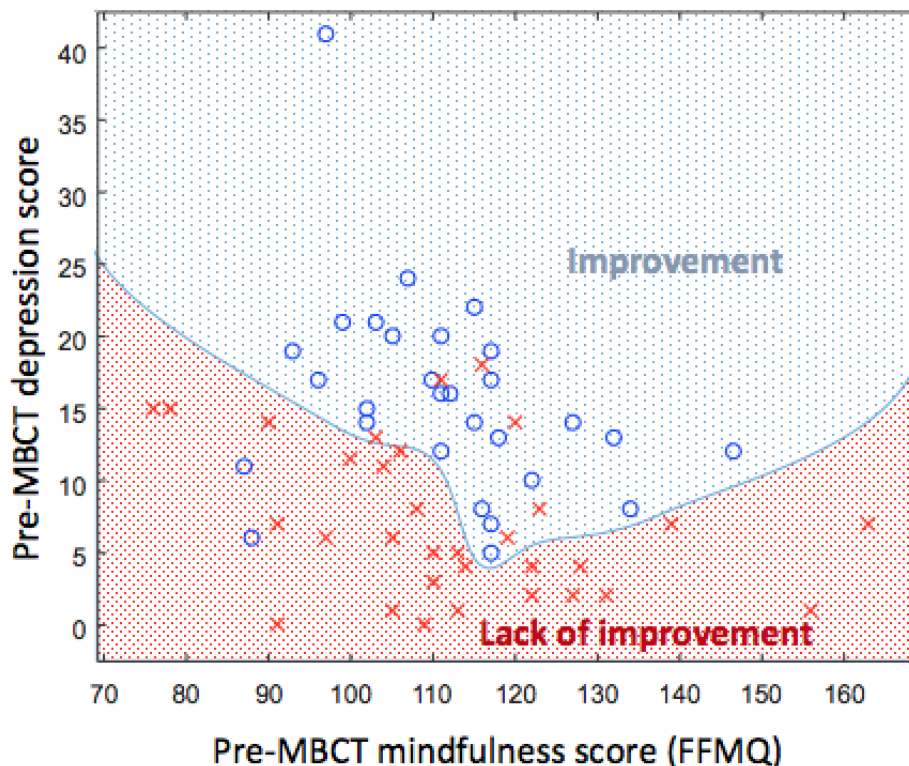
Figure 2 Representation of the results of SVM classification of improved versus non-improved patients. FFMQ = Five Facet Mindfulness Questionnaire. MBCT = Mindfulness-Based Cognitive Therapy.

The percentage of misclassified validation examples is 24.6 (LOO = 75.4), reflecting a good generalization capacity of the classifier. The model's sensitivity is 79.3% and the specificity is 71.9%, reflecting the quality of the obtained classifier to classify the improved and non-improved subjects.

3.3.2 Characterization of the Population Participating in the Whole MBCT

At the end of the SVM analysis (Orthogonal Forward Regression), three factors were selected to characterize the adherent versus non-adherent patients with MBCT. Adherent patients are subjects with below-average or above-average scores for the Mindfulness Questionnaire (FMI) and Bodily Dissociation Sub facet (SBC) and a low self-compassion score (Figure 3). Non-adherent patients are subjects characterized at inclusion by mean scores on the Mindfulness Questionnaire (FMI) and Bodily Dissociation sub facet (SBC) with a scattered self-compassion score.
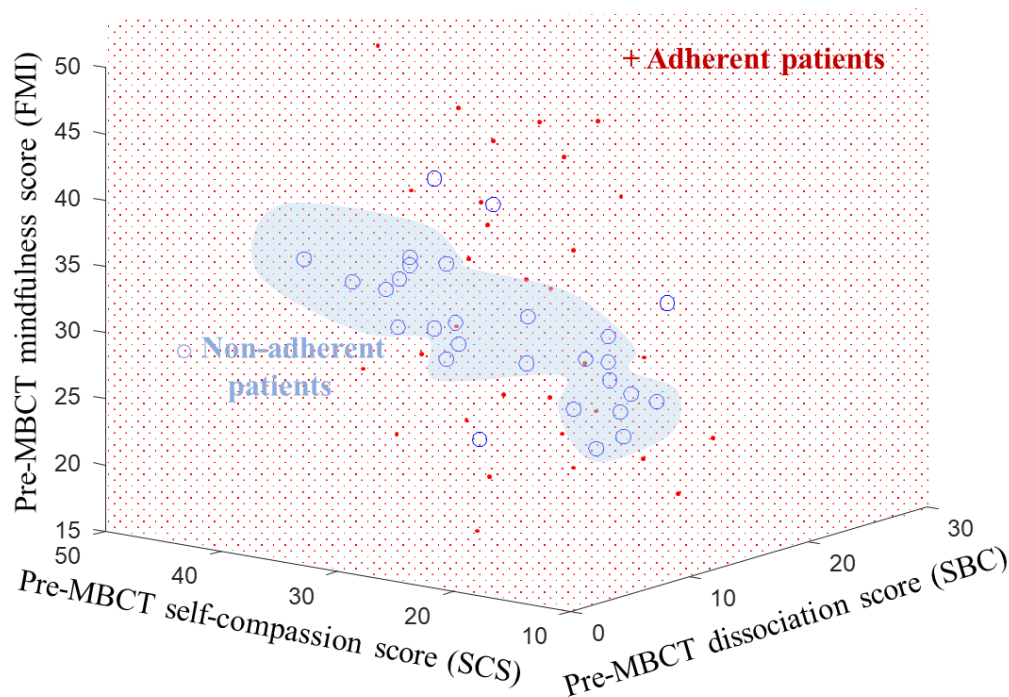
Figure 3 Representation of the SVM results classification of adherent versus non-adherent patients. FMI = Freiburg Mindfulness Inventory; SBC = Scale Body Connection.

The percentage of misclassified validation examples is 37.3 (LOO = 62.7), reflecting an acceptable generalization capacity of the classifier. The sensitivity of the model is 48.4% and, the specificity of 71.9%. This classifier has a medium sensitivity, meaning that it classifies adherent subjects with errors, but a very good specificity, meaning that it classifies non-adherent subjects with few errors.

4. Discussion

4.1 Population of the Study

The results of this pilot study focused on a population mostly women (56.2%) in the second half of working life with a high education level. It was globally socially isolated and mostly unemployed. Although it is well known that psychiatric populations are also less professionally inserted because of their potentially debilitating symptoms [55], it must be highlighted that the MBCT sessions were scheduled during working hours, which led to the exclusion of the employed population. This could partly explain the under-representation of the employed population.

These sociodemographic data were consistent with those of another study conducted in the United States by Olano H. A. et al. [56], which highlighted the fact that men were half as likely to engage in meditation programs as women and that people with a high level of education were more frequently involved in such practices. One reason might be a greater tendency for women to introspect than men, as openness to one's feelings is perceived as a feminine characteristic [57].

It was a population of psychiatric patients from the University Hospital Centre who was offered participation in MBCT, so comorbid diagnoses were multiple. Nevertheless, from the shared hospital file, three major groups could be identified: unipolar depression, bipolar mood disorder, and anxiety spectrum disorders. MBCT has demonstrated clinical efficacy on depressive [25] and anxiety [24]

symptoms with a high standard of proof, so there was a therapeutic indication of our program for these patients. More marginally were the comorbid diagnoses of chronic pain, eating disorders, alcohol dependence, and an acute psychotic disorder.

Clinically, it was a symptomatic population with a mean Beck Depressive Inventory score corresponding to a moderate depressive episode. A certain proportion of participants (15.79%) did not show symptoms of a depressive episode at inclusion in the study.

The participants had often experienced depressive relapse (an average of 4 episodes during their lifetime), and the onset of depressive disease and treatment began a long time ago (16 years of evolution on average).

Overall, the psychological resources of our population were low, which can be expected from a psychiatric population, with initial scores on the mindfulness scales indicating a less mindful population than the general population [43, 44]. The anxiety state and rumination scores were higher than in the general population [47, 52]. The quality of life estimated by participants was low [58]. Compassion for oneself was diminished about the general population [50] and self-esteem [59]. The two sub-scores obtained at the SBC were average for body awareness and higher than the general population for bodily dissociation [60].

4.2 Efficiency of the MBCT Program

We note a high attrition rate in our study, with 50% of the participants lost to follow-up at the last session of MBCT. This percentage is higher than what is found in the literature (where it amounts to an average of 26%), although a review of the literature finds a wider range (10-50%) [61]. Attrition throughout MBCT sessions was not collected on a session-by-session basis, but most subjects who stopped the program did so before the fourth session.

The population's characteristics partially explain this dropout rate. Depression is indeed the diagnosis associated with the highest dropout rate of CBT, compared to other psychiatric diagnoses [23], which can be explained by the attributes of depression itself: hopelessness, psychomotor retardation, and social withdrawal are all symptoms that prevent patients from engaging in therapy. Our MBCT program is also provided at the public hospital (free of charge) and is offered to patients coming for a routine consultation. Participation in MBCT was more due to the therapist than the patient himself, compared to programs for which a fee is charged that appeal to the patient's motivation. The program schedule could also be a brake on adherence (Tuesday 15-17 h and Friday 10 h-12 h).

The results of intention-to-treat and per-protocol analyses show a significant decrease in Beck's score at the end of the program, with a differential score of 1.68 in intent-to-treat and 3.27 per protocol. As a reminder, the category changes mainly concern patients classified in the moderate depression and severe pre-MBCT depression categories who move to less clinically severe categories, which seems consistent given the greater margin of progression for these patients. The clinical improvement we found is consistent with the literature [15].

Given that MBCT may be of similar efficacy to other active therapies for currently depressed individuals, further research could continue to examine the efficacy of MBCT in other psychiatric conditions (e.g., anxiety disorders). While many RCTs have explored MBCT for depression, far fewer RCTs have been conducted on other psychiatric conditions potentially amenable to the active treatment ingredients offered in MBCT [30]. Numerous other psychiatric conditions share core

cognitive and affective features with depression (e.g., rumination in posttraumatic stress disorder) and may be positively impacted by MBCT.

4.3 Efficiency Prediction Models

The point of models obtained by machine learning is to get a multidimensional "typical profile" of patients who can benefit the most from MBCT. Therefore, we can enhance MBCT's efficiency by prescribing it to a certain type of patient and/or by helping patients to develop the dimensions highlighted by the predictors of pre-post benefits and adherence.

4.3.1 Predictors of Pre-Post Changes

Supervised learning analyzes select two variables to predict which subjects will improve and which will not. The improved subjects suffer from severe depression and have a sufficient level of trait mindfulness evaluated by the FFMQ.

This result is consistent with the literature. Indeed, trait mindfulness is found in other studies as a factor of efficacy on anxiety and depressive symptoms [33, 35], with a better response from participants with a high level of trait mindfulness.

Regarding the efficacy observed in the most severely depressed patients, it may be hypothesized that there is a greater margin of progression for these patients and that learning new modes of cognitive functioning by practicing mindfulness meditation would particularly help. However, our data suggest that the program is unsuitable for all patients with severe depressive symptoms. Indeed, for the results of the meditation program to be optimal, these patients must also have a sufficient level of trait mindfulness, therefore, a certain facility to enter states of mindfulness. This two-dimensional model allows us to define a typical patient profile for which the MBCT is most effective.

The quality of the model leads to proposing a pre-assessment of patients prescribing a mindfulness program to target patients who will benefit the most from a mindfulness program. It also leads to thinking about the modalities of the programs to be deployed to allow patients not currently improved by the MBCT program to benefit from mindfulness training adapted to their functioning.

4.3.2 Adherence Predictors

Supervised learning analyzes describe the subjects that will be adherent with those that will not be adherent with three variables: trait mindfulness (FMI), body dissociation (SBC), and self-compassion (SCS). We get a three-dimensional model.

The subjects who perform all eight sessions are characterized by an "outsized" profile: low or high level of mindfulness assessed by the FMI and bodily dissociation, and low level of self-compassion. Subjects who have not completed all eight sessions are characterized by an average profile in mindfulness and body dissociation, while their self-compassion score is variable.

As a reminder, in the literature, only ruminations and high cognitive reactivity [27, 29] were found as predictors of attrition in MBCT. These cognitive characteristics can be correlated with a low level of trait mindfulness [62], one of the profile features found in our results.

If the model is only of acceptable quality in terms of generalization, it has good specificity. These results suggest that other variables contribute to patient adherence to the MBCT program. Nevertheless, its specificity leads to thinking about the modalities to be implemented to allow patients to complete the program. Thinking the motivations of these patients could be considered.

4.4 Limits

The small number of participants in each group, coupled with the high rate of attrition and the inconsistent filling of questionnaires by patients, leads to a decrease in the generalization power of the model obtained by machine learning.

Another limitation of our study concerns the efficacy predictors. The absence of a control group prevents us from comparing the quality of the predictors when receiving MBCT with a group receiving only the reference treatment (pharmacological treatment) or receiving another group cognitive-behavioral intervention that would be close to the interventions based on mindfulness and control for confounding factors.

In our study, adherence is defined as attending the 8 sessions of MBCT. Similar results could have been achieved with a lower number of MBCT sessions. We chose to include eight sessions to be by the prescribed MBCT protocol. Furthermore, we do not evaluate home-based practice, which consists in doing 45 minutes of daily meditation. However, we know the importance of home-based practice during and after the program is completed, which contributes to the effectiveness of the MBCT [63]. This would be a parameter to include in a future study.

Furthermore, information about the time course of dropout from the MBCT program can be informative for better studying the psychological mechanisms implied in attrition/adherence and then for adjusting modalities of the MBCT program that improves adherence. A "psychological" commitment assessment should complete this information. In a study by Holdsworth et al. [64], this commitment is theorized as "all the efforts that clients make during treatment (both during and between sessions) to achieve change", including physical presence at sessions, psychological involvement, home practice achievement and, the therapeutic relationship. Including this definition of adherence may be interesting for an integrative view of the problem.

4.5 Strengths of the Study

Innovative studies combining psychotherapy and machine learning are rare. To our knowledge, this is the first study using machine learning in mindfulness, making it particularly original. The potential of machine learning in psychiatry is important given its power of prediction, whose usefulness for the diagnosis, prognosis, and treatment of mental pathologies has been suggested. Machine learning appears useful for capturing the heterogeneity underlying psychiatric phenotypes, even in small experimental samples [65]. Also, this study opens the door to future research avenues to deepen our understanding of the moderating factors for MBCT effectiveness and adherence. These factors cannot explain the phenomenon's complexity, but they can guide the therapist and allow a more personalized approach to mental healthcare.

5. Conclusion

Studies combining psychotherapy and machine learning are few. To our knowledge, this is the first study using machine learning in mindfulness, making it particularly original. The potential of machine learning in psychiatry is important given its power of prediction, whose usefulness for the diagnosis, prognosis, and treatment of mental pathologies is suggested.

Our exploratory study results provide preliminary evidence that the predictive power of machine learning helps with the design of standard patient profiles to facilitate more personalized care for patients followed in psychiatry, especially those with symptoms of depression and anxiety.

In addition, our study findings suggest that it would be interesting to include in the MBCT more psychoeducation on why a given factor makes the practice of mindfulness difficult and may ultimately lead to abandoning the MBCT program. However, further studies are needed to explore many aspects of this area.

Author Contributions

CL, MM and MT designed the study; FV made the statistical analyses; MM and PP led the MBCT program and helped in searching the literature; MD and MM designed and wrote the manuscript; CL acted as advisor.

Competing Interests

The authors declare that there is no conflict of interest regarding the publication of this article.

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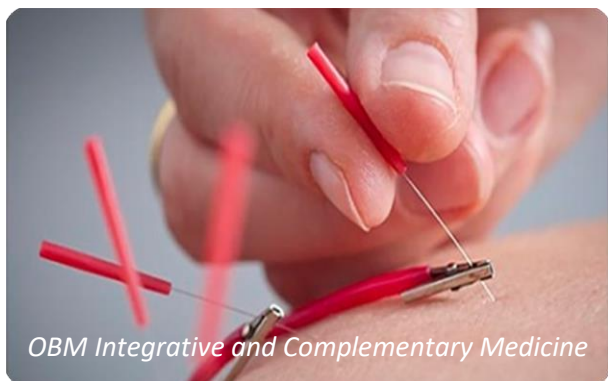
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