Formal Modeling of Behavioral Activation for Depression

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P19: Practical Course in Empirical Research Methods II: “Formal Modeling of Psychological Theories”

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18.03.2024

Introduction

The aim of this work is to showcase how to formalize a theory step by step by applying the "Theory Construction Methodology" by Borsboom et al. (2021) to an already existing theory.

In following the theory of the "Behavioral Model of Depression" is investigated which is rooted in the „Reinforcement Theory of Depression" by Lewinsohn (1974) and serves as the theoretical foundation of the "behavioral activation"-treatment for patients suffering from depression, which will be the focus of the following formalization. However, since the term "behavioral activation" has further developed and been expanded in the last years the review by Dimidjian et al. (2011) will be used as a basis for the formalization. Introducing the theoretical framework, it is postulated that antecedents of depression are events of crisis which lead to a disruption of the usual behavioral pattern and emotional response. This can further result in a reduced rate of positive reinforcement as well as an increased rate of aversive experiences which in turn lead to an increased state of self-awareness, including self-criticism and negative expectancies. Finally, this entails increased depression, manifesting itself in behavioral, emotional, somatic, and interpersonal consequences which lead to a self-reinforcing circle of the aspects outlined above that proceed, worsen, and stabilize depression. The treatment of behavioral activation then targets the crucial aspect of the reduced rate of positive reinforcement and increased rate of negative experiences (Dimidjian et al., 2011).

Methods

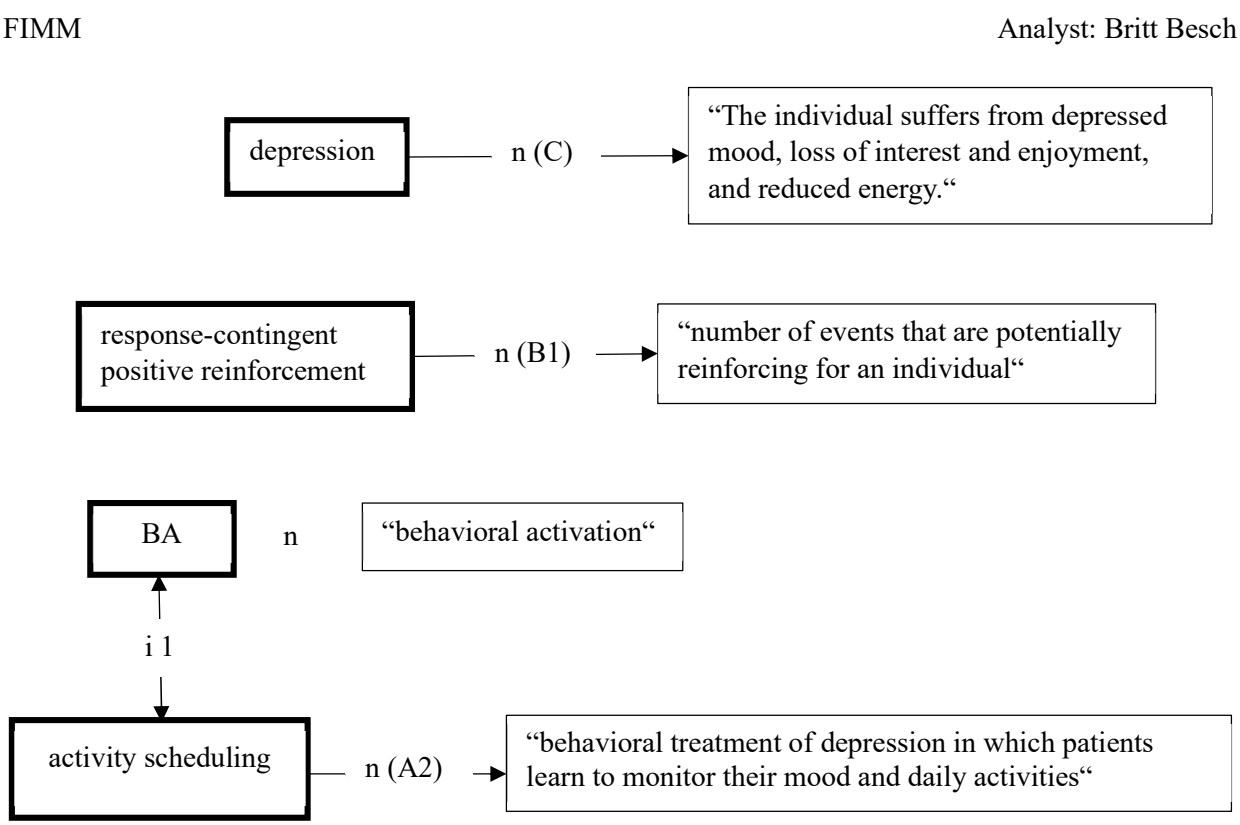
The code for the formalization can be accessed in the following repository: https://github.com/BrittBesch/Besch_EmpraModelingBA_2024.git.

Central Constructs of the Theory

For simplification, firstly, the focus of the formalization is set on the behavioral activation itself and not on the variety of mechanisms potentially causing and maintaining depression. Secondly, to further narrow it down the model is reduced to the three constructs "behavioral activation", "response-contingent positive reinforcement", and "depression", which have been identified as the most crucial ones to explain the effect of behavioral activation. These are defined in Figure 1, which was made by following the guidelines of the "Visual Argument Structure Tool" (VAST) by Leising et al. (2023).

Figure 1

VAST display for the three main constructs



The VAST display is based on concrete definitions of the constructs derived from literature which are summarized in Appendix A. The IDs in the table match the relationship assignments in Figure 1. However, again for simplification, a few definitions have been reduced to some sub-aspects.

The definition of depression was shortened to the minimum necessity of required symptoms for a diagnosis after ICD-10 (World Health Organization, 2019). Behavioral activation was reduced to the concrete aspect of treatment conduction, leaving its overall abstract aims as originally defined (see Appendix A, A1) aside. Furthermore, it is narrowed down to the method of "activity scheduling". This aligns with the reduction of the construct "response-contingent positive reinforcement" to the number of potentially positive events, therefore focusing only on the matter of attending these events and excluding more complex aspects such as the expected value or personal ability to actually benefit from the event which would have been addressed by methods such as social skills or reward training that have been associated with behavioral activation before but are not included in the definition of the treatment in this work.

Analysis of phenomenon of interest

The main phenomenon of interest as already highlighted above is the effect of behavioral activation as a treatment for depression. Robustness of phenomena will be considered on two dimensions: empirical evidence and generalizability.

For evaluating the evidence the meta-analysis by Cuijpers et al. (2007) which specifically investigated activity scheduling as a form of behavioral activation is considered. Looking at the individual studies, six out of 10 studies are not significant and show confidence intervals which include zero. However, a pooled effect size of $d = 0.87$ and a 95% CI [0.60, 1.15], indicating the difference between intervention and control conditions, was found. The 10 included studies report effect sizes between $d = 0.38$ and $d = 2.33$.
This indicates rather strong empirical evidence.

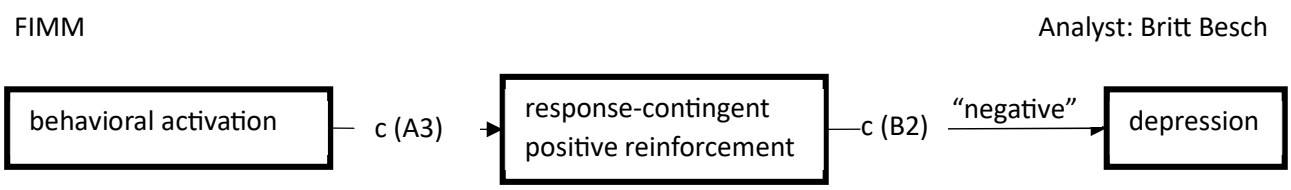
The generalizability is evaluated using the "UTOS-framework" according to Findley et al. (2021). Investigating the generalizability across the unit dimension, the studies from Cuijpers et al. (2007) show a variety of age-groups, mixed gender, comorbidities, as well as a sample of lower socio-economic status. Samples were recruited from the community and from clinical settings. However, only studies from Australia and the US were considered.
Treatment delivery varied in the number of sessions (between four to twenty).
The outcome variable depression was measured by using up to 10 different self-reports-scales across the studies included.
The setting in which the treatment was delivered varied between individual and group format (Cuijpers et al., 2007).
These findings suggest a rather high generalizability of the phenomenon.

Formulation of theory and the phenomenon

The theory of the origin of depression, and a possible mechanism of behavioral activation that can be derived from it, have been narrowed down to three central constructs to explain the phenomenon. The relationship among these constructs is displayed in Figure 2.

Figure 2

VAST display for the relationship between BA, positive reinforcement, and depression



Summarizing, this formalization assumes that there is a causal relationship between response-contingent reinforcement and depression, with low reinforcement leading to a higher severity of depression (see Appendix A, B2). Furthermore, behavioral activation as the method of activity scheduling which is supposed to encourage patients to pursue more potentially rewarding activities leads to more positive reinforcement (see Appendix A, A3). Thus, behavioral activation could lead to reduced severity of depression.

Building a formal model

For implementing the model the three variables, "ba", "pos_reinforcement" and "depression" were defined as shown in Appendix B based on simple plausibility. "ba" must be binary since it represents the two experimental conditions. "pos_reinforcement" and "depression" could both be empirically operationalized by self-reports and standardized to values in the range of [0, 1]. They cannot be negative or infinite since in regard of "depression" a person either does not suffer from it (0) or reaches a maximum (close to suicide) that can not be exceeded. The same applies to "pos_reinforcement". In extreme cases a person either does not conduct any positive events at all (0) or attends a number of events someone not suffering from depression would do which is still restricted to the finite amount of time a person has next to work and other obligations.

A summary about the functional relationships between the variables and the underlying considerations can be found in Appendix C. In general, a linear relationship between the number of sessions of behavioral activation and the number of positive reinforcing events was assumed. For the experimental condition the slope of the function was determined by the consideration that it might not be plausible to fully recover from a severe depression, e.g. suicidal tendencies, by a couple of behavioral activation-sessions. Therefore, it is assumed that the pos_reinforcement enhances on such a rate, that after a maximum of 20 sessions a person starting with a moderate depression (depression = .5) could potentially remit to depression = 0. The 20 sessions align with the maximum number of sessions conducted in the meta-analysis by Cuijpers et al. (2007). In regard of the control condition which does not receive behavioral activation the model was appended in a way that instead of having a steady rate of positive reinforcement, patients in the control group probably attend a reduced amount of rewarding events over time due to the vicious circle effect described by Dimidjian et al. (2011). Thus, no treatment will lead to a further decrease of reinforcing activities but maybe not on the same rate as an increase would take place since it is not active but a rather passive

process. The “time”-units are operationalized by the number of BA sessions received/not received, assuming they take place in regular intervals (e.g. every seven days).

The choices made for simulating a group of people are outlined in detail in Appendix D. Main considerations include that even though the depression variable is theoretically defined in the range [0, 1] in practice only people with considerably high depression scores will receive behavioral therapy. Furthermore, there might be a higher proportion of the population suffering from mild or moderate depression than the proportion of highly depressed patients. These assumptions apply to the variable of positive reinforcement in the same but invers way such that only patients with reinforcement scores in the range [0, .8] need therapy and with fewer people showing extremely low scores of positive reinforcement.

These assumptions are then implemented in R.

Evaluation of the formal model

The model is evaluated by simulating a sample of 1000 patients which receive 10 sessions of behavioral activation in the experimental condition. The number of sessions aligns about with the mean number of sessions of the studies considered in the meta-analysis by Cuijpers et al. (2007).

The effect for the mean difference in depression scores between the control and the experimental group is $d = 2.35$ with a 95% CI [2.19, 2.52]) in the model. This exceeds the pooled effect size of the meta-analysis of $d = 0.87$ by far (Cuijpers et al., 2007). Possible reasons will be discussed in the following section. Furthermore, the resulting dataset was visualized by boxplots (see R script).

Discussion

To discuss the formalization of the presented theory, the individual steps of the process will be reflected. Firstly, since the theoretical foundation of behavioral activation includes a variety of different mechanisms and constructs which are all mutually dependent it was difficult to narrow it down to just a few crucial constructs. During this process, the theory was drastically reduced to the single behavioral aspect such that the idea that depression is a disorder with multifactorial origins, also on a cognitive, emotional, and interpersonal level might have been lost. However, due to the vast body of literature there were multiple definitions for the chosen constructs one could work with. This made it rather easy to find material for a formalization in the first place. Nonetheless, especially in regard of behavioral activation which was primary a behavioral intervention based on mechanism of operant

conditioning but got expanded with cognitive and meta-cognitive elements it was difficult and felt rather arbitrary to choose a working definition since multiple options would have seemed plausible. Furthermore, it was interesting to recognize that depression was never defined in any of the papers which is probably the case due to the generally widespread understanding of it in the clinical area as an ICD-10 disorder which does not need further specification. Secondly, the identification and evaluation of the robustness of the phenomenon of interest worked well thanks to the meta-analysis by Cuijpers et al. (2007) which provided lots of information regarding the generalizability. Thirdly, deriving the general relationship between the constructs from the given literature was feasible. However, I initially did not consider that I would have to postulate the relationships not only for the behavioral activation condition but also for the control condition which became obvious and inevitable later during the implementation of the model. Then, while defining the concrete relationships between the variables I thought that I might have been able to generate a better model if my personal mathematical skill set was broader so that I would have had more options to choose from than simply assuming a linear relationship. Hereby, it also felt arbitrary to decide on a concrete value of a slope. The same impression applys for choosing the concrete sample characteristics. It would probably have been beneficial to the model if there had been research findings on the effects of behavioral activation sessions over time or statistics on the distribution of the depression severity in the population so that one does not have to rely on subjective decision based on pure plausibility. Finally, considering the evaluation step the simulated effect size is almost three times as high as the pooled effect size calculated by Cuijpers et al. (2007). Possible reasons for the mismatch could on the one hand originate in limitations of the meta-analysis since the number of studies included as well as the sample sizes were small and the quality questionable (Cuijpers et al., 2007). On the other hand, there are multiple features of the chosen model that could have caused such a large effect. The linear decrease/increase of positive reinforcement does probably not capture the complexities of how behavioral activation impacts depression. In particular, the slope chosen for the relationship between the treatment condition and positive reinforcing might have been optimistic in regard of improvement at the same time pessimistic for the condition without behavioral activation. Furthermore, the linear relationship between reinforcement and depression simplifies their connection severely and assumes that a higher number of positive events directly leads to enhanced mood, although it is known that depressed individuals have for example also difficulties benefitting and drawing energy from potentially awarding events so that this variable can probably not be transferred directly into an enhancement of the

disorder. In addition, the implemented skewed beta distribution was not chosen based on empirical data but subjective assumptions and could have led to a distortion of the effect.

Concluding, the most difficult part of the process for me was choosing the theory in the first place and following, the reduction of the theory to just a few constructs and simple definitions of them that still take the most important idea of the theory into account. This was probably the case because on the one hand, I might have chosen a rather complex theory which was not ideally suited for a formalization. Maybe identifying a few indicators which constitute a theory suited for modeling during the seminar would have been helpful. However, one could argue that every theory should be possible to formalize. On the other hand, the theory itself takes lots of different aspects into account aiming to explain depression in an all-encompassing but rather superficial way which makes it difficult to formalize the interaction between just a few factors in more depth.

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Appendix A

Definition from the literature of the constructs for creation of the VAST display

ID	Construct	Citation	Refer-ence	Simplifi-cation
A1	Behavioral Activation	structured, brief psychotherapeutic approach that aims to (a) increase engagement in adaptive activities (b) decrease engagement in activities that maintain depression or increase risk for depression, and (c) solve problems that limit access to reward or that maintain or increase aversive control. To achieve these primary aims, therapists may use a variety of behavioral strategies such as self-monitoring of activities and mood, activity scheduling, activity structuring, problem solving, social skill training, hierarchy construction, shaping, reward, and persuasion.	Dimidjian et al. (2011, pp. 3-4)	reduced to the aspect of „activity scheduling“ (further defined in A2)
A2	Activity Scheduling/ Behavioral Activation	behavioral treatment of depression in which patients learn to monitor their mood and daily activities	Cuijpers et al. (2007, p. 318)	
A3	Activity Scheduling	patients learn how to increase the number of pleasant activities and to increase positive interactions with their environment	Cuijpers et al. (2007, p. 318)	
B1	response-contingent positive reinforce-ment	the total amount of response-contingent reinforcement was a function of the number of events that are potentially reinforcing for an individual, the availability of such events in the environment, and the instrumental behavior of the individual in eliciting such reinforcement from the environment	Dimidjian et al. (2011, p. 6)	“number of events that are potentially reinforcing for an individual“
B2	response-contingent positive reinforce-ment	it was assumed that depression covaries with amount of response contingent reinforcement and is preceded by a reduction in such reinforcement.	Dimidjian et al. (2011, p. 6)	
C	depression	The individual usually suffers from depressed mood, loss of interest and enjoyment, and reduced energy leading to increased fatiguability and diminished activity. Marked tiredness after only slight effort is common. Other common symptoms are: reduced concentration and attention, reduced self-esteem and self-confidence, ideas of guilt and unworthiness (even in a mild type of episode), bleak and pessimistic views of the future, ideas or acts of self-harm or suicide, disturbed sleep, diminished appetite.	(World Health Organization, 2019)	„The individual suffers from depressed mood, loss of interest and enjoyment, and reduced energy.“

Appendix B

Variable definitions and assumptions

Construct	Scale level	Range	Anchors
behavioral activation (ba)	categorical	0 or 1	0 = no BA 1 = BA
Response-contingent positive reinforcement (pos_reinforcement)	continuous	[0, 1]	0 = no response-contingent positive reinforcement 1 = maximal response-contingent positive reinforcement (as someone without depression experiences)
Depression (depression)	continuous	[0, 1]	0 = no depression 1 = maximal depression (right before suicide)

Appendix C

Functional relationships

ID	Considerations	Function
c(A3)	BA = 1: • will lead to an increase of reinforcing activities. • It is assumed that after each session of BA, the pos_reinforcement enhances on such a rate, that after a maximum of 20 a person starting with a "moderate" depression score (0.5) could potentially remit to depression = 0.	BA = 1: pos_reinforcement(sessions) = pos_reinforcement + 0.5/20 * sessions
	BA = 0: • will lead to a further decrease of reinforcing activities over time but not on the same rate as an increase would take place since it's not active but a rather passive process. • "time"-units are operationalized by the number of BA sessions received/not received, assuming they take place in regular intervals.	BA = 0: pos_reinforcement(sessions) = pos_reinforcement - 0.1/20 * sessions
c(B2)	• if pos_reinforcement = 0: depression = 1 • if pos_reinforcement = 1: depression = 0 • if pos_reinforcement = 0.5: depression score about 0.5 (since it seems plausible that the number of positive reinforcements someone without depression experiences is reduced to the half)	depression = 1- pos_reinforcement

Appendix D

Choices for simulating participants

Person Parameter	Definition	Considerations	Chosen distribution
depression	standardized person's depression score	• should be in range [0.2; 1] at the beginning since it needs a certain threshold of depression score to have the need for BA • distribution: assumed that the prevalence of mild or moderate depressions is higher than the one for extreme cases	Firstly, draw a random variable X from a beta-distribution (a = 3, b = 5) and secondly apply a linear transformation to shift the variable into the desired range: X_new = 0.2 + 0.8*X
pos_reinforcement	standardized person's number of positive reinforcing events	• should about align with the definition of the relationship with the depression score: depression = 1-pos_reinforcement • should have invers range to depression: [0, 0.8] • Distribution: invers to the depression one	Firstly, draw a random variable X from a beta-distribution (a = 5, b = 3) and secondly apply a linear transformation to shift the variable into the desired range: X_new = 0.8 * X