Computational Modeling of Therapies related to Cognitive Vulnerability and Coping

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Abstract. Due to recent research, the neurobiological elements behind mental disorders such as depression become more and more clear. This paper presents an integrated computational model based on neurobiological insights and psychological theories. The model is used to analyse the effect of existing psychological treatments. The simulation experiments give an insight in the interaction between different cognitive components in mental disorders and illustrates why different treatments can have different effects for people with different genetic dispositions.

Keywords., Computational Modeling in Therapy, Cognitive Models in Cognitive Vulnerability and Coping, Simulation.

1. Introduction

Cognitive vulnerability and coping are important elements of the explanation of mental disorders, such as depression [4]. More and more, the neurobiological elements behind these disorders become clear. With the increased understanding of these mechanisms, also the possibilities increase to create adequate computational models of mental diseases. Such models can contribute to a better understanding of the mechanism, form a basis for e-mental health applications and can be used for the analysis of the effect of (combinations of) therapies.

In this paper, an integrated computational model is described that uses knowledge about cognitive vulnerability and coping. The model is a combination of two previously developed models and describes the dynamics of the cognitive states over time. A more detailed discussion for both domain models can be found in [1][2]. The integrated model is extended with a sub-model that describes two specific psychological treatments, i.e. Acceptance and Commitment Therapy (ACT), and Rational Emotive Behavioural Therapy (RBET). The combined model is used to analyse the effect of these treatments by performing simulation experiments.

The remainder of the paper is organized as follows. In Section 2, some recent insights about the neurobiological background of mental disorders are reviewed. Based on this, the subsequent section presents the integrated dynamic model of cognitive states related to mental disorders. In Section 4, a sub-model is introduced that describes the treatments. Both are used as basis for simulation experiments and their analysis in Sections 5 and 6. Section 7 concludes the paper

2. Biological Perspectives in Cognitive Vulnerability and Coping

Recent decades have witnessed an explosion of research on neurobiological aspects in mental health. It has become an important approach to unlock the mystery of mental disorders. In the neurobiological area important relationships between cognitive, behaviours, affective, and neurobiological underpinnings can be grounded. For example, negative appraisals of stressors lead to the release of cortisol and increase the vulnerability for depression. Cortisol has a vital role in shutting down the sympathetic function and to suppress the hypothalamus pituitary-adrenocortical (HPA) activities by a negative feedback mechanism on the hippocampus, amygdala, and pituitary and plays an important role to restore normal hormone levels [6]. Therefore, any dysregulation of the HPA implies that cortisol is inhibiting the peripheral nervous system to maintain physiological homeostasis. Another important concept to explain cognitive vulnerability is the cumulative burden borne by a brain and body adapting to stress (*allostatic load*) [9]. From this stand, it is predicted that the individual with active HPA activities and locus coeruleus-norepinephrine system (a nucleus in the brainstem involved with physiological responses to stress) will have the highest risk for allostatic load, and increased the risk of cognitive vulnerability towards stress. Reconsolidation is another biological process that relevant to cognitive vulnerability to the effects of extreme stress. It explains how old and reactivated memories can be integrated into an ongoing perceptual and emotional experience and becomes part of new memory [6]. Moreover, several clinical studies indicate that the consolidation process in amygdala and hippocampus are sensitive to disruption upon reactivation of several protein synthesis inhibitors.

In the coping styles literature it is shown that the magnitude of neuro-endocrine stress response depends on whether the stressor is appraised as threatening or as challenging. Threat appraisals are more strongly associated with prolonged higher reactive levels of cortisol (increased reactivity), while challenge appraisals are characterized by rapid cortisol responses with quick recovery [5][9]. Additionally, although the effective use of emotional-focused coping may dampen the endocrine stress response by not getting overwhelmed by negative affects, it will only work on the short time, where it is related to the sustained levels of cortisol and sympathetic activation. In the long term, the sustained activation will result in physiological and affective problems. Coping is also related to the several active brain regions, where evidence is accumulating that coping is a part of the overall set of executive functions that regulated by the prefrontal cortex [6]. For example, problem focused coping strategies were related to the inhibitory control activities, and emotional-focused coping shown a poorer inhibition result [5].

Specifically, from both cognitive vulnerability and coping concepts, we can see several common aspects that each concept has important interplay with one to another. This interplay can be seen through the activities in HPA, cortisol, and also several brain regions activation. In a cognitive model perspective, this biological interaction can abstractly be seen in several important theories to explain cognitive vulnerability and coping process, namely; *(1)* Extended Hopelessness Theory of Depression and *(2)* Cognitive Motivational Relational Theory [8][13].

3. A Model for Cognitive Vulnerability and Coping

The model used in this paper is a combination of two previously developed models to explain the dynamics in human vulnerability towards stress and coping skill strategies. The detailed discussion for both domain models can be found in [1][2]. Figure 1 depicts the interaction of these two models.

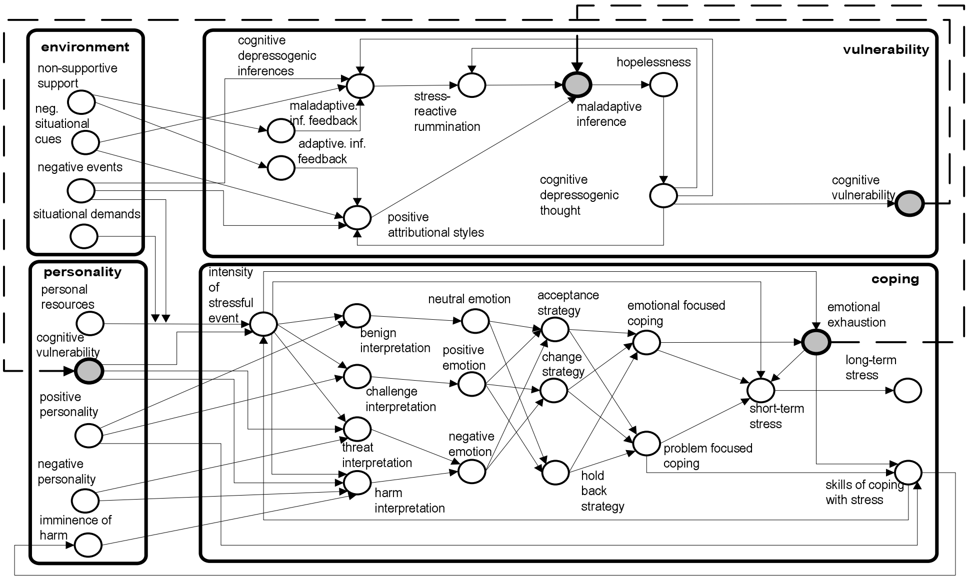

Figure. 1. The Integrated Domain Model of Cognitive Vulnerability and Coping Skills

3.1 Concepts in Cognitive Vulnerability & Coping

The cognitive vulnerability model has been developed based on the *Extended Hopelessness Theory of Depression*. In this theory, people who exhibit a negative inferential style, in which they describe, negative events (*NeV*) to stable and will affect many aspects of life will most likely to infer themselves as fundamentally useless [7]. One of the important concepts from this theory is the analysis on how social support mitigates a risk of relapse (positive feedback (*AiF*)), and indirectly escalates the risk of relapse (maladaptive inferential feedback (*MiF*)), related to negative reflection of received support (*NsP*) [7]. By combining either one of these two factors together with situational cues, it leads to the formation of either cognitive depressogenic inferences (*CdI*) or positive attributional styles (*PtS*) [5]. Situational cues (*SiC*) refers to a concept that explains individuals' perception that highly influenced by cues from events (environment) [11]. These later develop where individuals have trouble in accessing positive information (stress-reactive rumination (*SrR*)), and further increase a negative bias towards future inference (maladaptive inference (*MdI*)) [7][11]. After a certain period, both conditions are related to the development of hopelessness (*HpS*), and later will lead to the development of cognitive depressogenic thought (*CdT*) and cognitive vulnerability (*CoV*) [8].

In a coping model, the *Cognitive Motivational Relational Theory* (CMRT) is used [13]. Several factors such as *situational demands* (*SiD*), *personal resources* (*PrA*), and *negative events* play important roles to influence perception towards incoming stressors (*IsE*) [4]. Normally, a person appraises two types of appraisals; the primary and the secondary. The primary appraisal is made to evaluate person's well being. Firstly, the situation can be appraised either as harm/loss (*HrM*), threatening (*ThT*), challenging (*ChL*) or benign (*BgN*). Later this process will determine individuals' emotion perception; negative *(NgE),* positive *(PsE)* or neutral *(NuE)* emotion [13]. Negative emotion is related to perceiving *harm* and *threat*, neutral emotion is corresponded to *benign* condition and positive emotion is attributed to perceiving *challenge*. Secondly, a person evaluates whether he or she has the resources to deal with the stressors. It is commonly related to the emotional attribution, where a positive and neutral emotion results in *acceptance (AcP)* and *change (ChG)*, while the negative emotion triggers *holdback* (*HdB*) [2]. Later, it will lead to the *problem* (*PrF*) and *emotion-focused coping (EmF)*. A problem-focused coping is associated with rational efforts to get the problem solved, while emotion-focused coping strategies entail efforts to regulate the emotional consequences of stressful events [14]. All these strategies can be proven useful, but many individuals feel that in a long run, emotion focused coping is associated with outcomes that people found unsatisfactory (emotional exhaustion in coping (*ExH*)) that later will develop short (*StS*) and term stress (*LtS*). Problem focused coping is associated with satisfactory outcomes (improved coping skills *(ScS)*[13].

4. Modeling Therapies for Cognitive Vulnerability and Coping

In this section, it shown how the influences of selected therapies (Acceptance and Commitment (ACT), and Rational Emotive Behavioural (RBET) Therapy) are modelled in the extended model presented in Section 3. First, important concepts in evaluating cognitive vulnerability and coping will be discussed, followed by ACT and RBET.

4.1 Important Concepts in Evaluating Cognitive Vulnerability and Coping

One of the very imperative features to verify the level of related conditions such as cognitive vulnerability and long-term stress is the continuous evaluation of changes in selected physiological and behavioural features within the individual. Using the domain model, the development of the vital features is analyzed and predicted. These features provide the dynamic relationships in the model. For example, the observable feature in a long-term stress can be related from the accumulation of short-term stress states and so forth [2]. There are several important concepts need to be measured, namely; long-term stress (*LtS*), emotional exhaustion (*ExH*), cognitive vulnerability (*CoV*), and coping skills (*ScS*). These concepts are calculated as follows:

$$LtS(t+\Delta t)=LtS(t)+\beta_l.[\text{Pos}(StS(t)-LtS(t)).(1-LtS(t))- \text{Pos}(-(StS(t)-LtS(t))).LtS(t)].\Delta t. \quad \textbf{(1)}$$

$$ExH(t+\Delta t)=ExH(t)+\psi_e.[(\text{Pos}((IsE(t)-ExH(t)).(1-ExH(t)))- \text{Pos}(-(IsE(t)-xH(t)).ExH(t))].EmF(t).\Delta t. \quad \textbf{(2)}$$

$$ScS(t+\Delta t)=ScS(t) + \phi_s.[\text{Pos}(ExH(t) - ScS(t)). (1-ScS(t))- \text{Pos}(-(ExH(t)–ScS(t)).ScS(t)].PrA(t).\Delta t \quad \textbf{(3)}$$

$$CoV(t+\Delta t)=CoV(t) + \upsilon_c.[\text{Pos}(CdT(t) - CoV(t)). (1-CoV(t))- \text{Pos}(-(CdT(t)–CoV(t)).ScS(t)].\Delta t. \quad \textbf{(4)}$$

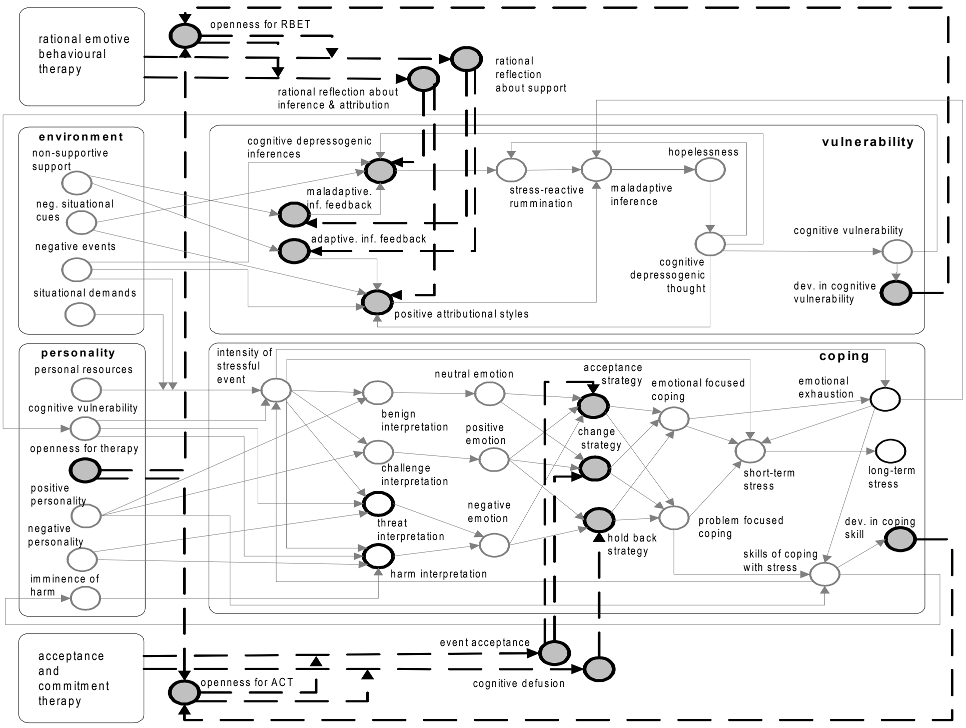

Figure 2. The Integrated Model in an Agent Based Therapy for ACT and RBET

The rates of change for all temporal relationships are determined by flexibility parameters β_l, ψ_e, ϕ_s, and υ_c respectively. The operator Pos for the positive part is defined by Pos$(x) = (x + |x|)/2$, or, alternatively; Pos$(x) = x$ if $x \geq 0$ and 0 else.

4.2 Intervention for Acceptance and Commitment, and Rational Emotive Behavioural Therapy

In this section it is shown how the influences of two types of therapies are modeled in the extended model presented in Section 3. First, acceptance and commitment therapy will be discussed, followed by rational behavioural emotive therapy. Figure 2 shows an overview of the relevant states and dynamics in the model. The states that are depicted in grey represent states have been added and corresponded to model the points of impacts in therapies. The same holds for the dashed lines. In this model, openness for therapy (*OfT*) is a state indicating how open the individual is for therapy, which is made specific for each particular influence of therapy, namely openness for ACT (*OfA*), and openness for RBET (*OfR*). Furthermore, the development in coping skills (*DeC*) and cognitive vulnerability (*DeV*) will influence openness for ACT, and RBET respectively.

$$OfA(t) = OfT(t).DeC(t). \quad \textbf{(5)}$$

$$OfR(t) = OfT(t).DeV(t). \quad \textbf{(6)}$$

Acceptance and Commitment Therapy: Fundamentally, ACT emphasizes such processes as mindfulness, acceptance, and values in helping individuals overcome obstacles in their lives. There are three core processes in ACT, however; only two processes (*cognitive defusion* and *acceptance*) are discussed here to change individual's coping preference [12]. Cognitive defusion (*CgD*) (means "detach from unhelpful thoughts and worries" and event acceptance (*EvA*) deals with reducing the effort to avoid certain situations (where discerning between thoughts, feelings, and experiences is a prominent focus) [12]. The effects from these processes will allow more acceptance and change strategies to take place in coping. This can be expressed as follows:

$$AcP(t) = \zeta_a.[\gamma_a.PsE(t) + (1-\gamma_a).NuE(t)].[1-((1-IeA(t)).NgE(t))] + (1-\zeta_a).IeA(t). \quad \textbf{(7)}$$

$$ChG(t) = \upsilon_g.[PsE(t).(1-((1-IcD(t)).NgE(t))] + (1-\upsilon_g).IcD(t). \quad \textbf{(8)}$$

$$HdB(t) = \zeta_h.[(1-PsE(t).(1-IcD(t)] + (1-\zeta_h).(1-IcD(t)). \quad \textbf{(9)}$$

where, $IeA(t) = EvA(t).\ OfA(t),$ and $IcD(t) = CgD(t).OfA(t)$.

Rational Behavioural Emotive Therapy: REBT suggests that human beings defeat themselves in two main ways: (1) by holding irrational beliefs about their self (ego disturbance), (2) by holding irrational beliefs about their emotional, or social comfort (discomfort disturbance) [3]. Therefore the RBET identifies those problematic ideas, and replaces them with more rational perspectives (such as positive perspectives to self attribution (*RtS*), and provided support (*RtO*)) [3]. As a result from this intervention process, it will restrain the progress of future irrational beliefs, and later provides effective new thinking on individual experienced conditions. The intervention effects are calculated as follows.

$$MiF(t) = NsP(t).(1-ItO(t)). \quad \textbf{(10)}$$

$$AiF(t)= (1-((1-ItO(t)).NsP(t))). \quad \textbf{(11)}$$

$$PtS(t) = [\eta_p.AiF(t) + (1-\eta_p).\ (1-\ (SiC(t).DyT(t).NvT(t).(1-ItS(t)))].AiF(t). \quad \textbf{(12)}$$

$$CdI(t)=[\alpha_c.MiF(t) + (1-\ \alpha_c).\ SiC(t).DyT(t).MiF(t)].(1-ItS(t)).NeV(t). \quad \textbf{(13)}$$

where, $ItO(t) = RtO(t).\ OfR(t)$ and $ItS(t) = RtS(t).OfR(t)$.

Here parameters, $\zeta_{a,}$ γ_a, υ_g, $\zeta_{h,}$ α_c and ψ_b represent the proportional factor for all respective instantaneous variables.

5. Simulation Results

In this section, simulation results are presented. The intervention as described in the previous section has been implemented in simulation environment. To this end, software to generate simulation traces was developed in Matlab. Using this simulation environment, we mimicked the intervention process to see its effect under several cases. Three fictional individuals are studied with divergent values for personality attributes. These values are chosen to depict the different influences of the therapies on different types of individuals. Table 1 shows the values for the most important variables of the model for each individual.

Table 1. Personality Attributes for the Simulation Experiments

Personality Attributes \ Individuals	*A*	*B*	*C*
Positive Personality	0.2	0.5	0.8
Personal Resources	0.1	0.3	0.7
Openness for Therapy	0.7	0.7	0.7
Situational demands, Situational Cues, Negative Events, and Situational demands	0.9	0.9	0.9

In all cases, the long term stress, emotional exhaustion, cognitive vulnerability, and coping skill value are initialized at 0.3. These simulations used the following parameters settings: t_{max}=1000 (to represent a monitoring activity up to 42 days), Δt=0.3, all proportional and flexibility rates are assigned as 0.5 and 0.3 respectively. These settings were obtained from several systematic experiments to determine the most suitable parameter values in the model. . For the sake of brevity, this section will only discuss the results of individual *A*. First, the simulation without any form therapy is shown (Figure 3(a)).

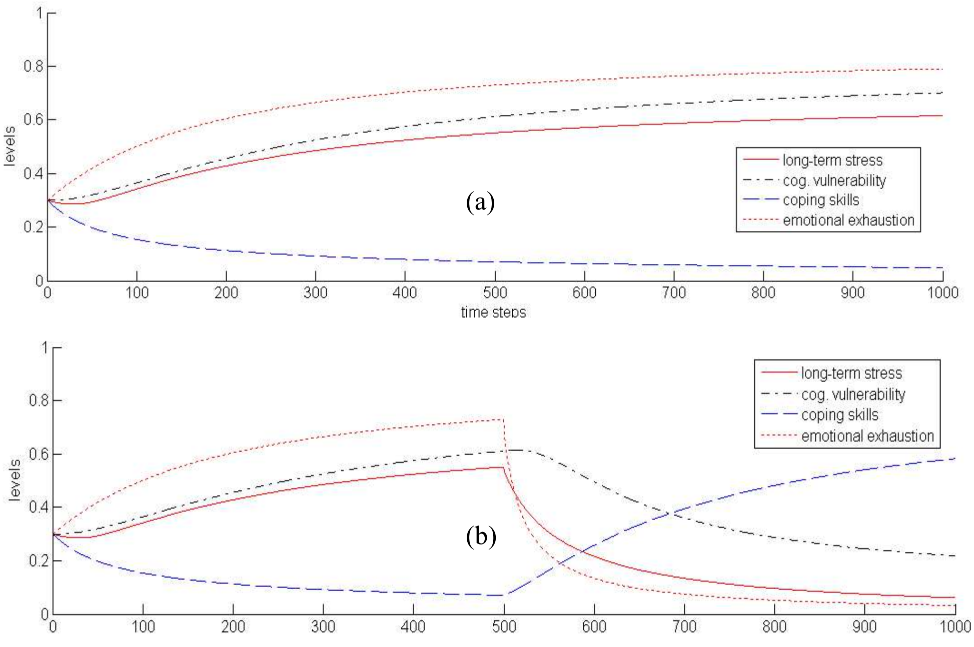

Figure 3. Individual type *A* (**a**) Without Following Any Therapy, (**b**) following the ACT therapy

The individual experiences very negative events during monitoring period. Since the individual is susceptible towards stress (low coping skills and highly vulnerable), a long-term stress follows [4][8]. Later it will lead an individual to fall into depression. For the second experiment; individual *A* is receiving the ACT therapy (Figure 3(b)). For this case, it can be seen that the long-term stress, cognitive vulnerability, and emotional exhaustion are decreased. In addition to this, it increases individual's ability to cope as well [13]. For the RBET, the same types of experiments have been conducted. Figure 4 shows the result from following this therapy.

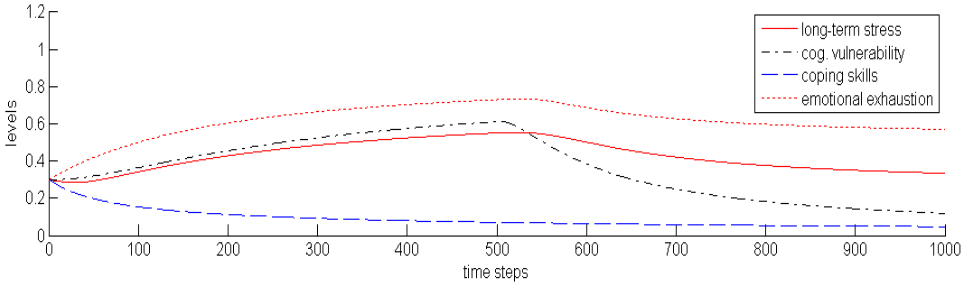

Figure 4. Individual type *A* following the RBET therapy

In this case, individual *A* experiences slow recovery in long-term stress and emotional exhaustion, and a rapid recovery from cognitive vulnerability. Another variability is used for the experiment is assigning different openness level for individual *A*. If the openness towards therapy is increased, the individual *A* recovers more quickly compares to lower openness values. In the case of individual *B*, for all three conditions, individual *B* recovers faster compares to individual *A*. Meanwhile individual C receives a very low negative effect from the incoming stressors, and manages to recover even without receiving any therapy [4]. In addition to these experiments, when an individual *A* follows both therapies in the same time, it shows a slightly faster recovery than following only a single therapy.

6. Automated Verification

In order to verify whether the model indeed generates results that adherence to psychological literatures, a set of properties have been identified from related literatures. Therefore, these properties will answer whether the model produces results that are coherent with the literature and appropriate to help people with cognitive vulnerability and coping problems, To allow the verification process to take place, these properties have been specified in a language called Temporal Trace Language (TTL). TTL is built on atoms referring to states of the world, time points, and traces. This relationship can be presented as a state(γ, t, output(R)) |= p, means that state property *p* is true at the output of role *R* in the state of trace γ at time point *t* [16]. It is also comparable to the *Holds*-predicate in the Situation Calculus. Based on that concept, dynamic properties can be formulated using a sorted predicate logic approach, by manipulating quantifiers over time and traces and first-order logical connectives such as ¬, ∧, ∨, ⇒, ∀, and ∃. A number of simulations including the ones described in Section 4 have been used as basis for the verification and were confirmed.

VP1: Effectiveness of ACT in problem focused coping
After a person has followed the ACT therapy for some times, the problem focused coping skills have improved.

VP1 ≡ ∀γ: TRACE, ∀t1, t2:TIME, ∀R1,R2,D1,D2:REAL
[state(γ,t1) |= has_value(ACT_therapy, R1) &
state(γ,t2) |= has_value (ACT_therapy, R2) &
state(γ,t1) |= has_value(problem_focused_coping, D1) &
state(γ,t2) |= has_value(problem_focused_coping, D2) &
t1 < t2 & R2 > R1] ⇒ D2 ≥ D1

VP2: Problem focused coping helps a person to recover faster than emotional focused coping

A problem focused coping skill is a better option compares to an emotional focused coping skill in a long -term recovery.

VP2 ≡ ∀γ: TRACE, ∀t1, t2:TIME, ∀M1,M2, D1, D2:REAL
[state(γ,t1) |= has_value(problem_focused_coping, M1) &
state(γ,t1) |= has_value(emotional_focused_coping, M2) &
state(γ,t1) |= has_value(long_term_stress, L1) &
state(γ,t2) |= has_value(long_term_stress, L2) &
t1 < t2 & M1 > M2] ⇒ L1 > L2

VP3: Effect of cognitive vulnerability towards long term stress

Reducing the cognitive vulnerability level will reduce the risk of future long term stress

VP3 ≡ ∀γ: TRACE, ∀t1, t2:TIME, ∀F1,F2,H1,H2, d:REAL
[state(γ,t1) |= has_value(cog_vulnerability, F1) &
state(γ,t1) |= has_value(cog_vulnerability, F2) &
state(γ,t1) |= has_value(long_term_stress, H1) &
state(γ,t2) |= has_value(long_term_stress, H2) &
t2 ≥ t1 + d & F1< F2] ⇒ H2 < H1

VP4: ACT results in higher recovery in stress than RBET

After a person has followed ACT, the long-term stress is lower than after following RBET

VP4 ≡ ∀γ1, γ2: TRACE, ∀t1,t2:TIME, ∀M1,M2,L1,L2, d:REAL
[state(γ1,t1) |= has_value(ACT_therapy, M1) &
state(γ2,t1) |= has_value(RBET_therapy, M2) &
state(γ1,t2) |= has_value(long_term_stress, L1) &
state(γ2,t2) |= has_value(long_term_stress, L2) &
t2 ≥ t1 + d & M1 =1 & M2=1] ⇒ L1 < L2

7. Discussion

Because of the increased insights in the neurobiological basis of mental disorders, it is possible to make more detailed models of these disorders. In this paper, an integrated model that relates cognitive vulnerability and coping strategies has been presented. The model has been described in a computational software package, which allows performing simulation experiments that describe the development of the different factors over time. The simulation experiments that have been presented give an insight in the interaction between different cognitive components in mental disorders. It also shows that ACT therapy is more effective for improving coping skills, while RBET therapy has the largest effect on the factors related to cognitive vulnerability. Due to the interaction of the concepts, both therapies will contribute to less stress. The experiments suggest that there is a only limited added value in combining both therapies.

The model presented in this paper is based on neurobiological and psychological theoretical knowledge. Further research is required to investigate to what extent the simulations give an adequate description of actual development in persons with mental disorders. Based on questionnaires or continuous assessments using modern ICT tools such as mobile phones, the development of mood and stress of actual people could be monitored. The outcome of these experiments can be used to validate and tune the presented model. The validated models can be used as basis for e-mental health applications that guide patients and suggest the best interventions by predicting their effect.

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