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RESEARCH ARTICLE

Modeling the effect of regulation of negative emotions on mood

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Abstract
In this paper a computational model is presented that describes the role of emotion regulation to reduce the influences of negative events on mood. Emotion regulation is a process based on a set of regulatory strategies used by persons to down-regulate their negative emotions or to up-regulate their positive emotions. For a given situation, the selection of specific regulation strategies is dependent on that particular situation. The current paper presents work focusing on a cognitive reappraisal (re-interpretation) strategy, that involves changing the way one interprets a stimulus or situation, or alter the semantic representation of an emotional stimulus in order to reduce the influence of such stimuli. The model incorporates an earlier model of mood dynamics and a model for the dynamics of emotion generation and regulation. Example model simulations are described that illustrate how adequately emotion regulation skills can avoid or delay development of a depression. The presented computational analysis shows how regulation of stressful emotions helps unstable persons to avoid a depression, and to postpone it in very unstable persons. Furthermore, the analysis shows that if a stressful event persists for a longer time period, then emotion regulation can also help an unstable person to prevent the mood level from becoming too low, for a certain time.

Introduction

Emotions were traditionally seen as neural activation states without function (Hebb, 2002). However, relevant research provides evidence that emotions are functional (Damasio, 2000; Oatley & Johnson-laird, 1987) and provide

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information about the ongoing mutual interaction between a human being and his or her environment (Schwarz & Clore, 1983). Moreover, emotions have a strong impact on the way we interact with the social world (Gross, 2015). In addition to the theories that exist in social psychology, in recent neurological literature many contributions (e.g., Damasio, 2000; Schwarz & Clore, 1983) can be found about the relation between emotion and brain functioning. For example, emotional responses relate to activations in the brain within the limbic centers (generating emotions), and cortical centers (regulating emotions); e.g., Dalgleish (2004) and Papez (1937). Previously, emotions were often left out of cognitive models; however, since awareness is increasing that emotions play a vital role in human life, nowadays cognitive models are developed that include the generation and regulation of emotions as well. A useful basic theory for the latter is Gross theory about how individuals regulate the emotions they have, when they have them and how they experience and express them (Gross, 1998).

Emotions are different from mood, and emotion regulation is different from mood regulation (Gross, 1998; Gross, 2001). Emotions are instantaneous in nature and are specific reactions to a particular event, usually for a short period of time. Emotions help us to set priorities in our lives, taking initiatives in changing situations or making decisions based on how we feel, whether we are happy, angry, frustrated, bored or sad. In psychology, emotion regulation is considered as an important aspect in the context of generation of human behavior (Gross, 2015). Recent literature shows that emotion regulation is gaining attention from a variety of biological and cognitive disciplines (Hartley & Phelps, 2010; Miller, Rodriguez, Kim, & McClure, 2014), as well as from social and health related areas (DeSteno, Gross, & Kubzansky, 2013; Shaver & Mikulincer, 2014). Emotion regulation describes how a subject can use specific strategies to affect the emotional response levels.

Mood, on the other hand, is a more general feeling such as happiness, sadness, frustration, or anxiety that exists for a longer period of time (Gross, 2015; Larsen, 2000). Mood regulation usually involves the deliberate choice of mood-affecting activities, such as pleasant activities (Cuijpers, van Straten, & Warmerdam, 2007). Moods tend to have less definite behavioral response tendencies than emotions; therefore, mood regulation may be distinguished from emotion regulation by its predominant focus on changing subjective feeling states (Larsen, 2000). It has been found that recurring events triggering stressful emotions have a bad influence over time on mood and can easily lead to depression when subjects are vulnerable to that (Kessler, 1997; Monroe & Harkness, 2005).

The current paper is based on an extension of material presented earlier in (Abro, Klein, Manzoor, Tabatabaei, & Treur, 2014). In this paper, a computational model is introduced that combines the short-term emotional reaction on stressful events with the long-term dynamics of mood. The model is based (1) on an existing model for mood dynamics (Both, Hoogendoorn, Klein, & Treur, 2008; Both, Hoogendoorn, Klein, & Treur, 2015) and (2) on the theory of emotion regulation introduced by (Gross, 1998; Gross, 2001; Gross, 2002). Various simulation experiments have been performed to analyse how the process of emotion regulation can help persons maintain a healthy mood in case of the occurrence of stressful events that recur from time to time or even continuously.

The paper is organized as follows. First, some background information about the mood model and the process of emotion regulation presented. Then, the integrated model is explained in detail. In Section 'Simulation Results' simulation results are provided to show the influence of stressful events in different scenarios, thereby providing evidence for the feasibility of the model. The next section is a discussion. Finally, the last section concludes the paper.

Background on emotion regulation and mood dynamics

The model presented in this paper adopts Gross' theory of emotion regulation and an existing model of mood dynamics (Both et al., 2008; Both et al., 2015). Both elements are introduced here briefly.

Emotion regulation

Controlling emotions or regulating them is often related to the suppression of an emotional response, for example, expressing a neutral poker face. This kind of regulating emotions is sometimes considered not very healthy, and as a risk for developing serious kinds of health problems. However, it has been found that the strategies to regulate emotions are much more varied. For example, closing or covering your eyes when a movie is too scary, or avoiding an aggressive person are other forms of emotion regulation mechanisms (Goldin, McRae, Ramel, & Gross, 2008; Gross, 2002). In daily life, decreasing negative emotions seems as the most common form of emotion regulation. Also in the literature, emotion regulation is often described as the process to down-regulate negative emotions, and particularly much attention has been paid towards reduction of the experiential and behavioral aspects of sadness, anger and anxiety (Richards & Gross, 2006). On other hand, there has also been a particular focus on the feelings of love, interest, and joy to up-regulate positive emotions (Quoidbach, Berry, Hansenne, & Mikolajczak, 2010).

In recent literature on emotion regulation, another distinction has been made by Gross (2014). Emotion regulation is further classified according to two broad categories. The first one is called internal emotion regulation (intrinsic emotion regulation): when such people who have the objective to regulate their own emotions. The other category is named external emotion regulation (extrinsic emotion regulation): when a person has the objective to regulate another person's emotions (Bloch, Haase, & Levenson, 2014; Levenson, Haase, Bloch, Holley, & Seider, 2014; Zaki & Williams, 2013). The current paper focuses on the first category.

The framework originally introduced by Gross describes how emotions can be regulated or controlled in different phases of the process when emotions are generated (Gross, 1998). Gross distinguishes cognitive regulation of emotions, which occurs relatively early in the emotion generation process (e.g., re-interpretation) and behavioral regulation of emotions, that happens relatively late in the emotion generation process (e.g., suppression).

Over a longer period of time several strategies for emotion regulation have been described in the literature. In general, they are classified into two major categories. The first category covers the *antecedent-focused strategies* that can be used before an emotional response has an effect on the behavior. In this category of emotion regulation, emotions may be regulated at four different points in the emotion generation process (a) selection of the situation, (b) modification of the situation, (c) deployment of attention, and (d) change of cognition. The second category is formed by the *response-focused strategies*, which can be used in situations where the emotion response already is coming into effect; this is also called modulation of responses (Gross, 1998).

Cognitive reappraisal (re-interpretation) is an emotion regulation strategy that involves changing the way one interprets a stimulus or situation in order to change its affective impact. Reappraisal involves the use of cognitive control to modulate semantic representations of an emotional stimulus, and these altered representations in turn attenuate activity in the amygdala (Buhle et al., 2013).

In the current paper, the focus is on antecedent focused strategies, in particular re-interpretation of world information by belief change.

Modeling emotion regulation

Based on the theory of emotion generation and regulation described above, a computational model of emotion regulation has been introduced (Manzoor & Treur, 2013) and applied in the context of social contagion and decision making. More details about this model can be found in (Manzoor & Treur, 2015). However, here a brief summary of these concepts and their dynamics is given. As illustrated in the dashed box in the upper part of Fig. 1 the following concepts play their part in the model: control state *cs*, beliefs *bel*, feeling *feel*, preparation *prep*, and sensory representation state *srs*. The aim of the model is to describe how negative beliefs and feelings are generated, and how more positive beliefs can be generated to regulate the negative feelings. The model is inspired by a number of neuroscientific theories such as Kim et al. (2011), Phelps, Delgado, Nearing, and Ledoux (2004), Sotres-Bayon, Bush, and LeDoux (2004), and Yoo, Gujar, Hu, Jolesz, and Walker (2007). From fMRI experiments it has been found that emotion regulation occurs through the interaction between prefrontal cortex and amygdala. Here less interaction or weak connections between amygdala and prefrontal cortex leads to less adequate emotion regulation; e.g., Kim et al. (2011).

In the considered scenario, the sensory representation srs(w) of a world state w is associated both with a negative and a positive belief, as a basis for two different interpretations of the same world information. They suppress each other by a form of inhibition. Only the negative belief has a connection with the preparation for a negative emotional response prep(b) with b a type of (negative) emotion. The feeling state, feel(b), has an impact on this preparation state, prep(b), which in turn has an impact on feeling state, feel(b), through the sensory representation state, srs(b), for bodily expression of emotion b, which makes it recursive; this is called an as-if body loop in the literature (e.g., Damasio, 2000).

Often people respond to stressful events in different ways, depending on the type of event and on the emotion

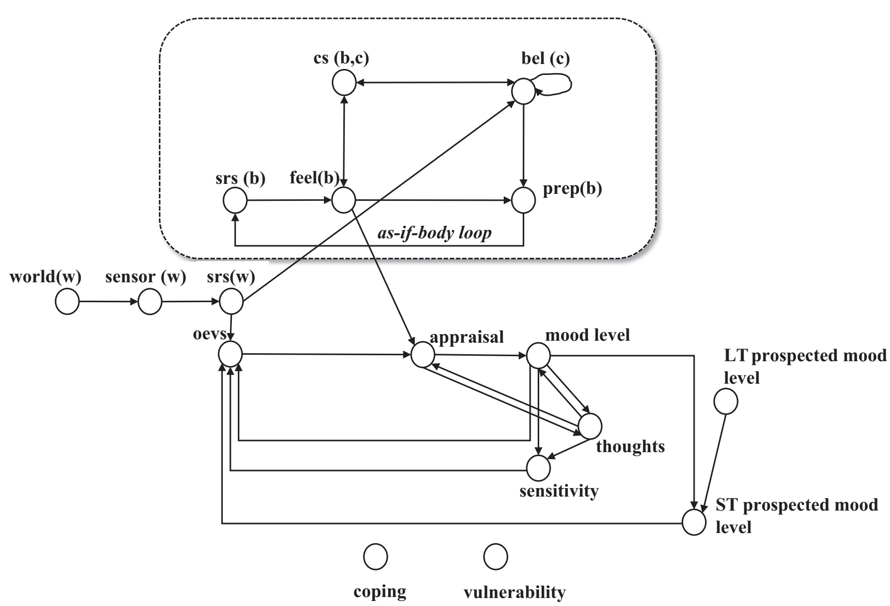

Fig. 1 The integrated model: emotions about stressful events and their influence on mood. Here the dotted box indicates the integrated emotion generation and regulation process, and the part below that box shows the model for mood dynamics. Furthermore, srs = sensory representation state, cs = control state, bel = belief, prep = preparation, feel = feeling, oevs = objective emotion value of situation (for more details, see Table 1).

regulation strategies they choose. Much literature regarding emotion regulation can be found and a number of dynamic models have been proposed, which focus on the person and the situation in which they interact over time to make alteration or adapt change (Bonanno & Burton, 2013). In the model presented here, antecedent focused emotion regulation addressing reappraisal in particular is achieved by the interplay of three states cs(b, c), bel(c), feel(b), where c is a specific belief and b is a specific type of emotion. Negative weights are assigned to the connections from the control state, cs, to negative beliefs, bel(c), and negative feelings, feel(b). Positive weights are assigned to connections in the opposite direction which take care of monitoring of the feelings.

In the example scenarios, only two beliefs are taken into account: a positive belief which may associate to good feeling and a negative belief which is related to a negative (or stressful) feeling; for the sake of simplicity there is only one negative feeling state in the scenarios. A control state is used to determine whether an unwanted emotion through a negative belief has occurred (as a form of monitoring, happening in the prefrontal cortex). If so, by becoming activated, the control state suppresses these negative effects. Furthermore, as they concern opposite interpretations of the world information, both beliefs inhibit each other, which is modeled by assigning negative weights to their mutual connections.

In the literature (Gross & Barrett, 2011), emotion generation and emotion regulation are sometimes considered as overlapping in one process. In the model introduced here on the one hand both sub processes (emotion generation and regulation) are clearly distinguished, on the other hand, by the cyclic connections between them and the dynamics created by these cycles, the processes are fully integrated into one process.

Modeling mood dynamics and depression

The model of mood dynamics is depicted in the lower part of Fig. 1. The main concepts include the *mood level*, *appraisal* and *coping skills* of a person, and how the levels for these states affect the external behavior in the form of selection of situations over time (*objective emotional value of situation*). The model is based upon a number of psychological theories; see (Both et al., 2008; Both et al., 2015) for a mapping between the literature and the model itself.

In the model, a number of states are defined, whereby to each state at each point in time a number (activation level) on the interval [0, 1] is assigned. First, the state *objective emotional value of situation* represents the value of the situation a human is in (without any influence of the current state of mind of the human). The state *appraisal* represents the current judgment of the situation given the current state of mind (e.g., when you are feeling down, a pleasant situation might no longer be considered pleasant). The *mood level* represents the current mood of the person, whereas *thought* indicates the current level of thoughts (i.e., the positivism of the thoughts). The *long term prospected mood* indicates what mood level the human is striving for in the long term, whereas the *short term prospected mood level* represents the goal for mood on the shorter term (in case you are feeling very bad, your short term goal will not be to feel excellent immediately, but to feel somewhat better). The *sensitivity* indicates the ability to select situations in order to bring the *mood level* closer to the *short term prospected mood level*. *Coping* expresses the ability of a human to deal with negative moods and situations, whereas *vulnerability* is the opposite: how vulnerable the person is for negative events and how much impact that structurally has on his mood. *Coping* and *vulnerability* have an influence on all internal states except the prospected mood levels, but in Fig. 1, those arrows are left out for clarity reasons. Finally, *world event* indicates an external situation which is imposed on the human (e.g., losing your job). A short definition of each state and its role is explained in Table 1. In Section 2.1 of Both et al. (2015) more technical details of this model for mood dynamics can be found.

Integrated model

The integrated model describes how the emotion generation and regulation mechanisms influence the mood dynamics. It describes how specific stressful events generate specific instantaneous negative feelings, which have a negative effect on the (subjective) appraisal (also called sevs — subjective emotional value of the situations of the person) of the more general situations of the person and thus on the mood. When emotion regulation is taking place, the instantaneous feelings will be less negative and thus reduce the influence of the stressful events on the mood. To implement this principle in the model, a connection from the negative feeling in the regulation model to appraisal state in the mood model is introduced. The purpose of this connection is to model the effect of negative but short term feelings on the (longer term) mood. In the model, only negative feelings are considered. For beliefs, there is both a positive and a negative variant. The world(w), sensor(w), srs(w) states may lead to either the negative or the positive belief (represented as bel(c1) and bel(c2) here), as alternative interpretations of the same world information. These belief states may have different activation values over time. Initially one can have a high value and the other one a low value. But over time the high value can become lower (due to the emotion regulation mechanism), whereas the low value becomes higher and eventually becomes dominant over the other value. This is how a belief change process is shown in the simulations. Recall that a short definition of each state and its role is explained in Table 1.

Simulation results

In this section, example simulation results are presented that show how emotion regulation can help to change bad beliefs and feelings into more positive beliefs and feelings, and thus protects the mood against stressful events. First, some details of the model design and its implementation and the parameter values used are described.

As mentioned, for the model of mood dynamics (the lower part of Fig. 1) an existing model described

Table 1 Definition of the states of the model.

Domain	Formal name	Description
Environment	World (w)	**World state w**: This state characterizes the current world situation which the person is facing. A situation can be an event or series of events one has no control over, or that are chosen or influenced by the person
Mood Model	Oevs	**Objective emotional value of situation**: The objective emotional value of situation (oevs) represents how an average person would perceive the situation
	Appraisal	The current judgment of the situation given the current state of mind (e.g., when you are feeling down, a pleasant situation might no longer be considered pleasant)
	Mood level	The complex notion of mood is represented by the simplified concept *mood level*, ranging from low, corresponding to a bad mood, to high, corresponding to a good mood
	Thought	The mood level influences and is influenced by *thoughts*. Positive thinking has a positive effect on the mood and vice versa
	Sensitivity	This state concerns the ability to change or choose situations in order to bring the mood level closer to prospected mood level. A high sensitivity means that someone's behavior is very much affected by thoughts and mood, while a low sensitivity means that someone is very unresponsive
	ST prospected mood LT Prospected mood	**Short-term and long-term ST Prospected mood**: The mood level someone strives for, whether conscious or unconscious is represented by *prospected mood level*. This notion is split into a *long term (LT) prospected mood level*, an evolutionary drive to be in a good mood, and a *short term (ST) prospected mood level*, representing a temporary prospect when mood level is far from the prospected mood level
	Coping	This state concerns constantly changing cognitive and behavioral efforts to manage specific external and/or internal demands that are appraised as taxing or exceeding the resources of the person The term *coping* represents the skills one has to deal with negative moods and situations
	Vulnerability	Having a predisposition for developing a disorder. Persons with high vulnerability for depression will use thoughts mostly to downregulate their appraisal, whereas balanced persons will consider their appraisal as similar to the OEVS and their thoughts
Emotion generation	Sensor(w)	**Sensor state for w:** The person observes the world state through the sensor state, which provides sensory input
	srs(w)	**Sensory representation of world state w**: Internal representation of sensory input
	srs(b) feel(b)	**Sensory representation of body state b**, and **Feeling associated to body state b**: Before performing an action, a feeling state feel(b) for the action is affected by a predictive as-if body loop, via the sensory representation state srs(b). This gives a sense of valuing of a prediction about the action before executing an action to perform it. Here b is embodying the associated emotion. In the considered scenarios b is a negative emotion
	bel(c)	**Belief**: Interpretation of the world information; in the case of different interpretations for the same world information, they may suppress each other
	prep(b)	**Preparation for an action involving b**: Preparation for a response involving body state b
Emotion regulation	cs(b,c)	**Control state of reappraisal of belief c to avoid feeling b**: This control state is monitoring beliefs and associated feelings, to determine whether an unwanted, negative emotion through a belief has occurred. If so, by becoming activated the control state suppresses this belief, which gives the opportunity for alternative beliefs to become dominant

in Both et al. (2008) is used. The numerical details of this part of model are given in Section 2.1 of Both et al. (2015).

In the emotion regulation model, the activation level of a state is determined by the impact of all the incoming connections from other states thereby being multiplied by their corresponding connection weights. In the simulations, the connection weights were set at the following values:

$w_{worldstate\_sensor}$	1.0
$w_{sensor\text{-}srsw}$	1.0
$w_{srsw\text{-}PosBel}$	0.4
$w_{srsw\text{-}NegBel}$	0.9
w_{NegBel_prep}	0.9
w_{Prep_srsb}	0.9
w_{srsb_feel}	0.9
w_{feel_prep}	0.4
w_{cs_feel}	−0.2
w_{cs_negBel}	−0.35
w_{NegBel_PosNeg}	−0.3
w_{PosNeg_NegBel}	−0.1

When no emotion regulation takes place w_{feel_cs} and w_{negBel_cs} are taken 0. For scenarios in which emotion regulation takes place, the value of w_{feel_cs} changes from 0 to 3; and w_{negBel_cs} change from 0 to 0.05.

In particular, for a state causally affected by multiple other states, to obtain their combined impact, first the activation levels V_i for these incoming state are weighted by the respective connection strengths w_i thus obtaining $X_i = w_i v_i$ and then, these values X_i are combined, using a combination function $f(X_1, \ldots, X_n)$. In the context of emotion regulation model, the combination function is based on the following function:

$$V_{new} = V_{old} + \text{adapt}_{ER} * \text{th}(\tau, \sigma, x_1 + x_2 + \cdots + x_n) \quad (1)$$

where adapt_{ER} is an adaptation factor, determines the speed with which the value of state changes (is updated). The adapt_{ER} for all states of the emotion regulation model is equal to 6. This value is taken as a relatively fast speed factor, in contrast to the changes of the mood model. It is assumed that emotions concern fast, short term processes, whereas mood concerns a more long term process which is much slower. Moreover,

$$th(\tau, \sigma, X) = \left(\frac{1}{1 + e^{-\sigma(X-\tau)}} - \frac{1}{1 + e^{\sigma\tau}}\right)(1 + e^{-\sigma\tau}) \quad (2)$$

Table 2 shows the value of σ and τ for each state.

Simulation of the emotion regulation mechanism

The aim of this first simulation is to show the effects of emotion regulation on beliefs and negative feelings. Input for the model is formed by bad events. Bad events can come in all kinds of durations and intensities (per second). The presented approach is able to cover all these possibilities, using the two variables duration and (activation) level for intensity. In the experiment described here, it was chosen that a bad event happened for 3.3 h with intensity 1, which is an arbitrary choice. In this case, there are two different beliefs corresponding to this event, a negative one and a positive one as alternative interpretations of the world information For example, after losing a tennis match, negative belief is that you played awfully and blame yourself, and positive belief is that your rival was much more powerful and the stadium was full of his fans.

Fig. 2 shows the results of this simulation. In the simulation experiments always two variants are shown: one where emotion regulation is active (emotion regulation is ON), which is the natural case, and another one in which emotion

Table 2 Parameter values used in the simulation of emotion regulation model.

	NegBel	PosBel	prep	srs	feel	cs
τ	9	9	4	3	5	4
σ	0.1	0.1	0.4	0.2	0.10	0.5

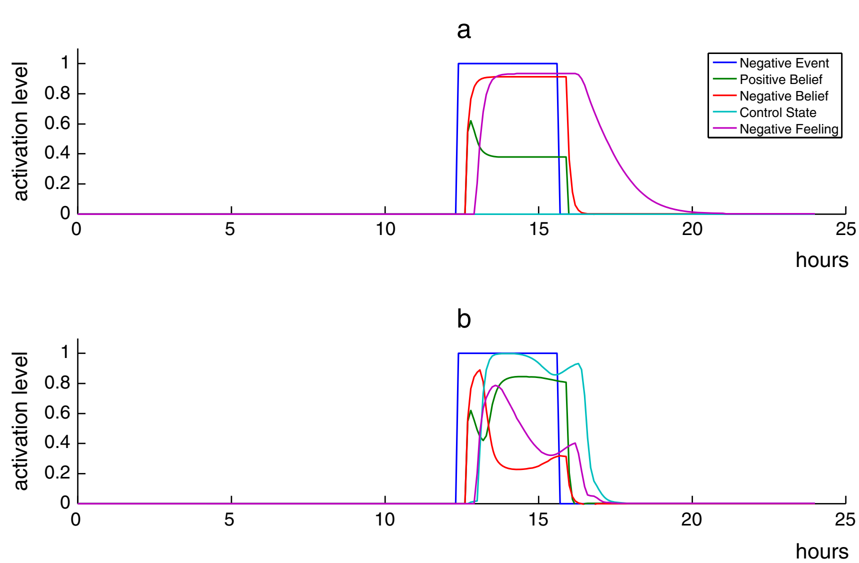

Fig. 2 Simulation results of the emotion regulation model for a case when a bad event happens. (a) Without emotion regulation and (b) with emotion regulation.

regulation has been made inactive (emotion regulation is OFF). This has been done to be able to see to which extent emotion regulation makes a difference. The variant without emotion regulation can be seen as an extreme case of a person with very poor emotion regulation capabilities. For this case, as can be seen, when no emotion regulation takes place (Fig. 2a), the negative event dominates and it leads to a high value of negative feeling. However, when the emotion regulation does take place (Fig. 2b), the generated negative belief and negative feelings lead to the activation of the control state, and consequently it causes weakening of the negative belief and due to this the positive belief can become dominant. Eventually, activation of the control state also decreases the value of negative feeling (purple line). This substantially reduces the effect of the negative feeling: it can be seen that the integral of the area below the feeling is 2.3 times smaller than in the upper graph.

Simulation of mood dynamics

The integrated model was used to simulate three types of persons in different situations. The different types are characterized by different values for the parameters coping, vulnerability and LT prospected mood level. These values are presented in Table 3. The coping values were chosen from average (0.5) to low (0.1) to very low (0.01) to get a distinction in different types of coping skills. The vulnerability is taken as 1 − coping value in the model.

The first type of person is an emotionally stable person, defined by having good coping skills that balance out any vulnerability and by having the desire to have a good mood. An emotionally slightly unstable person is defined by having some vulnerability and bad coping skills and the desire to have a medium mood. The third type is an emotionally very unstable person defined by having poor coping skills.

Please note that as start value for OEVS the equilibrium state is used; this needs to be calculated for each type so that when no events occur, the person stays balanced with all variables equal to LT prospected mood level. For stable person the OEVS is 0.8, for slightly unstable one it is 0.94 and for very unstable person the stable OEVS is 0.999.

The six weights between mood, thoughts and appraisal can also be varied to simulate different personal characteristics. However, in these simulations they have been set at the following values: $w_{appraisal\_mood}$ 0.7, $w_{thoughts\_mood}$ 0.3, $w_{appraisal\_thoughts}$ 0.6, $w_{mood\_thoughts}$ 0.4, $w_{mood\_appraisal}$ 0.5,

Table 3 The values of the parameters for different types of persons.

	Person 1	Person 2	Person 3
Characteristic	Stable	Slightly unstable	Very unstable
Coping	0.5	0.1	0.01
Vulnerability	0.5	0.9	0.99
LT prospected mood	0.8	0.6	0.6

Table 4 Simulation results for a case that three bad events happen.

	Person 1		Person 2		Person 3	
	Without emotion regulation	With emotion regulation	Without emotion regulation	With emotion regulation	Without emotion regulation	With emotion regulation
Week 1	0.7900	0.7809	0.4362	0.5002	0.3247	0.3985
Week 2	0.8035	0.7982	0.4507	0.5016	0.2791	0.3296
Week 3	0.7982	0.8005	0.4655	0.5053	0.2484	0.2835

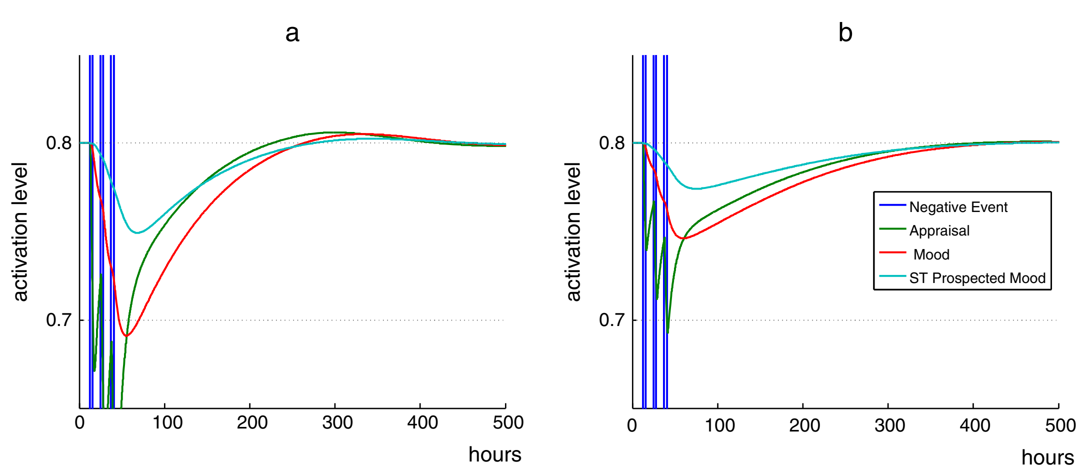

Fig. 3 Simulation results of the first scenario for person 1 (stable) (a) without emotion regulation and (b) with emotion regulation.

$w_{thoughts\_appraisal}$ 0.5. In each iteration, the value of each state (V_{new}) in the mood model is defined according the weighted sum of its inputs and its old value (V_{old}):

$$V_{new} = V_{old} + \text{adapt}_{mood} * (W_1V_1 + W_2V_2 + \cdots) \quad (3)$$

Since the speed of mood model is much slower than emotion model, the adaptation factor for all states in the mood model is 0.1. By comparing the adaptation factors of the mood model and the emotion regulation model, we see that the states of the emotion regulation model are updated 60 times faster than the states of the mood model. This is in line with the background provided in the introduction, which says that the emotions are much more short-time events than mood.

First scenario

In the first scenario, three short (3.3 h) bad events occur with the time interval of 12 h. The length of the scenario is three weeks (504 h). Table 4 shows the value of mood after one, two and three weeks, and the minimum value

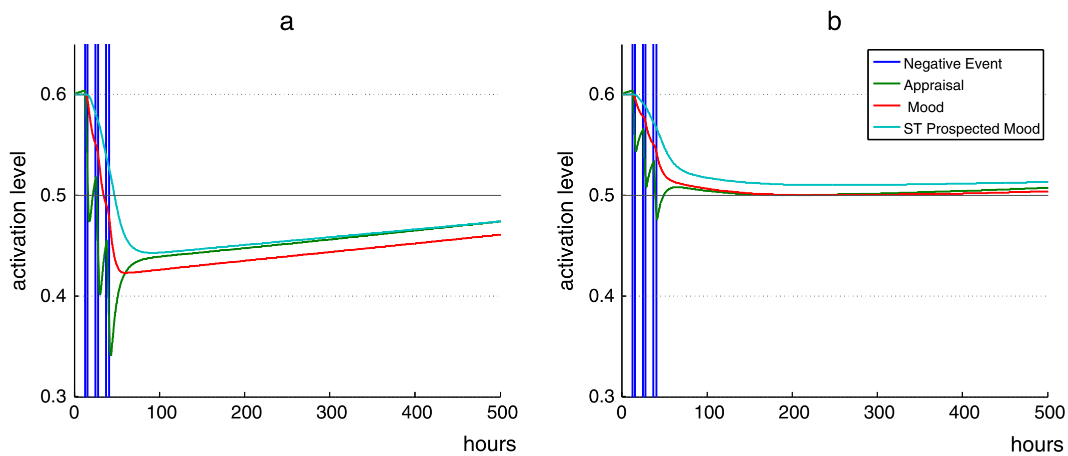

Fig. 4 Simulation results of the first scenario for person 2 (unstable) (a) without emotion regulation and (b) with emotion regulation.

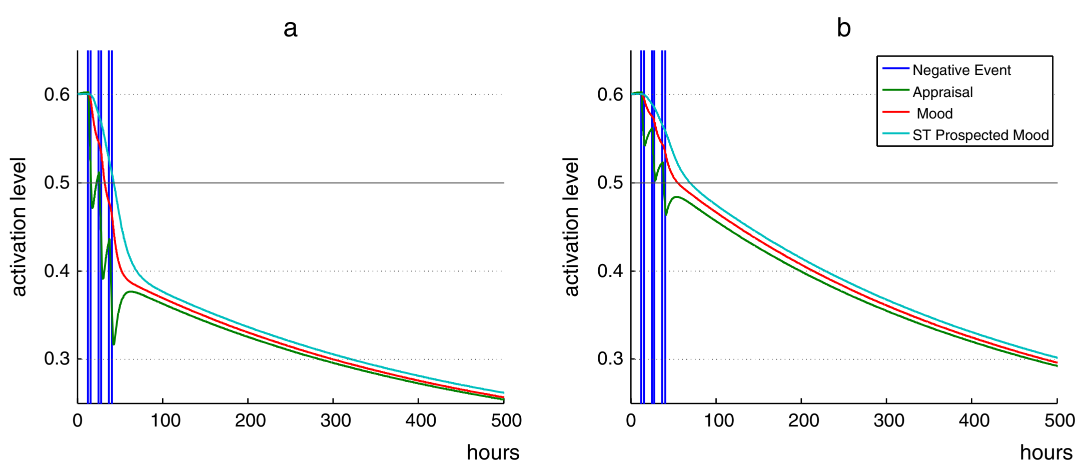

Fig. 5 Simulation results of the first scenario for person 3 (very unstable) (a) without emotion regulation and (b) with emotion regulation.

Table 5 Simulation results for a case when bad events happen every 3 weeks during one year.

	Person 1		Person 2		Person 3	
	Without emotion regulation	With emotion regulation	Without emotion regulation	With emotion regulation	Without emotion regulation	With emotion regulation
Minimum	0.7608	0.7818	0.4465	0.4829	0.0027	0.0041
Average	0.7929	0.7942	0.4706	0.4925	0.0038	0.0052
Maximum	0.8018	0.8002	0.4947	0.5042	0.0049	0.0063

of mood, for each person when the emotion regulation is ON or OFF.

As Table 4 shows, a stable person does not require emotion regulation to handle these bad events (the value of mood does not change significantly when emotion regulation is on or off). However, emotion regulation is critical for person 2 (unstable). In fact, if emotion regulation does not take place, he/she will become depressed after these bad events (a depression is defined as a mood level below 0.5 during at least 336 h (two weeks); cf. (American

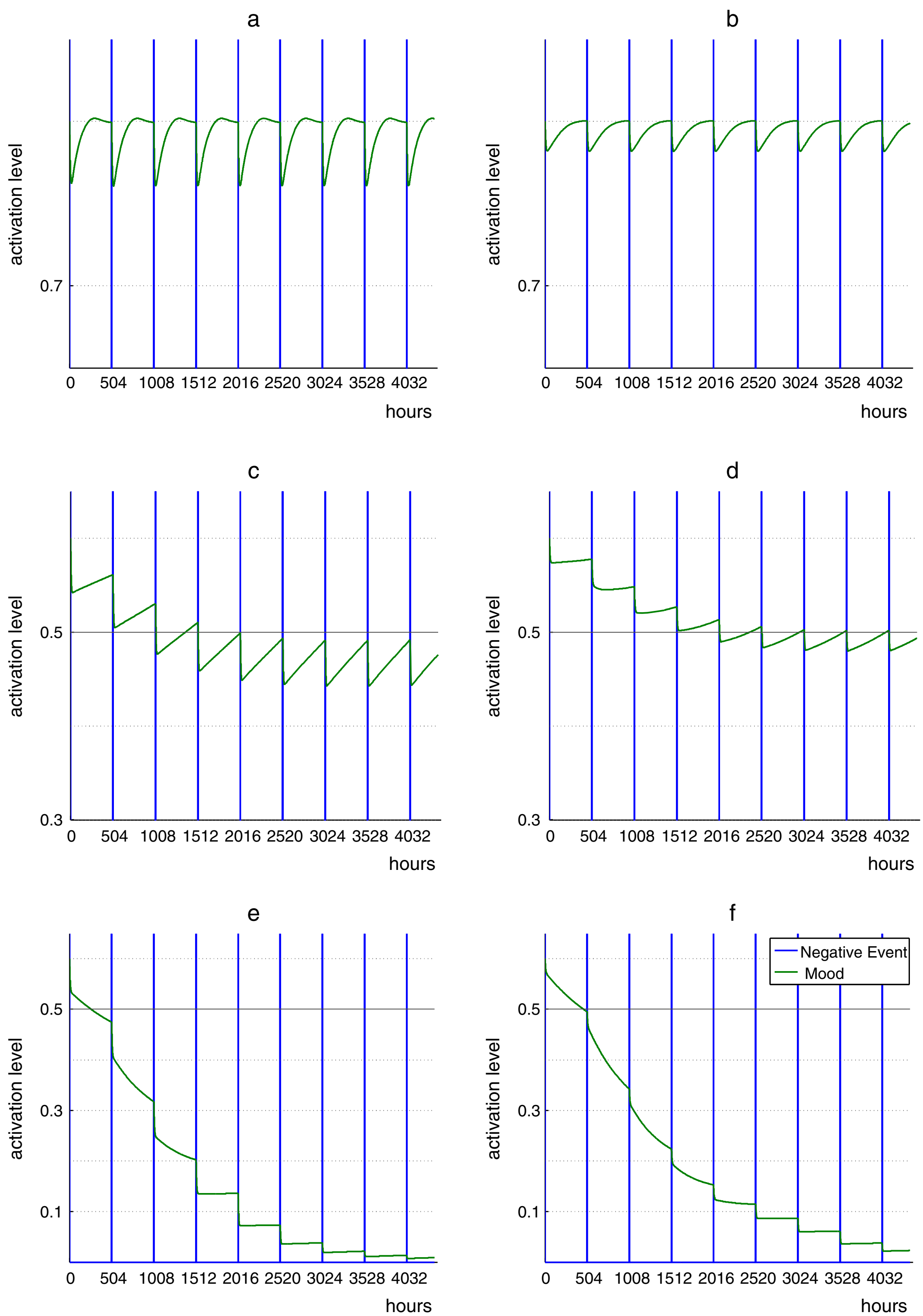

Fig. 6 Simulation results of the second scenario for the three different persons characteristics (a and b) stable person (c and d) unstable person (e and f) very unstable person Without emotion regulation (left hand side) With emotion regulation (right hand side).

Psychiatric Association, 1994)); while if emotion regulation does take place, the value of the mood will not go below 0.5 during this simulation. In contrast, the emotion regulation does not save a very unstable person from depression. However, even in this case, the emotion regulation enables the person to avoid the depression for the time being (time at which the value of mood becomes less than 0.5) for almost one day (22.8 h).

Figs. 3—5 show the results of the simulation of the first scenario for stable (Fig. 3), unstable (Fig. 4), and a very unstable person (Fig. 5). In the case of unstable person, when emotion regulation is OFF (Person = 2, Regulation = 0) events lead to a depression. While emotion regulation is ON (Person = 2, Regulation = 1), it decreases the effect of negative events and saves the person from depression.

Second scenario

In the second scenario, bad events occur every 3 weeks in one year. Table 5 shows the minimum, average and maximum value of mood in last 3 weeks of this simulation for each person.

Fig. 6 shows the results of this simulation for a stable (graphs in the first row), unstable (graphs in the middle row), and a very unstable person (graphs in the last row). As it can be seen, after each bad event the person tries to recover his/her situation. However, in case of person 2, if emotion regulation is OFF, the mood will not raise to 0.5. In contrast, when emotion regulation is ON, after each bad event, moods fall to below 0.5 and again recovers to a value higher than 0.5.

Third scenario

In the third scenario, the effect of the size (duration) of the event is observed. To do so, the average value of mood level, in 2 weeks (336 h) after the event (with different length) is calculated. Fig. 7 shows the results for three different personalities. Please note that, the horizontal axes show time, including the duration of the bad event, while the vertical axes show the mood level, 2 weeks after occurrence of event.

For instance, in the middle graph (unstable person), green dashed lines show that if a bad event (with the strength of 1) lasts for one day (24 h), the value of mood level, 2 weeks after occurrence of event will be:

- 0.2978, if emotion regulation is inactive
- 0.3854, if emotion regulation is active

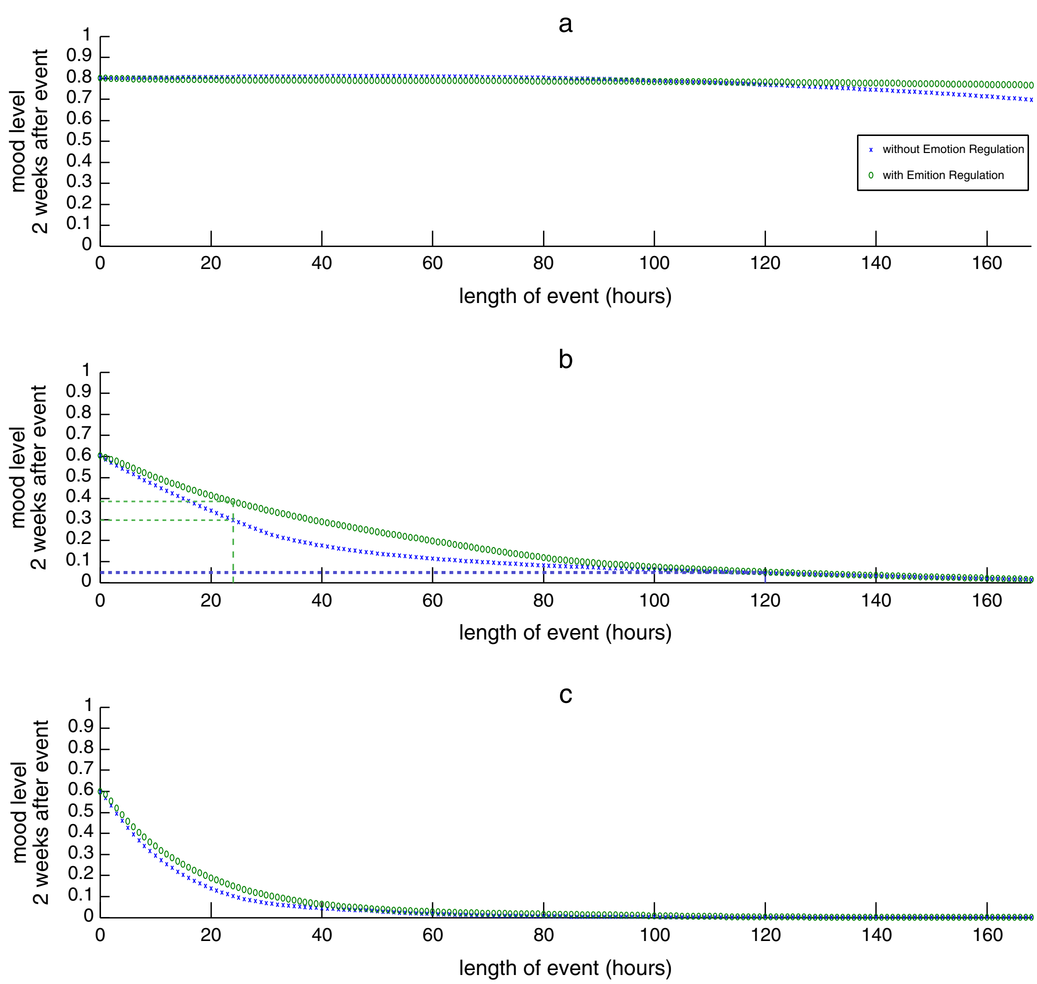

Fig. 7 Simulation results of the third scenario showing the value of the mood level, 2 weeks after occurrence of an event (with different size) for three different personalities (a) stable person (b) unstable person and (c) very unstable person.

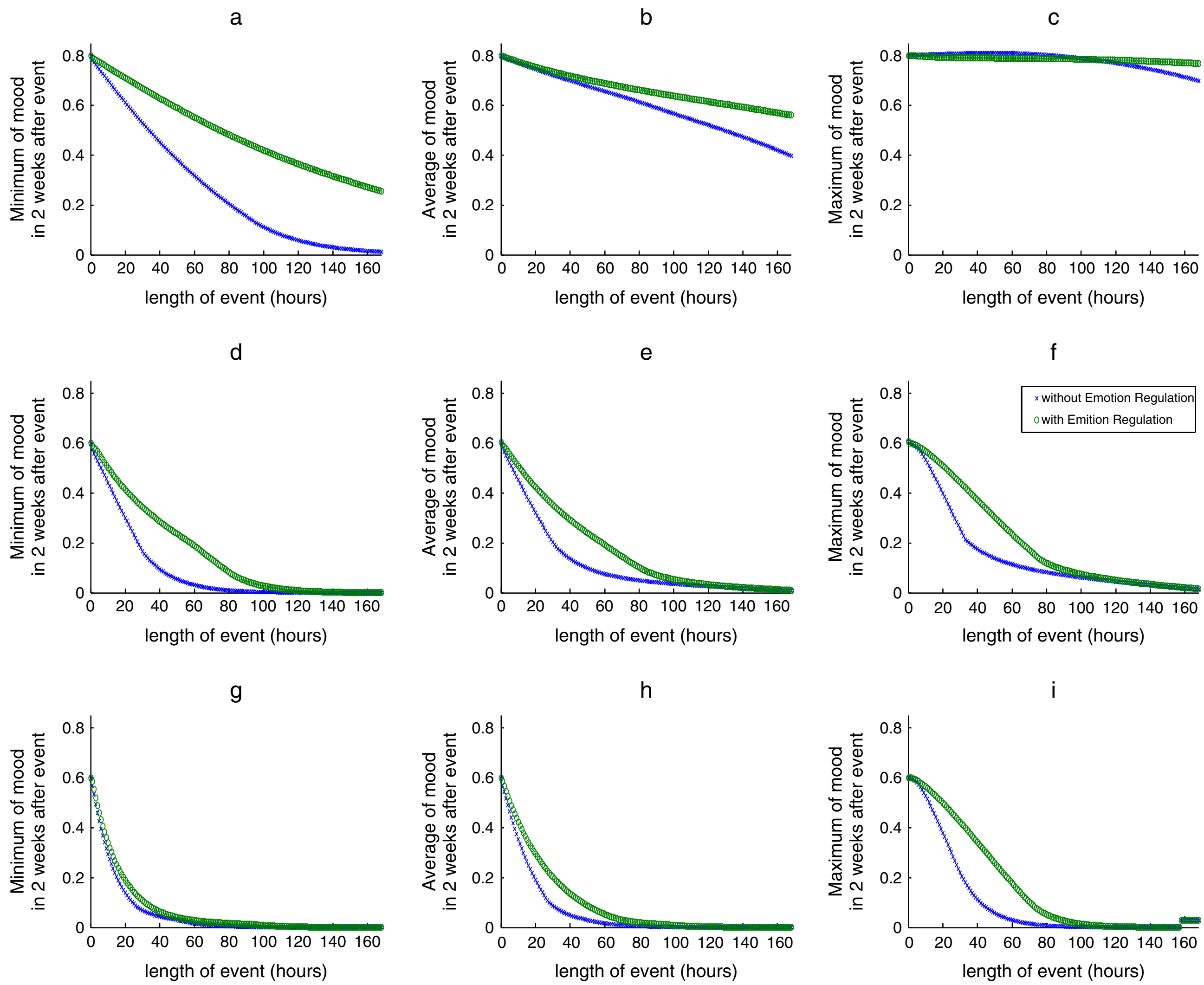

Fig. 8 Simulation results of the third scenario Minimum (left column), average (middle column) and maximum (right column) value of the mood level, at 2 weeks after the occurrence of an event (with different size) for three different personalities (a—c) stable person, (d—f) unstable person and (g—i) very unstable person.

However, if the event lasts for 5 days (120 h), the value of mood level, 2 weeks after occurrence of event will be:

- 0.04529, if emotion regulation is inactive
- 0.05109, if emotion regulation is active

The simulations show that for a range of separate events, emotion regulation can be helpful to considerably prevent decreasing the mood level. As it is clear in the aforementioned example, emotion regulation does not have a considerable effect for the long term when the duration of an event is too long.

Another observation that can be made is that the range of event durations for which emotion regulation has a considerable effect, is different for different personalities. As it can be seen in the Fig. 7, this range is smaller for more unstable person, in comparison to more stable persons. On the other hand, this range starts from a longer duration of events for a more stable person. This means that for a very stable person, with high coping skills, emotion regulation does not make much difference to handle events with a short or medium duration, whereas for a very unstable person, emotion regulation makes a real difference just in case of short bad events.

Fig. 8 explains the results of the third scenario in more detail. To understand the changes of mood in 2 weeks after the occurrence of event, minimum, average and maximum of mood level are shown in Fig. 8.

Discussion

In this paper, a computational model has been presented for the effect of emotion regulation (Gross, 1998) on the more long term dynamics of mood. This model was used to analyze (by performing simulation experiments) the effect of emotion regulation on the mood level of persons with different characteristics. The simulation results show how in certain circumstances emotion regulation can help unstable persons to avoid a depression and to postpone it in very unstable persons. Moreover, for a stable person model simulations show that emotion regulation is not required. Another experiment shows that if the unwanted events are prolonged for longer periods then emotion regulation can also help an unstable person to prevent the mood level from becoming too low, for a certain time. This is in line with literature addressing the effect of stressful events on depression, such as Kessler (1997) and Monroe and Harkness (2005). In this way creating the model helped think through the dynamics more clearly.

These kinds of agent based models have a potential as a basis to build systems that could help individuals to learn to appropriately regulate their behavior in a catastrophic situations, or stress management systems where an avatar can help a person to overcome stressful or negative feelings. It has been seen that in many fields in the public domain, for instance involving police officers or transportation employees, it is required to control the negative feelings. Virtual reality based training applications can be designed where an avatar equipped with the kind of agent based model presented in this paper could help people to overcome or to deal gracefully with negative situations in their professional life.

In future work, a focus will be on modeling the effect of learning emotion regulation, i.e., to learn to generate positive beliefs about different events. Such learning can be supported, for example, by training in real or virtual training environments.

Conclusion

The computational analysis presented in this paper shows how regulation of stressful emotions helps unstable persons to avoid a depression and to postpone it in very unstable persons. Furthermore the analysis shows that if a stressful event persists for a longer time period, then emotion regulation can also help an unstable person to prevent the mood level from becoming too low, for a certain time.

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