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Monitoring the Impact of Negative Events and Deciding About Emotion Regulation Strategies

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Abstract. Humans have a number of emotion regulation strategies at their disposal, from which in a particular situation one or more can be chosen. The focus of this paper is on the processes behind the choice of these regulation strategies. The paper presents a neurologically inspired cognitive computational model of a monitoring and decision mechanism for emotion regulation incorporating different strategies (expressive suppression, reappraisal or reinterpretation, and situation modification). It can be tuned to specific characteristics of persons and events.

Keywords: Cognitive modeling · Emotion · Regulation

1 Introduction

Emotions play a vital role for a person to function responsibly in society. Proper handling of negative emotions such as stress and anxiety help us to perform our daily life activities in an efficient manner, and not become vulnerable to stress-related disorders such as depression or PTDS. It has been found that individuals can apply different emotion regulation strategies [1]. Several types of emotion regulation strategies exist which can be effective in particular circumstances. Two of them which have received much interest of researchers over the years are reappraisal and emotion suppression [2]. An important but often neglected part of the emotion regulation process is a decision making process determining under which circumstances different strategies are selected [3]. Which strategy is applied depends on a number of factors, such as a person's context, an internal monitoring and assessment concerning her feeling intensity, and her individual characteristics or preferences. Empirical studies such as [4] show that individual differences exist when it comes to prefer one strategy over another and also these differences exist when some individual applies a combination of emotion regulation strategies.

In this paper the role of monitoring and assessment, and control mechanisms to recognize a type of negative emotion and to choose for one or more strategies are explored computationally. The first process acts as an identification stage as described in [3, 5, 6] which recognizes and assesses the negative feelings and their intensity.

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Based on this assessment one or more control states are activated for specific emotion regulation strategies. For example, if the intensity of an emotion is very high, then multiple regulation strategies might be employed at the same time (which also depends on the personality traits). On the other hand if the intensity is very low, then only emotion suppression could be enough to be applied or if it is of a moderate level, then it could be the case that only appraisal and emotion suppression are chosen. Several simulation experiments that have been realized show how the model can take into account different kinds of personalities and varying levels of negative stimuli and feelings.

2 Neurological Background

When emotional responses compete with important goals or with socially more appropriate responses, often regulation of them takes place [7, 8]. Emotion regulation can make use of a variety of specific strategies to affect the emotion response levels [9]. Emotion regulation uses control functions in order to activate one or more of the different strategies to generate, maintain and adjust the emotional responses [10]. By such emotion regulation mechanisms, persons have the ability to suppress negative influences from the environment and maintain a form of emotional homeostasis [11, 12]. Emotions can be regulated in different stages of the emotion generation process [11–13] distinguish antecedent-focused strategies (those that address processes before an emotion has an effect on the behavior) from response-focused strategies (those that are used when the emotional response is already coming as expression or behavior). Note that the different types of emotion regulation share a common effect on the level of emotion, but may differ much in the path followed to achieve this effect. Moreover, multiple strategies can be used at the same time, so that multiple paths are followed in parallel with a combined effect on the emotion level.

The current paper focuses on the monitoring and control for three different emotion regulation strategies: (1) situation modification (2) reinterpretation, and (3) expressive suppression [12, 14]. Here the first two are antecedent-focused strategies and the third is a response-focused strategy. Situation modification [12] addresses the very first part of the causal chain from trigger to emotion, namely the external trigger itself by performing actions that change the external situation in such so that the trigger becomes more harmless. Reinterpretation works by changing the assigned meaning or interpretation of an emotional stimulus in a way that changes its emotional impact [15]. Expressive suppression is a form of response modulation that involves inhibiting ongoing emotion-expressive behavior [12].

The model presented here was inspired by a number of neurological theories relating to fMRI experiments. Much emphasis has been put in the literature on the role that is played by a bidirectional interaction between the amygdala and the prefrontal cortex (PFC). In experiments often fMRI measurements have been made focusing on activity in these brain areas, and anatomically their connections have been analysed. For both, correlations have been found with (the extent of success in) actual emotion regulation; e.g., [16–18]. For example, it has been found that less interaction or weak connections between amygdala and prefrontal cortex lead to less adequate emotion regulation [8]. The general idea is that upward interaction from amygdala to PFC can have the function of monitoring, in order to get an internal representation of the level of emotion within the prefrontal cortex, which is used to achieve a form of assessment of this level of emotion within the prefrontal cortex, whereas the downward interaction from PFC to amygdala makes it possible to control and modify amygdala activation. In the process of monitoring and assessing the level of emotion, leading to PFC activity, interaction with some areas other than the amygdala may occur as well, as these areas can also play an important role in developing emotions and feelings.

So, upward interactions can be considered from multiple areas. Also in relation to the control function of the PFC and connections from there to other areas some differentiation is needed. For different regulation strategies different brain areas need to be affected. For a response-focused strategy such as expressive suppression, maybe a main effect can be to suppress amygdala activation in a more direct manner, but maybe also other areas involved in actual expression of the emotion have to be suppressed. Furthermore, for an antecedent-focused strategy such as reinterpretation it is quite plausible that the control from the PFC has to affect the interpretation, and not the amygdala in a more direct manner. For example, in this case the PFC may affect (working) memory in order to achieve the reinterpretation. After this reinterpretation has been accomplished, in turn the renewed emotion generation process (based on the new interpretation) will affect the emotion level, including amygdala activity. In such a case a more direct suppression of amygdala activation might still take place as well, but then that effect may have to be attributed to a different regulation strategy which occurs in parallel, for example, expressive suppression.

After all, it is also a matter of clear definition to distinguish the different strategies. For example, it may be tempting to define the reinterpretation strategy in such a manner that it also includes the expressive suppression strategy, given empirical data that may have difficulty to distinguish the two. However, from a conceptual perspective it is more useful to define the two strategies as exclusive so that different paths can be attributed to different strategies, even if they occur in the same experiment. The latter choice is made in this paper. To control different pathways in order to achieve emotion regulation according to different strategies the PFC has to involve different areas within the brain. In some recent studies such as [16, 19] attempts are made to relate different regulation strategies to activity in different brain areas. See, for example, [16] which describes that expressive suppression relates to an increase of brain activation in a right prefronto-parietal regulation network, and reinterpretation engages a different control network comprising left ventrolateral prefrontal cortex and orbitofrontal cortex.

3 The Cognitive Model

The computational model was designed as a temporal-causal network model; see [20]. An overview of the states and causal relations of the proposed model is depicted in Fig. 1. A description of each state is available in Table 1. The states of this model can be classified in six groups: the environment, emotion generation, emotion regulation selection strategy 1, 2 and 3, and, last but not least, an internal monitoring and selection mechanism for the decision making. The monitoring process is modelled by the connections from the feeling state fs_b to a number of monitoring states ms_i (which can be any number but in the simulations has been chosen as 3), and the selection process is modelled by the connections of the monitoring states to the control states. The upward connections model the connections from amygdala to PFC that are used for monitoring the lower level processes in the brain (see Sect. 2). If the feeling intensity reaches at a certain threshold (which may differ for different kinds of persons), the monitoring system reflects this by activating some of the monitoring states. In addition, by some inhibiting connections between them the monitoring states are made mutually exclusive and recognize specific types of stressful situations: monitoring state ms_1 recognizes low intensity feeling, ms_2 recognizes moderate level feeling and ms_3 high intensity negative feeling. This inhibition-based process between the monitoring states can be considered as a form of assessment, leading to one unique indication of the situation concerning the stress level.

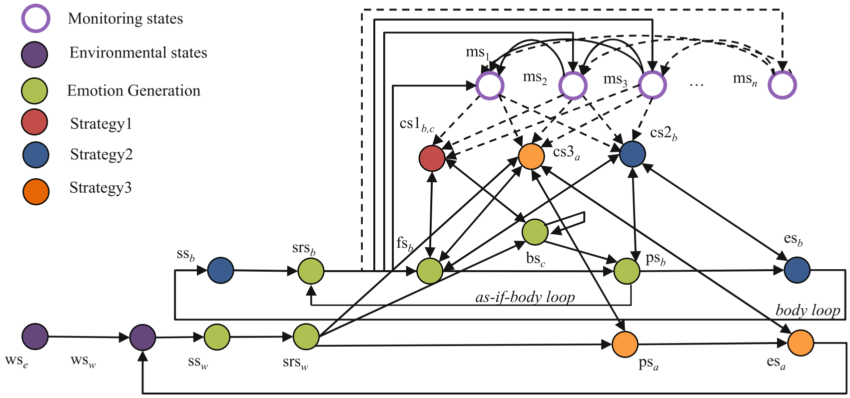

Fig. 1. Conceptual representation of the computational model

This single monitoring state obtained is the basis for a form of decision, by activating one or more control states for specific regulation strategies. A person's characteristics for these monitoring and decision processes are represented by the weights of the connections to the monitoring states and from the monitoring states to the control states, respectively. The selection process involves the three emotion regulation strategies covered here. Depending on the situation and personality of an individual, one, two or all of these regulation strategies are selected. For example, if the feeling is intense then situation modification may be chosen by the person, depending on her characteristics.

The main states representing the environment are ws_w and ws_e. Here ws_w indicates the person's environment state and ws_e covers external events which may affect the environment of the person. The state of the world is sensed by the person via sensor state ss_w and represented by state srs_w.

This sensory information can be interpreted by both a positive belief bs_{c1} and a negative belief bs_{c2}, which represent two different interpretations of the same world condition. These conflicting beliefs compete with each other by mutual inhibiting connections. In the considered scenario, the negative belief bs_{c1} has an effect on the state of preparation for negative emotional response ps_b which leads to sensory body representation srs_b and to the negative feeling fs_b. Subsequently, fs_b has an impact on

Table 1. Overview of the states of the proposed model (see also Fig. 1)

Domain	Formal	Informal name	Description
Environment	ws_w	World state *w*	This characterizes the current world situation which the person is facing
	ws_e	World event *e*	Circumstances in the world affecting the world situation in a stress-inducing way
Emotion Generation	ss_w	Sensor state for *w*	The person senses the world through the sensor state, providing sensory input
	srs_w	Sensory representation of *w*	Internal representation of sensory world information on *w*
	srs_b	Sensory representation of *b*	The person maintains a body representation srs_b for *b* in the brain. Here *b* is embodying the associated emotion, in the considered scenarios a negative emotion. Before performing an action, a feeling state fs_b for the action is generated by a predictive as-if body loop, via the sensory representation state srs_b.
	fs_b	Feeling associated to body state *b*	
	bs_c	Belief state for *c*	Interpretation of the world information; in the case of different, exclusive interpretations for the same world information, they may suppress each other
	ps_b	Preparation for *b*	Preparation for a response involving body state *b*
Emotion Regulation Strategy 1	**Reappraisal** Re-interpretation of world information by belief change: changing the assigned meaning to a stimulus with negative emotional effects (e.g., by believing that a noisy restaurant will become more quiet soon).		
	$cs1_{b,c}$	Control state for reappraisal of belief *c* to avoid feeling *b*	By becoming activated this control state suppresses the belief for *c*, which gives the opportunity for alternative beliefs to become dominant.
Emotion Regulation Strategy 2	**Suppression of emotion-expressive behaviour** Inhibition of the expression, for example, hide one's true feelings from another person (e.g., hiding one's fear when standing up to a bully).		
	$cs2_b$	Control state for expressive suppression to avoid feeling *b*	By becoming activated this control state suppresses the execution state for *b*.
	ss_b	Sensing body state *b*	To maintain the body representation srs_b for *b*, the person senses the body state *b*.
	es_b	Execution state for *b*	Body expression of *b*, for example a fear expression

Emotion Regulation **Strategy 3**	**Situation modification** For this strategy the person performs an action in the external world to change a situation which triggers negative emotions into a better one (e.g., leaving a noisy restaurant and enter a quiet place).		
	$cs3_{b,a}$	Control state for situation modification *a* to avoid feeling *b*	By becoming activated this control state activates the preparation and execution of action *a* to change the situation.
	ps_a	Preparation for action *a*	Preparation to modify the situation by action *a*
	es_a	Execution state for action *a*	The action *a* is changing the situation (decreasing the level of world state *w*)
Monitoring and Selection processes	ms_1	Recognizes low feeling level	The monitoring states are involved in two processes, one which is responsible for monitoring of the feeling (connections to the monitoring states) and reaching a form of assessment (by some inhibiting links between them), and the second process is concerned with the selection of the appropriate regulation strategies (connections from the monitoring states to the control states).
	ms_2	Recognizes moderate feeling level	
	ms_3	Recognizes high feeling level	

the preparation state ps_b, which in turn has an impact on feeling state, fs_b, through srs_b which makes the process recursive; this is often called an as-if body loop in the literature (e.g. [21]). Other states, depicted in Fig. 1, are control states related to three emotion regulation strategies described below.

As described in Sect. 2, emotions can be controlled in different phases of the process during which emotions are generated [12]. The first strategy discussed focuses on reinterpretation of the world information by changing bad beliefs about the situation into more positive ones; this is done as follows. Suppose two beliefs bs_{c1} and bs_{c2} are two different, exclusive interpretations of the world state, where bs_{c2} associates to bad feelings fs_b. The exclusiveness is modelled by mutual inhibiting connections. Suppose the person has generated belief state bs_{c2} as dominant, and by her monitoring and decision mechanism she decides for activation of control state $cs1_{b,c}$. Consequently this control state weakens the belief bs_{c2} and due to this, the positive belief bs_{c1} can become dominant, which provides an alternative, more positive interpretation of the world. Also expressive suppression can be used to decrease negative emotions. In the model, when it is decided to activate control state $cs2_b$ for this second strategy, this suppresses the expression of the emotional response es_b. This es_b is sensed by the person him or herself through the body loop, and through that it has a decreasing effect on the emotion level. The third emotion regulation strategy considered is situation modification. Leaving an annoying place or person is an example of this strategy. In the model the control state for this kind of emotion regulation is $cs3_{b,a}$. A decision to activate this control state leads to preparing and performing an action *a* (i.e., states ps_a and es_a) which can change the situation (characterized by ws_w), for example walking away from a noisy place to a quiet place.

The conceptual representation of the model is represented as a number of states and connections between them, shown in Fig. 1 and verbally in Table 1, with in addition:

- For each connection from state X to state Y a *weight* $\omega_{X,Y}$ (a number between −1 and 1), for the strength of the impact through this connection; a negative weight is used for suppression
- For each state Y a *speed factor* η_Y (a positive value) and (a reference to) a standard *combination function* $\mathbf{c}_Y(...)$ used to aggregate multiple impacts from different states on one state Y.

For a numerical representation of the model the states Y get activation values indicated by $Y(t)$: real numbers between 0 and 1 over time points t, where the time variable t ranges over the real numbers. More specifically, the conceptual representation of the model (as shown graphically in Fig. 1 and verbally in Table 1) can be transformed in a systematic or even automated manner into a numerical representation as follows [20]:

- At each time point t each state X connected to state Y has an *impact* on Y defined as $\mathbf{impact}_{X,Y}(t) = \omega_{X,Y}\, X(t)$ where $\omega_{X,Y}$ is the weight of the connection from X to Y
- The *aggregated impact* of multiple states X_i on Y at t is determined using a *combination function* $\mathbf{c}_Y(..)$:

$$\begin{aligned}\mathbf{aggimpact}_Y(t) &= \mathrm{c}_Y(\mathbf{impact}_{X_1,Y}(t), \ldots, \mathbf{impact}_{X_k,Y}(t)) \\ &= \mathbf{c}_Y(\omega_{X_1,Y}X_1(t), \ldots, \omega_{X_k,Y}X_k(t))\end{aligned} \tag{1}$$

where X_i are the states with connections to state Y.

- The effect of $\mathbf{aggimpact}_Y(t)$ on Y is exerted over time gradually, depending on *speed factor* η_Y:

$$\begin{aligned}& Y(t+\Delta t) = Y(t) + \eta_Y[\mathbf{aggimpact}_Y(t) - Y(t)]\Delta t \\ \text{or} \quad & \mathbf{d}Y(t)/\mathbf{d}t = \eta_Y[\mathbf{aggimpact}_Y(t) - Y(t)]\end{aligned} \tag{2}$$

- Thus the following *difference* and *differential equation* for Y are obtained:

$$\begin{aligned}& Y(t+\Delta t) = Y(t) + \eta_Y[\mathbf{c}_Y(\omega_{X_1,Y}X_1(t), \ldots, \omega_{X_k,Y}X_k(t)) - Y(t)]\Delta t \\ \text{or} \quad & \mathbf{d}Y(t)/\mathbf{d}t = \eta_Y[\mathbf{c}_Y(\omega_{X_1,Y}X_1(t), \ldots, w_{X_k,Y}X_k(t)) - Y(t)]\end{aligned} \tag{3}$$

For all states for the standard combination function either the *identity function* **id(.)** or the *advanced logistic sum combination function* $\mathbf{alogistic}_{\sigma,\tau}(...)$ is used [20]:

$$\mathrm{c}_Y(V) = \mathrm{id}(V) = V$$

$$\mathbf{c}_Y(V_1, \ldots V_k) = \mathbf{alogistic}_{\sigma,\tau}(V_1, \ldots, V_k) = \left(\frac{1}{1+\mathrm{e}^{-\sigma(V_1+\ldots+v_k-\tau)}} - \frac{1}{1+\mathrm{e}^{\sigma\tau}}\right)(1+\mathrm{e}^{-\sigma\tau}) \tag{4}$$

Here σ is a steepness parameter and τ a threshold parameter. The advanced logistic sum combination function has the property that activation levels 0 are mapped to 0 and it keeps values below 1. The identity function id(..) is used for the states with a single impact: ssw, ssb. For all other states the advanced logistic sum combination function is used. For example, for the feeling state fs_b the model is numerically represented in difference equation form as

$$\begin{aligned}\mathbf{aggimpact}_{fs_b}(t) &= \mathbf{alogistic}_{\sigma,\tau}(\omega_{srs_b,fs_b} srs_b(t), \omega_{cs1_{b,c},fs_b} cs1_{b,c}(t), \\ &\quad \omega_{cs2_b,fs_b} cs2_b(t) \omega_{cs3_{b,a},fs_b} cs3_{b,a}(t))\end{aligned}$$

$$fs_b(t + \Delta t) = fs_b(t) + \eta_{fsb}[\mathbf{aggimpact}_{fs_b}(t) - fs_b(t)]\Delta t \quad (5)$$

In this way the model represented conceptually in Fig. 1 is transformed into a numerical representation of the model in terms of difference or differential equations. The simulations are performed by applying a computational simulation method to this numerical model representation, in a dedicated software environment. All the simulations were performed within the MATLAB™ environment.

4 Scenarios and Simulation Results

The computational model presented above has been used to perform number of simulation experiments addressing the selection of emotion regulation strategies. This has been done for different scenarios describing different cases with different levels of stimulus and negative feeling, and varying from selection of just one of the regulation strategies to selecting multiple regulation strategies at the same time. Scenarios also vary on certain characteristics of the person, such as: sensitivity of a person for negative stimuli, and a person's preferences for regulation strategies.

For example, some persons may have a higher preference for the situation modification strategy (e.g., they tend to try to escape from a disturbing situation), maybe in combination with a high sensitivity for disturbing stimuli, whereas other types of persons may prefer the other regulation strategies while staying in the same situation. More specifically, some persons are good in suppression of their negative feelings related to a stimulus and keep the same interpretation and stay in the same situation, whereas other persons may prefer to try to reinterpret (reappraise) the situation in a more positive way by changing the negative beliefs about the situation into positive beliefs, in oreder to reduce the level of negative feelings. Another category of persons may be quite sensitive to the stimulus and initially try to reduce their level of negative feelings by suppression and may use the reinterpretation strategy to make their positive beliefs more stronger against the negative beliefs, and if they fail to do so they still may try to escape from the bad situation or try to modify the situation in another way.

The simulation experiments demonstrate the role of the monitoring, assesment and decision making with an important role for the monitoring states, which are used as a basis to select one or more of the three available regulation strategies. The selection process starts when a monitoring state reflects that a certain type (level) of negative feeling arises. In a very first stage just a low level of negative feeling fs_b triggers monitoring state ms_1 (indicating a low level of feeling), which in turn may lead to a decision to activate one or more regulation strategies preferred by the person for such a low level of negative feeling (recall that these preferences are represented by the weights of the connections from the monitoring state to the three control states). Then there are two possibilities: these strategies are adequate and limit the feeling level, or the feeling level still increases so that monitoring state ms_2 (indicating a mediate level of feeling) is triggered. In the latter case this monitoring state ms_2 in turn may lead to a decision to activate another selection of regulation strategies. Again there are two possibilities: these strategies may limit the feeling level, or the feeling level still increases to the situation that monitoring state ms_3 (indicating a high level of feeling) is triggered. In the latter case again another selection of regulation strategies can be decided for. A specific case of such a scenario is shown in Table 2. In the scenario indicated in this table the first regulation strategy used (after ms_1 is triggered) is suppression of the negative feeling.

Table 2. Regulation selection choices for an example scenario

Feeling level	Triggered monitoring state	Selected regulation strategies
Low	ms_1	Suppression
Median	ms_2	Reappraisal
High	ms_3	Situation modification

This means that based on ms_1 it is decided to activate control state $cs2_b$ in order to suppress the negative feeling. In a second stage, when the level of negative feeling increases further, due to the development of negative beliefs about the situation, this triggers the next monitoring state ms_2, and based on that it is decided to activate control state $cs1_{b,c}$ for the second regulation strategy: reappraisal (reinterpretation). This starts to down-regulate the negative feelings in a different way by changing (reinterpreting) the meaning of the stimulus (switching of a negative belief to a positive belief). The control state $cs1_{b,c}$ is usually slower compared to $cs2_b$, because humans often take much time to change their beliefs about the environment (stimulus), so it takes some more time to change beliefs. The third and last monitoring state ms_3 triggers when the level of feeling becomes high; then based on this it is decided to activate the third control state $cs3_{b,a}$ which initiates situation modification by performing the (physical) action needed to achieve that. As this situation modification strategy involves movement, it is slower and takes some more time compared to two other regulation strategies mentioned above which involve mental processes instead of physical action.

Note that in Table 2 for each monitoring state exactly one regulation strategy is selected. However, it is also possible that the strategies selected for a lower level of the feeling are still selected as well for higher levels of the feeling. The more specific simulation results discussed here are based on the following scenario. The person is in a restaurant which has become rather noisy, and this triggers negative feelings. First she suppresses these negative feelings. Moreover, she tries to suppress her negative belief about being in a noisy restaurant the whole evening to give space for a positive belief (it will soon become more quiet). However still some negative feeling remains. Therefore she decides to leave the restaurant. The simulation executes for 120 time points with $\Delta t = 0.1$. Details of the values for parameters used in the simulation are given in Table 3 (threshold τ, steepness σ, and update speed η) and in Table 4 (connection weights between all states).

Table 3. Values of threshhold, steepness and update speed

State	τ	σ	η	State	τ	σ	η
ms_1	0.08	50	6	es_b	0.5	4	6
ms_2	0.32	50	6	$cs2_b$	2	5	6
ms_3	0.6	50	6	ss_b	0.5	4	6
ps_b	0.4	4	6	ws_w	0.1	5	0.4
fs_b	0.1	4	6	ss_w	0.2	4	6
bs_{c1}	0.1	8	6	srs_w	0.2	4	6
bs_{c2}	0.36	15	6	ps_a	0.4	5	6
$cs1_{b,c}$	1.5	15	0.5	es_a	0.5	100	6
srs_b	0.2	3	6	$cs3_{b,a}$	1.2	5	0.1

Table 4. Values of parameters used: connection weights

Weight		Weight		Weight		Weight	
$\omega_{esa,wsw}$	−1	$\omega_{srsb,fsb}$	0.9	$\omega_{cs1b,c,fsb}$	−0.1	$\omega_{psb,cs2b}$	0.8
$\omega_{wsw,ssw}$	0.5	$\omega_{esb,cs2b}$	0.8	$\omega_{cs2b,fsb}$	−0.2	$\omega_{cs3b,a,esa}$	0.8
$\omega_{ssw,srsw}$	0.9	$\omega_{srsw,psa}$	0.1	$\omega_{cs3b,a,fsb}$	−0.3	$\omega_{psa,esa}$	0.7
$\omega_{srsw,bsc1}$	0.3	$\omega_{cs3b,a,psa}$	1	$\omega_{bsc2,psb}$	0.7	$\omega_{srsw,cs3b,a}$	0.8
$\omega_{cs1b,c,bsc1}$	0.0	$\omega_{fsb,cs3b,a}$	0.3	$\omega_{fsb,psb}$	0.7	$\omega_{ms1,cs1b,c}$	1
$\omega_{bsc1,bsc2}$	−0.2	$\omega_{fsb,ms1}$	0.9	$\omega_{cs2b,psb}$	−0.2	$\omega_{ms1,cs2b}$	1
$\omega_{srsw,bsc2}$	0.9	$\omega_{fsb,ms2}$	0.9	$\omega_{psb,srsb}$	0.6	$\omega_{ms1,cs3b,a}$	1
$\omega_{cs1b,c,bsc2}$	−0.25	$\omega_{fsb,ms2}$	0.9	$\omega_{ssb,srsb}$	0.8	$\omega_{ms2,cs1b,c}$	1
$\omega_{bsc1,bsc2}$	−0.2	$\omega_{ms2,ms1}$	−1	$\omega_{psb,esb}$	0.7	$\omega_{ms2,cs2b}$	1
$\omega_{fsb,cs1b,c}$	3	$\omega_{ms3,ms1}$	−1	$\omega_{cs2b,esb}$	−0.1	$\omega_{ms2,cs3b,a}$	1
$\omega_{bsc2,cs1b,c}$	1	$\omega_{ms3,ms2}$	−1	$\omega_{esb,ssb}$	0.7	$\omega_{ms3,cs1b,c}$	1
$\omega_{bsc1,cs1b,c}$	0.0	$\omega_{ms3,cs3b,a}$	1	$\omega_{fsb,cs2b}$	0.1	$\omega_{ms3,cs2b}$	1

Table 5. Personality variation for sensitivity

Person	$\omega_{srsb,fsb}$	Personality type
Person_ 1	0.3	Less sensitive to the stimulus
Person _2	0.6	More sensitive to the stimulus
Person _3	0.9	Most sensitive to the stimulus

The personality type concerning sensitivity to a stimulus has been taken into account by varying the connection strength of the weights $\omega_{srsb,fsb}$ between the sensory representation of the *b* and the feeling state fs_b. Table 5 shows the variation in personality type from less sensitive to most sensitive. The model has been executed a large number of times with such scenarios; in Fig. 2 one of them is depicted, the person has high sensitivity to the stimulus.

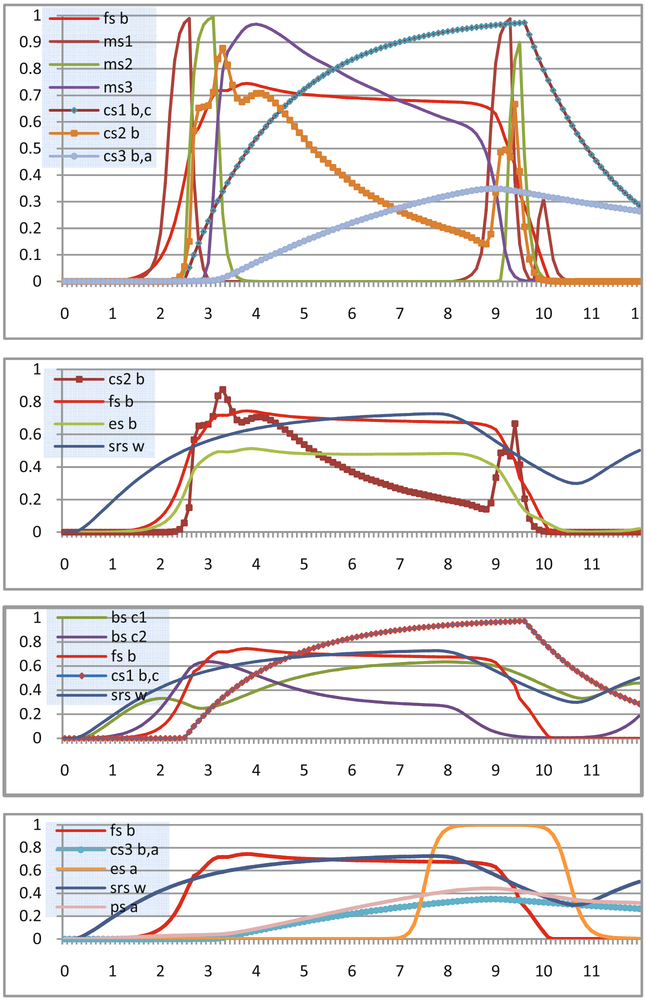

Fig. 2. Simulation results of scenario 3 for person_3 (most sensitive to the stimulus). Upper graph: monitoring and decision process. Three lower graphs: the 3 controlled regulation strategies

As the upper graph shows, when the simulation starts, first ms_1 becomes active, after a while ms_2, and in the last phase ms_3. The graph also shows the control states; first based on ms_1 it is decided to activate the emotion suppression control state $cs2_b$. It suppresses the negative feeling (shown in the second graph) but as the negative feeling still increases, ms_2 is triggered, and based on this it is decided to activate control state $cs1_{b,c}$ for the reappraisal strategy. This alters the beliefs by suppressing the negative belief, resulting in strengthening of positive belief and at the same time the negative feeling decreases (shown in the third graph). After applying two strategies, the level of negative feeling still is increasing, which triggers ms_3, and based on this it is decided to activate control state $cs3_{b,a}$ for situation modification. Due to this the person moves away (change of situation) from the stimulus and gets rid of the negative feelings (shown in the last graph).

5 Discussion

In this paper, a neurologically inspired cognitive computational model for internal monitoring and decision making about the selection of emotion regulation strategies has been presented. The model covers three emotion regulation strategies (expressive suppression, reappraisal or reinterpretation, and situation modification), adopted from [22] which lacks an internal monitoring and decision model as addressed in the current paper. A number of simulation experiments have been performed according to different scenarios, thereby considering different personality characteristics and intensities of stimuli. The decision process to select one or more particular regulation strategies primarily takes the assessed current feeling state into account, but can easily be extended to involve other elements as well.

The obtained human-like model can be used in different ways. As a first application it can be a basis for virtual characters showing emotions and applying emotion regulation strategies in a flexible way depending on the situation. Secondly, the model can be used as an ingredient to develop human-aware or socially aware computing applications; e.g., [23–25]. More specifically, in [25, 26] it is shown how such applications can be designed with knowledge of human processes as a main ingredient, represented by a computational model of these processes which is embedded within the application. Such computational models can have the form, for example, of qualitative causal models, or of dynamical numerical models. The computational model for decision making about emotion regulation proposed here can be used in such a way to design a human-aware software application to support persons with stress-related problems and professionals supporting them.

In the literature a number of computational emotion regulation models have been proposed over the years, one of which was presented in [27]. Here a theory of appraisal was modeled. The presented model is based on the idea that emotions are generated based on an individual's interpretation of the situation. In this approach the model is based on symbolic and numeric representations and appraisal operates on them, whereas our approach uses a dynamical systems representation. Different coping strategies are proposed in that paper, e.g., "belief-related coping" which can be related to reappraisal in the model proposed here. A difference is that the model presented in the current paper focuses on modeling the decision making process in an explicit manner, and that the modeling approach here is based on temporal-causal networks as described in [20, 28].

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