Proceedings Paper:

Cameron, D., Totterdell, P., Holman, D. et al. (1 more author) (2009) Control theory model of emotion regulation: A dynamic model of emotion. In: Proceedings of;. 10th IFIP Working Conference on Virtual Enterprises, 7-9 October 2009, Thessaloniki, Greece. .

Control Theory of Emotion Regulation: A Dynamic Model of Emotion

David Cameron[1], Peter Totterdell[1], David Holman[1], Stuart Bennett[2]

[1]Institute of Work Psychology, The University of Sheffield,
Sheffield, UK
[2]Department of Automatic Control and Systems Engineering, The University of Sheffield,
Sheffield, UK

Abstract. The design and development of a computer simulation model of emotion dynamics is described. The architecture of the model is based on a control theory of emotion regulation. Two levels of control are incorporated in the model. The lower level is organized around the use of deep acting and surface acting to regulate internal emotional state and display of emotion, and the higher level is organized around conservation of regulatory resource. The model resolves conflict between multiple goals of meeting emotional display standards while avoiding emotional exhaustion. Details of the implementation of the model and how it is being evaluated are presented.

Keywords: Emotion Regulation, Control Theory, Ego-depletion, Simulation Model

1 Introduction

There is an increasing acknowledgement that emotions and emotional experiences can be best understood when considered in terms of their dynamic properties [1], [2]. Emotions are often treated as short flash-like responses to an event, whereas they can unfold across time with intensity of response fluctuating in response to external and internal events [2]. These fluctuations depend on the way in which individuals appraise events and regulate their response to them. Although computer models have been developed that incorporate event appraisals in an attempt to capture such dynamics [3], [4], as yet no known computer models have been developed to examine whether the temporal dynamics of emotion states can be produced using principles of emotion regulation [5]. Emotion regulation is recognized as an effortful process, and hence a model of this nature could help expand our understanding of how emotion regulation relates to states of depleted psychological well-being, such as emotional exhaustion [6]. In this paper we present such a model and describe how it has been translated into a computer simulation that can be tested against empirical data from human volunteers. However, first we outline the theoretical basis for the model.

1.1 Control Theory

Control theory has been proposed as a cognitive architecture to explain a wide variety of behavior [7], [8]. A primary principle of control theory is that higher-level abstract goals set standards for lower levels of cognition, which in turn set standards for actions. Within each level, an input state is monitored and compared against the standard. A discrepancy between the two initiates an effector whose actions are aimed at changing the input state. The process continues until the discrepancy is reduced to zero. If behavior at a low level is insufficient for the current task, the standard that it must meet is adjusted by altering control at the next level up. For example, it has been postulated that there may be as many as nine layers of control for a task such as safe driving [8]. These layers include: gripping the steering wheel, assessing quality of driving, and being a responsible citizen. Each level in the control hierarchy impacts on the performance of lower levels of control. Emotion regulation can be viewed as the altering of one's emotional states to meet target (i.e. goal) states of emotion, and as such can be conceptualized using a control theory framework.

1.2 Emotion Regulation

According to the circumplex model of affect [9], feeling states such as emotions can be distinguished according to the extent to which they involve the orthogonal underlying dimensions of pleasure and arousal. For this early stage in the model's development, emotion is considered across just the first dimension; emotion states are conceived as varying in intensity of pleasure on a continuum from very positive to very negative. While, this limits the diversity of emotions modeled, the regulatory architecture of the model is relevant to other emotions too.

People often regulate their emotions in order to express emotions that meet the appropriate emotion display requirement for their situation. When people have to display specific emotions as part of their employment it has been termed emotional labor [10]. For example, customer service employees are often required to express positive emotions to customers regardless of their current emotional state. Emotional labor has been conceptualized in terms of control theory [11] because to meet such emotional display requirements, employees must assess their own emotional state and compare it to a held standard. If there is a discrepancy between the two then individuals use emotional regulation strategies to reduce this difference.

Two of the main processes by which people deliberately regulate their emotions to meet display requirements are deep acting and surface acting [12]. Deep acting is the process by which the internal emotional state is altered, through means such as remembering past emotional experiences (as in method acting), in order to facilitate the appropriate emotional expression. In contrast, surface acting affects a person's display of emotion but not the felt emotion. Continuous emotional regulation, particularly surface acting, appears to place a large strain on employees, which can result in emotional exhaustion and even burnout [13].

There is debate about the extent to which people maintain coherency between internal emotional state and expressed display state, with evidence both for [14] and against [15] coherency. In order for deep acting to influence the model's expressed state, and thus meet required display rules, a degree of coherency is necessary. A reciprocal influence as indicated by the facial feedback hypothesis [16] suggests that displayed emotional expressions can also have an effect on internal emotional states.

1.3 Regulatory Resources

A variety of theories have used the concept of resources to account for human behavior. Although the theories often refer to different resources (for example, individual self efficacy and social support are both seen as resources), they have in common the idea that people strive to obtain and conserve resources [13].

The strength model of regulation argues that all forms of self-regulation, including emotion regulation, require conscious effort that drains mental resources [6], [17], [18]. The drain on resources, or *ego depletion* as it is also known, causes diminished performance in subsequent regulation attempts. For example, conscious emotion regulation, such as the suppression of emotion expression while watching an upsetting film, has been demonstrated to temporarily deplete mental resources and reduce performance in a physical self-regulation task [18]. Regulatory resource has been linked with blood glucose levels. For example, participants who had undergone ego depletion were better able to self-regulate after consuming a sugary drink than those who had consumed a sweetened, but low sugar, drink [19]. A recent review indicates that available mental resource for different types of self-regulation may be a function of physical energy within the body [20].

Available energy is known to fluctuate throughout the day as a function of circadian and ultradian rhythms and time since sleep. The three process model [21] of alertness therefore provides a suitable starting point for modelling internal changes in resource availability. In this conception, resource steadily decreases as a function of time from last period of sleep and is further affected by circadian and ultradian rhythms. Resource is regained during periods of sleep. The aim for this model is to demonstrate how emotion states change dynamically as a function of the regulatory resource that is available for meeting display requirements.

2 Design of the Model

A brief overview of the model's structure and salient features is presented here, along with an outline of how it can be used to simulate the dynamics of interaction. The model is intended to provide a general description of behavior rather than a specification of actual neural processes.

2.1 Levels of Control

The structure of the model builds upon the aforementioned control model of emotional labor [11]. However, for the purpose of parsimony, that model has been simplified from the proposed four layers of control with ten values to control (in [11]) to two layers of control and four values to control (see figure 1). Higher, and more abstract levels of control (e.g., to maintain a desired self-concept [11 p.949]) have been omitted to create a model of emotional labor and emotional exhaustion based solely on the concept of regulatory resource.

The layers of control are divided so that the lower control loops (*emotion control*) regulate emotion to meet the standard set by the higher loops. In turn the standards set by the higher loops are controlled to preserve resource (*resource control*). The model has the potential for higher layers of control to be added (for example to model intentions in interpersonal regulation). However, the potential increase in accuracy of the model that comes from adding a layer may not be sufficient to warrant the accompanying increase in model complexity.

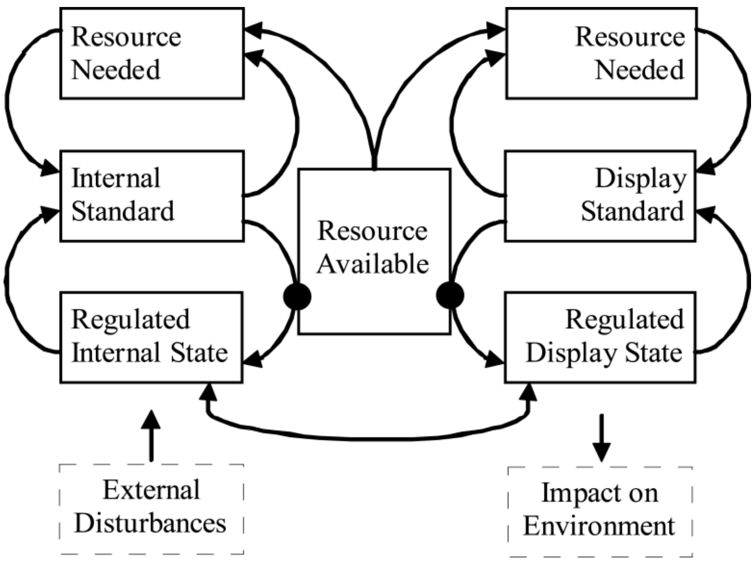

Fig. 1. Schematic of resource model indicating hierarchy of control. Points of high resource consumption are shown (*filled circles*).

2.2 Regulation of Emotion

Each of the two control layers in the model is further divided into two categories: internal emotion state and displayed emotion state. Emotion states are represented as numeric values along a single bipolar dimension from negative to positive. This is in keeping with the circumplex model of emotion [9] because it could represent a dimension such as unhappy-happy. Differences between different types of emotions are not currently addressed.

The internal states (left-hand side of the model) determine both the intensity of regulated emotion that is felt and the target for the intensity of emotion desired. If the model has sufficient resource, it will aim to reduce any discrepancy between those two values through internal regulation, (deep acting). Internal emotion state receives input from sources external to the model, such as the emotional expression that is output from a simulation of a second person.

The displayed states (right-hand side of the model) determine the intensity of regulated emotion that is expressed and the standard for the intensity that should be expressed. To reduce a discrepancy here, the model can either engage in deep acting (which in turn influences the display state) or, if there is insufficient resource for deep acting, surface acting. Displayed emotion sends outputs to destinations external to the model, such as emotional expression input into a simulation of a second person.

To address the issue of coherency between internal emotional state and displayed emotion state, the model includes two pathways connecting the internal and display states. The first pathway, from internal to display, is a necessary path to enable deep acting to have a positive effect while also ensuring that the display state somewhat reflects the internal state. The second pathway, from display to internal, is a path representing facial feedback. It is necessarily weaker than the first path to prevent surface acting having an unduly substantial impact on internal emotions.

2.3 Regulation of Resources

A central resource bank governs the model's choice of regulation method. During periods of high resource, the model regulates the internal emotion state and/or the display state. At moderate levels, the resource is considered too low for internal regulation so it regulates the display state and/or changes the target states at the higher level to a more achievable level. Finally, if resource is too low then target states are altered by means of initiating control at the higher level.

Resource in the model fluctuates throughout the day, is consumed by acts of self-regulation and is replenished with sleep. As predicted by the strength model [17], resource is consumed by regulation so that the model cannot indefinitely undergo successful regulation. Higher levels of regulation, such as deep acting, consume more resource than a readjustment of a target. Resource consumption is a function of both the duration of regulation and the distance from the emotion goal. Readjusting target states serves to reduce the initial consumption of resource, creating an emergent goal of resource conservation.

3 Implementing the Model

3.1 Overview of Model Dynamics

Within the model, emotional stimuli are represented as impulse disturbances to the internal emotional state. Emotional events are additive over time, such that multiple events will contribute to a higher emotional state than any single impulse. Working opposite this is a continual decay of the internal emotional state so that repeated stimuli do not result in a runaway effect - having two cups of tea is not twice as pleasurable as one.

Internal state is affected by emotion regulation as well as emotion stimuli; the effect of deep acting regulation is rapid and substantial so that it can overcome both the continual decay and stimuli disturbances of the internal emotion state. The effectiveness of regulation is determined by the fluctuations in resource availability.

The display of emotions operates in a similar manner, but disturbances come from the internal emotional state rather than external emotion stimuli. Without regulation towards a target display state, the display is guided by the internal emotion state. The effect of surface acting regulation is also substantial so that it can overcome disturbances.

3.2 Programming Details

A prototype of the model has been programmed using the Matlab environment, Simulink. The resolution of the model enables one data point to be generated per simulated minute, resulting in a total of 1440 data points across a modeled day. The model can be run over multiple simulated days to examine different effects, such as how broken sleep affects the model's regulation ability.

4 Evaluating the Model

The model will be tested and refined in a series of planned future studies: 1) The model's plausibility will be tested by altering its parameters to check its behavior under a range of boundary conditions, and the effects of individual differences will be examined by changing the model's parameters (e.g., the gain on inputs and outputs). 2) The model's behavior will be tested against time-series emotion data collected from human volunteers, 3) The model will be connected to its clone to simulate how two people affect each other's emotions, and the data will be compared against data from human dyads (e.g., married partners), 4) Multiple versions of the model will be connected to each other simulate a small social network. This data will be compared against data collected from small group interactions.

Figure 2 illustrates how the model can be used to compare the behavior generated by the simulation against real-time data collected from a human volunteer. The volunteer recorded her intensity of state happiness on waking and then on each hour until going to sleep. The model's internal emotion state was recorded at equivalent points in the simulated days. Resource recovery during sleep was determined by using volunteer's wake and sleep times.

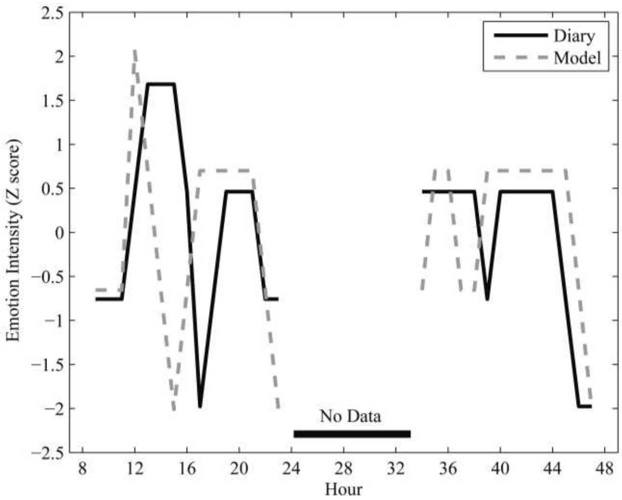

Fig. 2. Example comparison of diary data from a human volunteer (recorded happiness) and model data (positive internal state). As diary entries were not recorded between hour 24 and 33 (*bold bar*) modeled data for this time period have also been omitted.

In addition to examining how well the model's behavior fits human data, another question to consider when evaluating a simulation model is whether it can generate results that are outside of the range of empirical data. If the model can generate results well outside this range then matching empirical data is less impressive [22]. A method suggested in computational neuroscience research called *models-as-animals* ensures constrained data. Using the model as though it were a human volunteer (figure 2) opens up the possibility of replicating reported studies. However, sample size and other study design characteristics can affect statistical outcomes reported in studies, so replication of the method by which empirical data was collected is essential to ensure that simulation models are not incorrectly accepted or rejected [23].

Models that produce constrained data under circumstances that are representative of the research study being replicated provide a solid and compelling base from which to start generating predictions for further studies to test. For example, the emotion model could be used to examine the likely effects of rigid display requirements or altered sleep on emotions without subjecting human volunteers to aversive regimes.

Acknowledgements

This research was partly supported by ESRC large grant RES-060-25-0044: "Emotion regulation of others and self (EROS)". We would like to thank the three anonymous reviewers for their comments and suggestions.

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