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EMOTION REGULATION AS EMOTION MODULATION

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Abstract

Although the study of emotion regulation constitutes a thriving research field, there is still an ongoing debate about the very notion of emotion regulation. According to a popular approach, regulation is a second-order process which is different from (and modifies) emotion. This view has been challenged by the fact that emotion regulates itself through different feedback loops. Emotional feedback suggests that regulation may be a form of control (as defined in control theory). In this paper, I argue that none of these characterizations captures all the intended applications of the notion and propose instead to identify regulation with modulation. In neuroscience, modulation is the process of changing the shape of an input-output relation. This is a notion that can be applied to the different regulatory strategies proposed in the literature and which is compatible both with second-order and feedback regulation.

KEY WORDS: Emotion; Regulation, Feedback; Modulation.

Resumen

Aunque el estudio de la regulación emocional es un campo de investigación pujante, todavía hay un debate en torno a la noción misma de regulación emocional. Una propuesta muy difundida afirma que la regulación es un proceso de segundo orden que es diferente (y modifica) a la emoción. Esta caracterización ha sido cuestionada sobre la base de que frecuentemente las emociones se regulan a sí mismas por medio de diferentes formas de retroalimentación. La retroalimentación emocional sugiere que la regulación podría ser una forma de control (tal como es caracterizada en la teoría del control). En este trabajo, argumento que ninguna de estas dos caracterizaciones captura todas las aplicaciones pretendidas de la noción y propongo en cambio identificar a la regulación con 'modulación'. En neurociencia, la modulación es el proceso de cambiar la forma de una relación input-output. Esta es una noción que puede ser aplicada a las diferentes estrategias regulatorias propuestas en la literatura y que es compatible con la regulación de segundo orden y la retroalimentación emocional.

PALABRAS CLAVE: Emoción; Regulación, Retroalimentación; Modulación.

1. Introduction

The study of emotion regulation is a relatively recent field of research in which a great variety of psychological disciplines are involved. Significant progress has been made in understanding

emotion regulation in the cognitive, neural, behavioral, developmental and social domains (Gross 2014). However, the main concept that defines the area is difficult to characterize. Although there is some consensus regarding the characterization of specific processes that regulate emotion, there is still some debate around the general notion of emotion regulation. Gross has proposed that regulative processes are second-order processes that modify emotions and are different from them (e.g. Gross and Thompson 2007 and Gross 2008). Against this approach, it has been argued that emotions often regulate themselves through different kinds of feedback loops (Kappas 2011). This implies that emotion and emotion regulation are not always different processes and therefore Gross' proposal cannot provide a general characterization of emotion regulation.

In this paper, I postulate emotion modulation as a notion that can be applied both to second-order valuations and to feedback processes. In section 2, I present the second-order approach. In section 3, I develop the emotional feedback challenge and show that it has a problematic implication for our understanding of emotion regulation. Once we reject the idea that second-order processes are constitutive of emotion regulation, we are left with a notion that is either too strong or too weak. The idea of control, as it is usually understood in control theory, underlies Kappas' examples of emotion self-regulation. I argue that no plausible reading of 'control' can be used as an alternative characterization of a general notion of regulation. The strong reading of the term excludes all second-order regulative processes. The weak reading (a weak notion of feedback processing) can be plausibly applied indiscriminately to all cognitive processes. In section 4, I propose to characterize emotion regulation as emotion modulation. In neuroscience, modulation is the process of altering the function of a given neural structure, that is, the process of modifying the shape of its input-output relation. I claim that this notion has the right degree of generality for characterizing regulation. On one side, this proposal makes no assumption regarding the mechanisms that can implement regulation. This process can be implemented both by second-order valuations and by feedback loops. On the other side, the notion is not trivial. It is always possible to distinguish any given process from its modulation. Finally, in section 5, I test the proposal by showing that it can be applied to problematic forms of emotion regulation.

2. Emotion as Second-Order Valuation

'Regulation' is not the only elusive notion we need to characterize in order to clarify the conceptual foundations of emotion regulation studies. Concerning the notion of emotion, Gross (2015) cautiously resists providing a definition and offers instead an emotion prototype, that is, a set of typical, salient and diagnostic properties of emotions. Emotions are events often constituted by a sequence of four related sub-events: (1) The presence of a relevant (often external) situation causes a subject to (2) pay attention to some aspects of that situation. Then, (3) the subject evaluates those aspects expected with respect to her goals. Finally, this evaluation causes (4) a series of changes in experiential, behavioral, and neurobiological response systems.

A classification of emotion regulation strategies naturally emerges from this characterization of emotion episodes. Different kinds of emotion regulation can be understood as interventions on different components of emotion (Gross 2015). A brief description of these strategies is relevant because they constitute (part of) the intended applications of 'emotion regulation'. An adequate characterization of the notion should apply to most of them. First, we can alter the situation that contains an emotion eliciting stimulus. This can be done in two different ways. Situation selection is the set of actions that make it more (or less) likely that one will have an encounter with the emotional stimulus. We apply this strategy, for instance, when we try to avoid attending an annoying family reunion. Situation modification is the set of actions that modify the situation which contains (or does not contain) the relevant stimulus in order to reduce (or enhance) its emotional impact. We apply this strategy, for instance, when we ask a friend to support us while we face a stressing situation. In what follows I will use 'situation manipulation' as a general term for these two strategies.

Attentional deployment is the strategy of directing attention towards or away from emotionally meaningful aspects within a given situation in order to enhance or inhibit the emotional response. When we try to avoid making eye contact with someone we are attracted to or scared of in order to diminish the emotional response we employ this strategy. Cognitive change is the strategy of modifying our emotions by changing the way one appraises a situation. An appraisal, as usually characterized by appraisal theorists, is the process of detecting and assessing the significance of some aspect of the environment for our well-being (Moors, Ellsworth, Scherer and Frijda 2013). This process usually involves different dimensions of evaluation. For instance, it

requires determining whether a given situation is beneficial or harmful and determining one´s capacity to deal with that situation. Cognitive change is modifying one or more of these dimensions of evaluation. For instance, one could regulate the fear elicited by the encounter with a scary-looking animal by thinking that the animal is probably not dangerous or by considering that we are able to defend ourselves from it. Lastly, response modulation directly influences experiential, behavioral, or physiological components of the emotional response. This includes a wide variety of strategies. One can employ different drugs that target specific somatic aspects of the emotional response. For instance, we can take anxiolytics to reduce muscle tension or beta-blockers to reduce sympathetic hyper-reactivity. Deep breathing relaxation or physical exercise can be also used as forms of response modulation. Another common form of response modulation involves regulating emotion expressive behavior (Gross, Richards and John 2006).

Although characterizing interventions on different variables of the emotion process is relevant for distinguishing between different regulatory strategies, this is not sufficient for understanding what emotion regulation is. Modifying the value of a variable in a mechanism is not sufficient for regulation. The normal functioning of any mechanism always involves the modification of some of its components by a given input. Characterizing regulation in this way would trivialize the notion (i.e., it would apply to all cognitive processes). Gross (2015) provides a more detailed model of emotion regulation. It is what he calls 'The Extended Process Model of Emotion Regulation'. He claims that this model is necessary in order to answer more specific questions about emotion regulation. For instance, a more detailed characterization is required to explain how various emotion regulation strategies are actually started or stopped or how different strategies are chosen. However, for the mentioned reasons, this model is also required to address the more fundamental question of what emotion regulation is.

Gross' proposal is that emotion regulation is a valuation process. This is a process that involves different components. The first two components are the world (designated by a "W" variable) and the perception of the situation being evaluated ("P"). The third component is a valuation or appraisal ("V"). More specifically, Gross characterizes a valuation as a juxtaposition of a representation of the world with a representation of a desired state of the world (a goal or target state). Finally, an action component ('A') represents the actions or action impulses that are caused by the relevant valuation which are supposed to reduce the gap between the perceived state of the world and the desired state of

the world. Emotion regulation takes place when a valuation mechanism or system takes the state of some component *c* of the emotion process as a target and evaluates it either negatively or positively, activating action impulses that are intended to modify or sustain *c*.

As Gross points out, a valuation process has the same components as emotion: the W-P-V-A sequence can be identified with the abovementioned situation-attention-appraisal- response sequence. This means that emotions are valuations in this sense. This is why emotion regulation can be seen as a *second-order* valuation. It is a valuation process that targets a component of other valuation processes. It is relevant to note that this does not imply an identification of emotion with appraisal. As mentioned above, a valuation process includes all of the components associated with the emotion prototype.

This is only an outline of the extended process model. There are at least two dimensions along which emotion regulation can be further characterized. First, Gross divides valuation into three different stages: an identification stage (which determines if emotion regulation is required), a selection stage (in which the most suitable strategy is chosen), and an implementation stage (in which it is decided how the strategy should be carried out in the given context). Second, valuation is not always a high-level process. Ochsner and Gross (2014) describe different neural systems supporting valuation at different cognitive levels. Core level valuations (which occur in the amygdala and ventral striatum) are links between stimuli and reinforcers. Contextual level valuations (which occur in vmPFC/OFC) place these links in their historical, social, and motivational context. Finally, conceptual level valuations that represent the value of stimuli in belief-desire terms (in rostral and dorsal medial PFC) that may be verbalizable and consciously reportable.

Although these additional aspects of the model are important to understand how emotion regulation works, they are not necessary in order to characterize the notion of emotion regulation. The trivialization problem mentioned above can be avoided by endorsing the minimal characterization of emotion regulation as a second-order valuation. This proposal already implies that not any process that results in the modification of a component of an emotion counts as regulation. More generally, not any process that results in the modification of a component of a cognitive mechanism counts as a regulation of its function. According to this proposal, regulation only occurs when this modification is the result of a second-order valuation. This characterization of emotion regulation is specific enough to draw a conceptual distinction between a process and its regulation and abstract enough to be applied to the

different strategies we considered. However, there are instances of emotion regulation that do not depend on second-order valuation. In the next section, I will examine different self-regulatory processes implemented by emotions.

3. Emotion Self-Regulation and Emotion Control

One of the main arguments that Kappas (2011) proposes in order to undermine the view that emotion regulation requires second-order processing is that negative emotions are self-terminating events. When a given stimulus (e.g., a spider) elicits a negative emotion (e.g., fear), the emotion produces a behavior (e.g., killing the spider, running away, etc.) that is oriented to suppress in some way the presence of the eliciting stimulus and, consequently, the emotion itself. Kappas affirms that all negative emotions are self-terminating in this sense and that this involves some kind of self-regulation.

These processes are inconsistent with Gross' view because they imply that regulation does not require any additional process that is different from emotion. According to the emotion prototype proposed by Gross, the behavioral response that produces the elimination of the emotion-eliciting stimulus (and therefore the termination of emotion) *is a constitutive part of the emotion episode*. The physiological, experiential and behavioral responses produced by a valuation constitute the fourth component of the emotion process. This means that, *pace* Gross, these regulatory processes are not different from the emotion itself.

These considerations show that this is an objection that depends on Gross' view of *emotion*. Based on an argument proposed by Gross and Barret (2011), Gross (2014) affirms precisely that there are many different ways to define an emotion, each of which suggests a different take on how (and whether) emotion and emotion regulation should be distinguished. Gross and Barret (2011) argue that basic emotion approaches (in which emotions are determined by well-defined biological mechanisms) and appraisal theories (in which emotions are defined by a specific set of evaluations) are consistent with a clear distinction between emotion and emotion regulation. In contrast, in psychological and social constructionist approaches, which view emotion as the result of individual or social cognitive processes, the distinction between emotion generation and emotion regulation seems arbitrary or artificial

Having this idea in mind, we can say that Gross' claim is that his emotion prototype approach is one of the views that is consistent with the distinction between emotion and its regulation. In turn, we can see

Kappas' argument as an objection to this claim. In what follows, I will deal with this reading of the objection. I will argue that the prototype approach is consistent with the distinction. Thus, I do not intend to claim that emotion and emotion regulation are distinct under any view on emotion.[1]

Surprisingly, Gross (2015) dismisses Kappas' objection by merely stipulating that regulation implies (specifically under the prototype view of emotion) second-order processes. The problem with this response is that emotion self-termination can be characterized as an instance of what is known as 'control', a process that is *prima facie* similar to regulation. Control is characterized in control theory as a form of negative feedback loop. A feedback system is constituted by a 'plant' (the object to be controlled), a sensor to measure the output of the plant and a controller to generate the plant's input. The output signal is compared to a desired reference signal and the discrepancy is used to compute corrective control action (Doyle, Francis and Tannenbaum 1992, pp. 1, 27). In emotion self-termination, the emotion can be taken to be an output signal. When this signal is sensed, its input (the presence of a spider) is modified through the controller (e.g. the motor systems responsible for the behavior of killing the spider) to obtain the desired reference output signal (the absence of fear). If we accept that control in this sense is (some form of) regulation, then emotion self-termination is a regulatory process and therefore we cannot identify regulation with second-order valuation. In order to reject this idea, one should distinguish between regulation and control. Although Gross does not offer reasons to draw this distinction, they are indeed different.

As mentioned in the previous section, second-order valuation is useful in order to avoid the trivialization problem. This is why we cannot simply reject Gross' characterization. If we accept that regulation is a genuine phenomenon, we need to provide an alternative proposal. A candidate suggested by the consideration of emotion self-termination is the notion of control. However, one should notice that this is not a proposal advanced by Kappas himself. He only proposes these cases of control as counterexamples to the second-order view and not as instances of an alternative *general* notion of regulation. My point is that, once we reject the second-order view, the notion of control provides an alternative possibility for providing a general characterization.

[1] It is possible that there are few views under which the distinction can be made. I have argued elsewhere (Wajnerman Paz 2019) that even some biological approaches, such as Tooby and Cosmides evolutionary view, blur the distinction between emotion and its regulation.

Nevertheless, this proposal is problematic. We saw that control theory characterizes a control system as a kind of feedback mechanism which directly manipulates (through its controller) its own input. Instances of second-order regulation are feedback processes in some sense. Some aspect of the emotion process (one of its outputs) triggers a second-order process which in turn modifies this aspect of the emotion. However, these are not instances of control because the regulation is not produced by the same mechanism that produces the output (the emotion itself or one of its components). As we have seen, Gross distinguishes between many regulatory neural mechanisms that are different from those underlying emotions themselves (i.e., mechanisms for core, contextual and conceptual level regulation).

An alternative possibility is to identify regulation with a more general notion of negative feedback, which would include both cases of control and 'indirect' feedback processes, such as those implemented by second-order regulation. The problem is that this notion would be too wide. It is plausible that there is no cognitive (and non-cognitive) process performed by a living being which is not a feedback process in this sense. Maturana and Varela's famous insight was precisely that all (or most) processes performed by living beings are interactions with their environments aimed at regenerating and realizing the network that performs these processes (i.e., autopoiesis, Maturana and Varela 1980, pp. 78-79). Autopoietic theory draws a clear line between organisms and their environments (Villalobos and Razeto-Barry 2019) and therefore autopoiesis may involve mechanisms in the environment that are different from those in a living being (sometimes even including mechanisms in other living beings). Thus, autopoiesis is perhaps not a form of control (in the sense of a more or less 'direct' feedback function). However, it involves at least an indirect feedback process of an organism (i.e., feedback meditated by mechanisms in the environment). This insight implies that if we identify regulation with negative feedback it would be impossible (or very hard) to find any mechanism in a living being that is not regulatory and therefore the notion of regulation would be trivialized.

To summarize, we cannot characterize regulation as control because this notion does not apply to Gross' second-order processes insofar as these constitute instances of indirect feedback. We cannot identify emotion regulation with a general notion of feedback because it would be too permissive. Plausibly all or most (cognitive and non-cognitive) processes in living beings can be understood as involving some form of (direct or indirect) feedback. In the following section, I will propose an alternative characterization.

4. Emotion Regulation as Emotion Modulation

In order to characterize emotion regulation within a prototype approach emotion, it is crucial to understand some aspects that emotions have under this view. As we saw, Gross characterizes an emotion process as a series of causally connected events that occur within a given time interval. A situation produces a shift in the attention focus of a subject, which in turn produces a given appraisal. Finally, the appraisal causes behavioral, experiential and physiological responses. The causal relations on which this process depends can endure for some time (i.e., they can be more or less stable). If fear is caused in a subject by the presence of a spider at time *t*, then (*ceteris paribus*) the presence of a different spider an hour later would also cause a fear response in the same subject. These two instances of fear can be seen as different manifestations of the same set of (more or less) stable causal relations.

This characterization of the emotion process is relevant for distinguishing between two ways in which it can be altered. Two kinds of interventions can be identified by contrasting situation manipulation with the other regulative strategies. In situation manipulation, an emotion is produced or inhibited merely by presenting, removing or modifying the relevant eliciting stimulus. This is simply the form of feedback control implemented by Kappa's fear example: an emotion can be controlled by merely presenting, removing or modifying the inputs or causes on which its occurrence depends. In contrast, the other regulatory strategies modify an emotion process by *altering the stable causal relations between its components*. For instance, given the input situation for a given emotion, attention deployment changes the normal attentional response to that situation. Cognitive change modifies the normal appraisal reaction to a given attentional focus. Response modulation changes some of the causal reactions of response systems to a given appraisal.

Situation manipulation does not modify any causal relation in this way. If I prevent fear by removing a spider from a subject's environment, reintroducing the spider in the environment will bring back fear. The causal relation is intact. All the other regulatory strategies require (at least momentarily) breaking or modifying some of the causal links on which the emotion process depends. Following the terminology introduced in the last section, I will call 'emotion control' to merely presenting, removing or modifying the normal cause of an emotion. In contrast, I will call 'emotion modulation' the interventions

that change the causal response of a component of the emotion process to a previous component in the chain. This characterization shows why situation manipulation cannot produce modulation: given that it is the first component in the emotion process, there is no previous emotion component from which it could be disconnected. In what follows I will justify the adopted terminology by showing its connection to well-known neural processes.

At the cellular level, neurons can be related in different ways which are relevant to the implementation of different computational and information processing operations (e.g., Silver 2010). The response of a neuron *b* (its spiking or spike rate) can be said to be driven by the responses of another neuron *a* when a given variation in *a*'s spiking causes a specific variation in *b*'s spiking through the synapse which connects them. This relation can be excitatory (usually when glutamate is the neurotransmitter mediating synaptic communication) or inhibitory (usually, when the neurotransmitter is gamma-aminobutyric acid or GABA).

In contrast, the neuron *b* can be said to be modulated by a neuron *c* when, although *c*'s spiking cannot cause *b*'s spiking (or not spiking) by itself, it can change the input-output relation between *b* and its driving input *a*. For instance, *c* can work as a neural gain which increases the response of *b* to *a*'s spiking. Sometimes (although not always) neuromodulation depends on the kind of neurotransmitter released by *c*. The more common neuromodulators are dopamine, serotonin, acetylcholine, histamine, and norepinephrine. For instance, different models characterize dopamine as responsible for gain modulation (Figure 1) (e.g., Servan-Schreiber, Printz and Cohen 1990, Moyer, Wolf and Finkel 2007, Thurley, Senn and Lüscher 2008).

Neuromodulation can also be defined as the alteration of the neural input-output function through changing neuronal properties, presynaptic release, or postsynaptic responsiveness of cellular or synaptic properties. Neuromodulation is often identified with heterosynaptic plasticity, in which the alteration of cellular and synaptic properties is achieved through the activity (e.g., neurotransmitter release) of *another* neuron. This notion is different from homosynaptic plasticity (exemplified by processes such as synaptic depression and long-term potentiation), in which the properties of a neuron or a synapse are altered by *its own* pattern of activity (Katz and Calin-Jageman 2009).

This distinction is very relevant for our discussion, insofar as it is similar to the difference between Kappas' self-regulatory mechanisms and Gross' second-order regulation. Interestingly, in this case, we have

a common notion that can be clearly applied to both forms of plasticity. Here, I will use 'modulation' to refer to the modification of the input-output function of a mechanism, irrespective of how this modification was achieved.

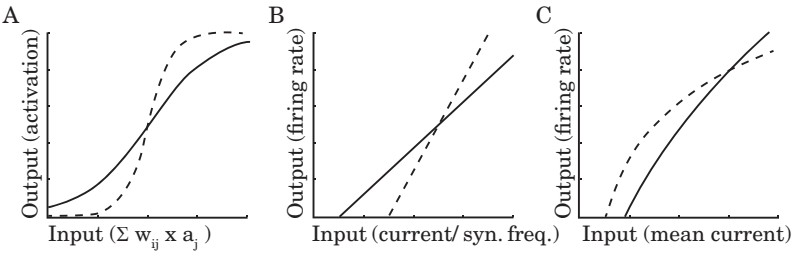

Figure 1, from Hass and Durstewitz (2011). Different models of neural gain generated by dopamine modulation of a neuron input/output (I/O) function. Solid lines represent neural normal function, dashed lines represent the result of dopamine modulation. A) One of the earliest computational proposals was that dopamine increases the slope (gain) of this sigmoid I/O function (Servan-Schreiber, Printz and Cohen 1990). B) Simulations in a biophysically and morphologically highly realistic representation of a striatal MSN provided evidence for this idea (Moyer, Wolf and Finkel 2007), although I/O functions for the simulated MSN were almost linear. C) Dopamine modulation in prefrontal cortical pyramidal cells in vitro stimulated with a fluctuating somatic current input (Thurley, Senn and Lüscher, 2008).

It is clear that the process of emotion modulation I have described is a *high-level* form of neural-level modulation. Emotion modulation is changing the input-output relation between one of the (cognitive level) emotion components and subsequent (cognitive) component(s) in the process. Thus, I propose to identify emotion regulation with a form of *high-level modulation*. This characterization seems to have the right degree of generality. On the one side, it avoids the trivialization of regulation implied by the feedback proposal. Although all cognitive processes performed by living beings may be instances feedback, not all of them are modulatory. Notice that even if many cognitive processes are actually modulated, this situation would be consistent with the distinction between regulatory and non-regulatory processes. We can always distinguish between performing a given function (the implementation of a given input-output relation) and the *modification of that function*.

The possibility that many processes are modulated introduces a further concern. As Katz and Calin-Jageman (2009) point out, modulation is a ubiquitous phenomenon at the neural level, that is, it may be the case that all neural mechanisms involve some form of modulation. This implies that the *generation* of any cognitive process (including emotions) requires modulation at the level of the neural mechanisms implementing them. However, this does not mean that we cannot distinguish between the modulation and the generation of such processes. As I mentioned above, I identify emotion regulation with *high-level* modulation and, specifically, with the modulation of the high-level components which, in Gross' view, constitute an emotion. Thus, even if the *production* of the appraisal in an emotion process (e.g., judging an object as dangerous) requires modulation at the level of its underlying neural mechanism, its regulation requires specifically the modification of *the relation between that evaluation and some of the previous high-level elements in the emotion process* (e.g., experience of the stimulus or attention state)[2]. The evaluation would be regulated when, for instance, we are able to evaluate the dangerous object as harmless without modifying the situation, perception or attention state (i.e., by changing specifically the causal relation between the stimulus and the original evaluation).

Another advantage of the proposal is that the notion of modulation is silent regarding its implementing mechanism. Whether cognitive change, for instance, is implemented by a feedback process, a second-order valuation or any other kind of process, it will count as an instance of emotion modulation. Modulation only describes the fact that an input-output relationship or function was modified in some way. As can be seen in Figure 1, the description of a modulatory process only requires the description of the original and the modulated input-output mappings. No additional components or activities are introduced. No assumption about the implementing mechanism is required. This means that the notion of modulation provides a description of the phenomenon of regulation that is neutral as regards its possible explanations.

In the next section, I will test the ability of this proposal to account for the different kinds of emotion regulation by considering three special cases: habituation, satiety and situation manipulation.

[2] By 'high-level' I refer to any level at which *cognitive* states appear. However, we saw that emotion regulation may occur at different cognitive levels (Gross' core, contextual and conceptual levels)

5. Testing the Proposal

5.1 Satiety and habituation

In addition to the emotion self-termination of negative emotions, there are two other forms of self-regulation (also mentioned by Kappas 2011). Phenomena such as habituation and satiety also imply that emotions are constitutively self-regulatory. Briefly, satiety is the form of self-termination that positive emotions possess. This is the mechanism that explains why we are not trapped in the positive feedback loops of positive emotional states. In turn, habituation is a form of self-regulation that both positive and negative emotions have. When a stimulus is presented repeatedly or continually (without significant changes) habituation will produce a reduction of its physiological and psychological responses.

As we saw, the behavioral response in negative emotions often results in the self-termination of the emotion. By contrast, positive emotions cause attempts to prolong or reinforce them (Oishi, Diener and Lucas, 2007). However, it is known that prolonging positive emotions indefinitely can render subjects dysfunctional (Smith, Mahler, Pecina and Berridge 2010). This is why satiety is necessary as a mechanism to stop the positive feedback loop. Positive states are constituted by an appetitive activity which is terminated by a consummatory response (see Georgiadis and Kortekaas 2010). We currently know, to some degree, the neural mechanisms underlying these processes ('wanting/reward' or 'pleasure/liking' mechanisms) (e.g., Berridge 2009).

It is clear that satiety is a form of emotion modulation. Satiety does not change the emotion-eliciting situation in any relevant way. The effect of satiety is simply to modify the causal relation between the stimulus and the emotional response. For instance, after having eaten or in the post-orgasmic phase of sexual intercourse, satiety (momentarily) inhibits or reduces the normal response to food or to a mating partner. It is known this inhibition depends on hormonal modulation (e.g., Balthazart, Castagna and Ball, 1997 and Balthazart, Reid, Absil, Foidart and Ball 1995. See also Ball and Balthazart 2008). Therefore, this regulative strategy is an automatic or sub-personal form of response modulation. Satiety modifies part of the normal autonomic response to a given stimulus. As mentioned in the previous section, response modulation is a form of modulation in the technical sense I propose. This means that satiety is a regulatory process according to the proposed approach.

A second form of self-regulation mentioned by Kappas is habituation. This is a passive process not only in the sense that (unlike self-termination in negative emotions) it does not require to remove or modify the eliciting stimulus, but also in the sense that (unlike satiety) it does not depend on a behavioral response (such as the consummatory behavior). Habituation is a form of regulation of both positive and negative emotions in which maintaining the presence of the eliciting stimulus (or repeatedly presenting it) diminishes the emotional response. At the behavioral level, habituation has a clear function for an organism.

It is an advantage for an organism to be able to distinguish between potentially dangerous and insignificant stimuli it repeatedly encounters. Being continually startled or distracted by such stimuli would be a waste of the creature's time and energy (Mazur 2017, p. 41). For instance, Mazur (2017) mentions a study by Dielenberg and McGregor (1999) which shows how animals can habituate to a fear-provoking stimulus if the stimulus repeatedly proves to be insignificant. In the study, rats were presented with a cat collar that contained a cat's odor. The response of the rats was to run into a hiding place and remain there for a given time. However, after several presentations of the cat collar, the rats' hiding times decreased and came close to those of the control group of rats that were exposed to a cat collar that had no cat odor on it.

It has been shown that, at least in some species, habituation to sensory stimuli depends on the mechanism of synaptic short-term depression in early sensory neurons (Mazur 2017, pp. 44, 45). Synaptic depression is a form of neural plasticity in which sustained signaling between two neurons diminishes the ability of pre-synaptic activity to generate post-synaptic activity. In the same way as in the case of the dopamine models mentioned in the previous section, synaptic depression can be modelled as a form of gain control (Tsodyks and Wu 2013). That is, synaptic depression modifies the input-output relationship between neurons and therefore is a form of modulation[3]. This means that habituation, at least when it is implemented by synaptic depression, is a regulatory process.

[3] As I mentioned, this is a form of homosynaptic plasticity. It is modulatory only according to a notion of 'modulation' that is more general than the one sometimes employed in neuroscience, which is limited to heterosynaptic plasticity.

5.2. Modulation with situation manipulation

I argued that modulation provides a good characterization of emotion regulation because it avoids the problems that alternative proposals face in accounting for the intended applications of the notion. The second-order valuation approach excludes different forms of emotional feedback. The control view either excludes second-order regulation or (if control is identified with a more general notion of feedback) it is trivially applied to any cognitive process. In contrast, we saw that modulation can be non-trivially applied to second-order valuations, feedback loops or any other mechanism. However, there seems to be an intended application of 'emotion regulation' which the modulation approach fails to account for.

In section 4, I contrasted situation manipulation with the other regulatory strategies and pointed out that, *prima facie*, only the latter count as instances of modulation. This may be a shortcoming if the strategy is one of the intended applications of 'regulation'. However, the implication is not problematic. Situation manipulation is a simple feedback process of producing or preventing the occurrence of an emotion by presenting, removing or modifying the stimulus that normally causes the emotion. As I argued in section 3, if we claim that this is sufficient for counting a given cognitive process as regulative then the notion of regulation would be plausibly trivialized, that is, it would be applied indiscriminately to all cognitive processes. This is why I posited that situation manipulation is a form of emotion feedback and not a form of emotion regulation.

Although situation manipulation is not a form of regulation *per se*, it can be used to regulate emotions. A systematic application of this strategy can result, in the long term, in the modulation of the controlled emotion. In the previous section I showed that habituation counts as an instance of modulation. Here I want to emphasize its connection to situation manipulation. As mentioned, habituation requires the sustained or regular presentation of the eliciting stimulus. This fact alone already implies that the systematic application of situation manipulation (in this case, sustaining or repeatedly presenting a stimulus) is a precondition for habituation. What is more interesting is that the pattern of presentations of the relevant stimulus can determine in a subtler way how habituation occurs.

Habituation is recognized by a series of standard effects (see Mazur 2017, pp 41-42). Some of these effects are the result of different patterns of exposure to the relevant stimulus. First, habituation is

usually a gradual process that progresses over a number of trials. The degree to which the response is decreased will depend on the number of trials or the length of the period of time in which the stimulus was sustained.[4] In the second place, if the stimulus is removed for some period of time after habituation occurs, the response will be recovered. The level of recovery depends on how much time the stimulus has been removed. In the third place, although habituation may disappear if the stimulus is not presented for a long period of time, if the same stimulus is presented again in a sustained manner, the rate of habituation should be faster than the first time. Later, if there is a third or fourth series of stimulus presentations, the habituation should be faster each time. All these effects show that situation manipulation can alter the way in which habituation occurs by altering the way in which the stimulus is presented. Different patterns of situation manipulation produce different forms of habituation and therefore, modulation. Although situation manipulation does not imply emotion regulation, it can become a regulatory process through specific patterns of stimulus presentation.

6. Conclusion

We have seen that a main difficulty in characterizing the notion of emotion regulation is to achieve the right degree of generality, that is, providing an approach that is neither too restrictive nor too permissive. A motivation for Gross' extended process model, which identifies regulation with second-order valuation, is to provide a characterization that is more restrictive or informative than the one we can formulate by merely considering the different regulatory strategies. However, Kappas tried to show that this proposal is too restrictive. The self-termination of negative emotions, habituation and satiety seem to be genuine regulatory processes that are excluded by Gross' approach.

I argued that the problem with Kappas' objection is that it leaves us without a clear understanding of what emotion regulation is. His emphasis on feedback processes suggests that the notion of control can be useful to understand regulation. Nevertheless, I argued that this notion excludes the possibility of second-order regulation and is therefore too restrictive. I also considered the possibility of using the more general notion of feedback, but it turned out to be too permissive.

[4] However, the process is not lineal, decrements are large at first but get progressively smaller as habituation proceeds.

I proposed to characterize emotion regulation as a form of high-level modulation. A first advantage of this proposal is that the notion of modulation refers to a kind of process that it is known to be implemented by the brain even at the cellular level. A second advantage is that identifying an instance of modulation only requires describing how an input-output relation has been modified. This means that the notion involves no assumption regarding the modulating mechanism. It can be implemented by both feedback processes and second-order valuations. The third advantage is that modulation avoids the trivialization problem. It is not too permissive because it provides a clear distinction between regulatory and non-regulatory processes. Also, modulation can be applied to almost all of Gross' regulative strategies. The only problem was situation manipulation. According to the approach, this is a form of emotion feedback.

I offered two reasons to show that this implication is not problematic. In the first place, if the conditions that are sufficient for situation manipulation were sufficient for emotion regulation, then our notion of regulation would be trivialized. This is why it is important to claim that situation manipulation is not regulation *per se*. In the second place, I showed that situation manipulation can eventually have regulatory effects. Different patterns of stimulus presentation can modulate emotion (through habituation) in different ways.

In a nutshell, if we understand emotion regulation as emotion modulation we can avoid the problems presented by the alternative proposals (characterizations that are either too narrow or too wide) while, at the same time, allowing regulation to be implemented by the different proposed mechanisms. Modeling second-order valuations implemented at different levels or modeling different kinds of feedback processes can be essential to explain and understand emotion regulation. However, these processes should not be used to define the relevant notion or *explanandum* phenomenon.

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