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Physics of Life Reviews 31 (2019) 257–262

PHYSICS of LIFE reviews

www.elsevier.com/locate/plrev

Review

Unconscious emotions of human learning

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Available online 24 October 2019
Communicated by Felix Schoeller

Abstract

Brain and behavioral data have provided ample evidence that the largest part of emotion processes occur below the threshold of conscious awareness. In this article, we present computational models of the relation between emotion and cognition describing emotions as homeostatic signals critical to need regulation. These models suggest that an innate drive to regulate information and accompany the genesis of meaning evolved over the history of life. Most emotions underlying this innate mechanism of knowledge-acquisition occur below the threshold of consciousness. We review empirical data on the emotions of deep learning in humans, and suggest three families of unconscious emotions regulating learning. Methods for their measurement are proposed and we suggest that these unconscious emotions are crucial to the well-functioning of cognition, language comprehension, and decision-making.

Keywords: Unconscious emotions; Language; Feelings; Interoception; Aesthetic emotions; Knowledge instinct; Learning; Cognitive hierarchy; Consciousness

It is generally accepted that the bodily activity underlying human emotions (e.g., changes in temperature and heart rate during fear) is accessible to consciousness, and that this body perception (i.e., the predictive processing of special interoceptive signals) determines human feelings [9]. However, empirical data also suggest that a large part of what we call emotion occurs below the threshold of conscious awareness (e.g., [4]). This lack of conscious access to most operations of emotional processes [25,52,48], has lead to a renewal of interest in the cognitive neuroscience of unconscious emotions [21,24,45,26]. Reactions to this idea of unconscious emotions have been both supportive [46] and hostile [7]. Most studies focus on so-called basic emotions and the maintenance of physiological homeostasis (stability of glucose, temperature, sleep, etc.). These emotions only requires conscious feelings when parameters go outside their safe ranges, that is when the situation threatens survival (as in e.g., hunger or fatigue). In other words, emotions allow the animal to become aware of its needs and overcome the constraints imposed by the central nervous system limited processing capacity [31]. Note that when exposed to a salient stimulus below the threshold of conscious awareness, some physiological systems respond, but others do not [49]. Furthermore, these emotions below the threshold of consciousness exist outside the structure of language organizing human cognition. When no

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https://doi.org/10.1016/j.plrev.2019.10.007
1571-0645/

words exist within the structure of language for aggregating bodily signals, the *meaning* of the feeling could remain unknown within a culture over age and generations (e.g., imagine experiencing fear for the first time and to never receive a logical and semantic explanation for the associated sensations). This begs the following questions: what emotions are below the scope of conscious awareness, and how can we study them scientifically?

Some answers to these questions can be found in the emerging physics of mind. Physics of mind is a new branch of science attempting to situate the human mind within its physical universe and to favor the development of new unifying models of its internal workings [35–37,47,13,44,51,3]. Elegant models of how an embodied brain learns to adapt its surroundings in real time [32,13,17] have lead to successful theories of the underlying mechanisms, their function and dysfunctions [30,17]. These parsimonious models have also lead to unexpected predictions about learning [38], the perception-action cycle [6], exploratory behavior [12,41], and associated emotional processes [41]. The physics of mind is founded on the principle that a new drive evolved in the course of the history of life for the purpose of pattern-recognition [37,44]. In fact, evidence suggests that this exploratory drive is more basic than food regulation [18] and has consequences on many other basic regulatory mechanisms, such as for example temperature [41]. Here we suggest that a wide range of emotional processes underlying this drive regulating information occurs below the threshold of consciousness. In the final section, we propose three families of emotions falling under this category and some suggestions for their measurement in future studies.

1. Innate acquisition and associated emotions

In cognitive neuroscience, emotional neural networks are described as *adaptive behavioral programs* reflecting the properties of the animal's environment [31], and closing the loop between perception and action for survival purposes (i.e., preparing behavior to salient stimuli). In this paper we take as a starting point the theory of instincts and emotions outlined in [14]. This theory defines instincts as neural sensory mechanisms measuring vital characteristics for the purpose of self preservation, and informing decision-making brain regions when these signals reach unsafe levels and threaten survival. The neural signals transmitting this information are emotional signals, and the associated states and feelings are experienced internally as emotions. In this way, emotions inform the organism about the satisfaction or dissatisfaction of physiological needs and stimulate appropriate actions through adaptive behavioral programs. For example, when the level of sugar in blood falls below a certain level, we feel an emotion of hunger and orient our behavior to start searching for food. Emotions are therefore fundamentally related to the needs of the organisms, the process of need satiation.

Perlovsky [32] extended the Grossberg-Levine theoretical model of instincts to the biological regulation of knowledge and cognition. Based on mathematical models of cognition and empirical studies of cultural artifacts, the emergence of a new drive in evolution was suggested, subsequently termed *the knowledge instinct*. This mechanism is sometimes referred to as curiosity or more generally exploratory behavior [5] and was the subject of a wide range of animal studies in the 1950s, in its relation to other biological drives [18]. Konrad Lorenz used the phrase "innate acquisition" [27]. This juvenile characteristic in lower animals sustains itself in human beings into advanced age (i.e., it acquires a neotenic character). As all primary drives in higher mammals, a rich emotional life accompanies the satiation of the knowledge instinct. In his seminal work, the German philosopher Immanuel Kant referred to emotions associated to cognition as aesthetic emotions [29]. The study of aesthetic emotions as a measure of the satiation of exploratory behavior and the knowledge instinct holds tremendous explanatory power and has been tentatively validated empirically (review in Schoeller [40]). The knowledge instinct and its associated emotions are described as neural mechanism measuring the correspondence (i.e., conditional similarity) between mental representations and their corresponding objects or states in the world. For example, one's mental representation of a chair can correspond at varying degrees to a given chair observed at any particular moment. In the absence of appropriate models or in the absence of knowledge instinct binding sensory-motor signals to cognitive models, virtually all behavior would be impossible. New aesthetic emotions emerged in the course of evolution to allow organisms control a wider range of reality, extending from predictable niches to the intricate details of a complex and uncertain universe.

Let us briefly discuss mental representations and the related mechanisms of perception. Consider attentively an object in your visual field, e.g. a computer. Pay close attention to your computer and try to remember the details of the object (colors, orientations, shape, patterns). Then, close your eyes and attempt to recollect (i.e., imagine) this object. Your imagination with closed eyes is not as crisp and clear as your perception with opened eyes from just a second ago. The mechanism of imagination is known as top-down neural projections from memory-representation to the visual cortex [22,23,16,15]. The vagueness of imagination in the absence of sensory input testifies that mental representations are vague [2]. When you open your eyes, the perception of the object becomes clear, this seems to occur immediately, but Moshe Bar and colleagues demonstrated empirically that it takes about 0.6 sec for recognition to occur [2]. During 0.6 sec, the knowledge instinct drives imagination towards matching ascending sensory signals projected from the retinas. Conscious perception occurs at the moment of matching and the perception of object is perhaps the most basic case of an aesthetic emotion. Everyday experience reveals that this aesthetic emotion is not conscious; it is rapid, automatic, and unintended. Vague imagination and its underlying mechanisms are less accessible to consciousness than crisp images from sensory signals processed by the primary visual cortex.

In everyday life, the aesthetic emotions allowing the perception of ordinary situations are situated below the level of conscious awareness, and are not registered by the perceiver. One does not feel affected when recognizing, say, a chair or a car. However, when we fail to understand our surroundings, and when the behavior of objects does not correspond to our expectations, this might generate a very unpleasant sensation. This is often used e.g. by horror movies to create strong reactions. The knowledge instinct is best felt, and its effects on behavior observed, when it is unsatisfied. We notice contradictions very early on in the process of perception, but only detect coherence at a higher level (e.g., at the situation level, or in the abstract realm). When the knowledge instinct is satisfied at the highest levels of the cognitive hierarchy (when establishing new meaningful abstract relations for example), one may feel positive aesthetic emotions consciously [42]. A mathematical description of aesthetic emotions corresponding to the rate of curiosity (i.e., derivatives of a conditional similarity) was proposed in Schoeller and Perlovsky [41] leading to subsequent discoveries concerning the phenomenon of psychogenic shivers (aesthetic chills), often associated to considerable achievements in the arts and sciences. Interestingly, psychogenic shivers have been shown to be related to social rituals and religious ceremonies, underlining the fundamental importance of sociality, cooperation, and shared agency for human evolution.

Aesthetic emotions binding perception and cognition are indispensable for survival and the largest part of their operations are situated below the threshold of conscious awareness. We do have words for beauty and other high-level conscious aesthetic emotions, but the meaning of such words is not yet exactly understood and is the subject of much scientific and philosophical debate. In fact, ordinary discussions about the meaning of beauty often lead to significant disagreement. Interestingly, the common escape from rigorous scientific debates upon the notion is eluded by the assertion that "aesthetic emotions are subjective", which indeed does not constitute a definition but a recognition of our failure to grasp the complex phenomenon of aesthetic emotions. In the scientific literature, one of the most studied aesthetic emotions is referred to as 'Being Moved'. Within the structure of language, being moved is a vague undefined notion, etymologically indistinguishable from the word emotion itself (based on Latin *ex movere*). It is often defined in terms of its underlying bodily signals: anomalies in the respiratory (chest) and thermoregulatory (shivers) systems, combined with self-handicapping tears. However, the meaning (i.e., top-down interoceptive inferences) corresponding to these ascending bodily signals is unclear. Similar undefined emotions are awe, the sublime, grace, and wonder. It is interesting to compare the evolution over time of consensus in language about aesthetic emotions with the evolution of cultures and the range of reality the highest models within the culture encompass and the scope of their actions in the universe [40]. Scientific definitions of aesthetic emotion are of prime importance for culture and we may expect profound cultural changes from their improved understanding.

2. Emotions of deep learning

In the past decades, there has been a growing tendency to describe the human brain as a hierarchical organ of prediction aiming to make sense of its surroundings and increase its possibilities of control [13,6]. The hierarchy of human cognition extends from the perception of objects (e.g. a chair), to situations (e.g. a concert), to more general and abstract concepts (e.g. a university, an education system, a country, and so on) synthesizing lower-levels. The lowest levels of the hierarchy have been well studied in psychophysics and visual cognition, but the highest levels of human cognition remain a mystery [40]. As we saw, conscious aesthetic emotions are associated to changes at the highest levels of the hierarchy. These emotions and their associated bodily feelings can provide reliable biomarkers for identifying concept models at the very top of a cognitive hierarchy. At every level of the hierarchy, concepts unify more concrete and less abstract concepts at lower levels. Abstract and general concepts at higher levels are vague and less available to consciousness than lower levels. We know about them mostly from language [33,34]. The mental representations at the very top of the cognitive hierarchy attempt to unify our entire life experience in a single concept. We perceive changes associated to this model as the meaning and purpose of life. Indeed, strong conscious aesthetic emotions are tied to improved learning of this concept [43]. The concept itself is vague and not accessible directly to consciousness. Can we use science and technology to increase introspective abilities at the highest levels of the cognitive hierarchy? Can we design experience triggering conscious aesthetic emotions extending the reach of consciousness toward the meaning of life? Improvement of the highest levels of the cognitive hierarchy is rare, even in the history of culture. Most of what we know about the highest levels of the mental hierarchy is derived from ancient knowledge encoded in language, symbols, books, and literature. The poor availability of upper cognition to consciousness renders the concepts of meaning and purpose difficult to understand with precision. When we come close to understanding-feeling that something vaguely resembling meaning can be generated at the highest level of upper cognition, we feel the emotions of beauty, and the conscious aesthetic emotions at the top of the mind hierarchy.

3. Types of unconscious emotions

To conclude, we would like to consider three types of emotions inaccessible to consciousness.

Meaning-making emotions in speech Emotionality reflected in the voice prosody plays a critical role in speech understanding and communication [1]. Usually, only speech holding strong emotional quality receive preferential attention, when e.g. an actor produces a voice with strongly-expressed prescribed emotion (a basic emotion, e.g. a fear, or surprise). Low-emotional speech, where emotionality is below consciousness, has received little if any scientific attention [39]. These unconscious emotions may be critical for communication and language understanding, they may help overcome cognitive dissonances associated with hearing an unexpected word, and carry new information [33,34]. It has been suggested that these emotions bind language and cognition [36]. How many emotions exist in prosody? What exact role do unconscious emotions play in speech production and understanding?

Meaning-making emotions in music Music is closely related to the emergence of language in humans and plays a critical role for emotion and cognition [20,19,28]. Many people feel "qualitative" emotional differences in each musical phrases of significant composers whose work has stand the trial of time. However it is extremely difficult to express these differences in language [8]. For example, what is a difference of the second phrase in Chopin Nocturnes from the ninth phrase? While the bodily feelings associated to a musical emotion can be strong and conscious, their meaning or qualities usually cannot be described in language and are not accessible to consciousness [8]. We use the word "quality" in lack of a better word. This may explain why musical emotions are often described as a mixture of basic emotions. Identifying instruments for measuring the qualities of musical emotions is a challenge for future research.

Meaning-making emotions during decision The cognitive system is very fast in identifying strategies to avoid uncertainty and contradiction, especially in the course of decision-making and action where the system cannot hold two contradictory positions simultaneously [10]. In the presence of a contradiction (virtually all decision-making situation involve virtual contradictions), the cognitive system quickly eliminates an option in favor of the chosen course of action [50]. The emotions underlying the rejection of one choice and the approval of the others are mostly unconscious and have been studied under the notion of cognitive dissonance [10]. Decision-making and the elimination of cognitive dissonances is underlied by negative emotions leading us to reject knowledge for the purpose of action. A recent model of decision-making emotion in the context of cognitive dissonance was devised and tested in Fontanari et al. [11]. The theory of cognitive dissonance has been described as one of most important advancements in psychology of the 20th century, nevertheless the unconscious emotions of cognitive dissonances have not yet been studied.

4. Conclusion and future directions

The function of science is to extend the scope of human consciousness, improving our perception of the natural world and our reach toward new phenomena previously inaccessible. The exploration of human emotions and their neural basis have the potential to extend considerably our self and collective perception, as well as our understanding of the processes governing human behavior and allowing meaning to flourish in culture. The study of unconscious emotions and their respective drives and functions can yield new insights for brain science and psychiatry. However, one fundamental question for future research concerns the measurement of unconscious emotions. Let us consider musical emotions, which qualities are often well felt. Today qualities of musical emotions are described in language (e.g., “this piece moved me”) and there is no direct way to measure these qualities *outside of language*. How could we measure the emotions underlying meaning-making in music and speech outside of language? A descriptive and simple protocol for such a measure could consist in asking a significant number of experiment participants to estimate subjectively the emotional similarities or differences between various musical phrases. Such procedure would help define a metric in the space of emotional qualities. Subsequent mathematical processing can be used to establish the dimensionality of this space and quantify emotional qualities.

Declaration of competing interest

The authors declare no competing interests.

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