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Chronological Prospective of Behavioral Decision Making: A Three Realm Model for Cognitive Processing and Behavior

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Abstract

There has been growing evidence on functional connectivity between brain regions that otherwise are not directly connected structurally, resulting in a paradigm shift from neo-phrenology to a network centric approach for understanding cognitive functions. Considering the burgeoning evidence on co-localization of brain areas associated with reward and punishment and competitive firing of neuronal populations, we here propose a three realm model for decision making and behaviour. According to the model, the brain encodes information either in the context of a reward or a punishment in different brain regions, based on associative function of the region. The neural networks associated with reward form a reward realm and those associated with punishment form the punishment realm. Decision making and behaviour is governed by a computational evaluation of this information of reward or punishment to a particular situation and is biased towards the realm that shows higher firing of neurons. On failure to associate a situation with information stored in the reward and punishment realms, the curiosity realm is activated to gather new information which is then stored either in the reward or punishment realm for future reference. This model provides a plausible explanation for the interaction of structurally unrelated brain regions during various cognitive functions and the co-localization of brain regional activity during both reward and punishment. The three realm model also explains for the development of personality traits and decision making based on conceptual and perceptual memory.

Keywords: Reward; Punishment; Curiosity; Decision making; Behaviour

Introduction

Understanding the functioning of the brain for execution of cognitive activities has been an enigma for scientists and philosophers since ages. Despite burgeoning evidences on role of different brain regions, neural networks and neurotransmitters providing explanations for diverse cognitive functions [1] the varying behavioural responses of individuals to similar situations [2] necessitates cautious interpretation of the neurological findings taking into account the psychological prospective of the behaviour. Studying the human brain using a human brain therefore remains the most challenging subject for physiologists, neurologists, neuroscientists and psychologists throughout the world. Though classical experiments by Edward L. Thorndike on cats [3] or Ivan P Pavlov on classical conditioning in dogs [4] have indicated towards the importance of reward and punishment in functioning of the brain and provided a framework for subsequent theories and research on the subject, the extent to which they govern cognition and decision making is still debatable.

Several researchers during the 19th century have emphasized on the role of reward in governing an organism's behaviour. Troland [5] in his Concept of Beneception has portrayed brain reward system as a guiding principle for directing an organism's behaviour towards beneficial goals that promote its survival and reproductive behaviour. Punishment on the other hand has been implicated in aversive behaviour. In order to understand the intricate relationship of reward and punishment with cognition and behaviour, it is important to define their scope. As explained by Berridge and Kringelbach [6] reward is an outcome of processes in the brain in response to a stimulus, rather than the stimuli itself. It comprises of three major components which may be conscious or unconscious viz., liking which forms the pleasure component or hedonic impact, wanting which denotes motivation for the reward and learning which may be implicit or explicit association, conceptualization and prediction for reward [6]. Punishment or inability to achieve reward is associated with a feeling of discomfort, dejection or defeat which could be psychological or physiological. Reward could be as simple as fulfilment of a basic physiological need like eating, sleeping etc. or as complex as motivationally achieving something extraordinary.

The Three Realm Hypothesis of Brain Computation and Human Behaviour

The behaviour of humans in any given environment or condition may be explained by interpreting it in terms of reward and punishment. We propose that all the behavioural responses are governed by computational processing of information between three major realms viz. reward, punishment and curiosity each further comprising of complex neural networks between different regions of the brain. Every activity a human does is the outcome of comparative evaluation for an expected reward or punishment. This phenomenon can be best explained through a simple example via should I work overtime? The rewards could be financial gain in the form of salary to meet my requirements, some incentive in the form promotion or self-satisfaction and appreciation which act as motivation. The punishments could be inability to meet family commitments, lack of appreciation, admonition or lack of incentive. The brain equates the rewards and the punishments

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and decides. If the rewards outnumber the punishment I work overtime and if the contrary is true I do not. Though the decision making process for an action is influenced by several factors that include experience, intuitions etc., the final decision is made by the brain based on a reward bias and punishment aversion. This role of reward and punishment in cognitive decision making finds support from Edmund T Rolls theory of 'biased activation theory of modulation of emotion' where he suggests that even emotion related decision systems choose between gene specific rewards which are perceptual and cognitive reasoning which is conceptual and calculates reward values that are suit the interest of an individual [7]. According to Rolls, emotions can be produced by the delivery, omission or termination of rewarding or punishing stimuli and cognition can influence and control emotions through a top down attentional influence of a part of the lateral prefrontal cortex. The close association of emotional and cognitive processes has also been advocated by Thierry Steimer even for a basic emotion like fear [8]. The cognitive apprehension of events and situations, according to Steimer, is critically involved in emotional experiences and influences coping strategies. This cognitive apprehension very well associates the outcome with a reward or punishment.

The third realm that governs human behaviour is curiosity which encompasses inquisitiveness for acquisition of new knowledge through investigation, observation and experience [9,10]. When a situation per se fails to activate the reward or punishment realms, the brain explores the curiosity realm. The innate drive for curiosity could be genetically programmed (ex; emotional systems) or reward biased but not reward definitive. In other words, the individual expects for information which could be a reward or be used for a reward but is not sure about it. The acquired drive for curiosity could be governed by past experiences of reward or punishment in similar situations and conceptual cognition. Rolls [7] suggests that behaviour reflects a pervasive, dynamic competition between emotional systems that have been genetically programmed by our phylogenetic history and cognitive systems that are informed by our ontogenetic history and governed by our declarative knowledge and explicit goals. In the present context, curiosity about an object lying in a hill side is an innate drive while that about an object lying in a public place in low intensity conflict areas is an acquired curiosity based on a punishment information 'any unidentified object could be a bomb'. Hence, acquired curiosity may not always be reward biased as proposed by Litman [11]. In either case, the brain explores the curiosity realm when it does not get definite inputs on the situation from the reward or the punishment realm. The information thus gained is then encoded through neural networks either in the reward realm or the punishment realm for future computation and cognitive control. As suggested by Okon-Singer et al. [12] cognitive control is engaged when a) there is uncertainty about the optimal course of action, b) potential actions are associated with the possibility of error or punishment, or c) there is competition between alternative courses of action (e.g., flee/freeze, go/no-go). Acquired curiosity is more likely to be governed by cognitive control processes in threatening environments in order to minimize risk, promote probabilistic learning, and avoid potentially catastrophic actions [13,14].

Dynamics of the Realms Governs Ensuing Behaviour

The plethora of cognitive, affective and social functions that determine behaviour are precisely an outcome of choreographed interactions of different neuronal networks embedded in brain regions [15]. Studies by Timothy et al. [16] show that distribution of punishment signals and reward or reinforcement signals are largely similar in the human brain. The authors also suggest that reward and punishment may influence a wide range of cognitive and perceptual processes than was previously imagined. Leknes and Tracey [17] in their 'Opponent-process theory' propose that same regions of the brain are involved in pain and reward processing and they share an inversely proportional functional relationship i.e., pain decreases pleasure and rewards alleviate pain. Based on these findings it may be hypothesized that brain encodes specific types of information in specific brain regions all of which are further categorized as either information related to reward or punishment during a particular pattern of situation that could be spatial, circumstantial etc., based on specific coding of neurotransmitters, their receptors and factors influencing synaptic strength. The brain then decides on the type of behaviour to be displayed based on permutations and combinations of these coded information for a particular situation in both reward and punishment circuits and finally giving way to the stronger signal. This hypothesis finds support from the 'integrate-and-fire attractor network model' which has been electro-physiologically tested and elaborately discussed by Insabato et al. [18]. The model suggests that there are populations of neurons in an attractor network which respond to each of the possible choices, biased by evidence for the choice. The population that fires higher represents the decision. Similarly, the 'motivation-decision model' proposed by Fields [19] suggests that human beings have developed the unconscious ability to endure pain or sometimes, even relieve pain if it can be more important for survival to gain a larger reward like in case of child birth.

There has been burgeoning evidence on the dynamism of network modules that have been shown to continually evolve and reconfigure across time and cognitive states [20]. fMRI studies have also shown existence of less modular configurations in the brain during resting state where there is a cross-talk between different modules [21]. There is an emerging consensus on wide distribution of neural networks between brain regions and the interactions vary based on cognitive states and requirements [22]. Robust functional connectivity between brain regions lacking direct structural connectivity has been shown to integrate complex cognitive functions like emotion and perception through a less understood 'connectomic complexity' [12,23].

Brain Processes Information from Reward-Punishment-Curiosity Realms Based on Knowledge

While knowledge is the retrievable information of previous experiences that are encoded as memory, wisdom pertains to judicious application of knowledge through thoughtful decision making, altruism and insight [24,25]. Decision, according to Montague and Barnes, [26] is an outcome of both representation of choices and an evaluation of the consequences of the choices. This evaluation of consequences may therefore be conceptual or perceptual based on knowledge and experience. A review of neuroimaging by Jung and Haier [27] advocates a 'parieto-frontal integration' model that maintains coordination between different brain regions associated with intelligence and reasoning. The predominant role of experience in determining a behavioural response has been vehemently advocated by the Behavioristics. BF Skinner [28] proposed that everything a person does is ultimately based on past and present rewards and punishments. In other words it is the past experience of reward or punishment which directs human behaviour. This however does not take into consideration the Psychoanalytic postulate of Id by Sigmund and Anna Freud which emphasized on innate biological instincts for reward and pleasure [29]. A careful study of both the theories and its correlation to cognitive development reveals that while during birth and initial stages of cognitive development, the Freudian concept is more applicable, the concept of Behaviouristic is apt during later stages of cognitive development and adulthood when memories and experience are well formed. This proposition is very well supported by Erikson's eight stage theory of psychosocial development that eloquently describes the transition from hope to wisdom [30]. For example, at birth a child's behaviour is primarily governed by the reward realm of satisfaction and satiety on suckling. This is an innate biological instinct guided by gene specific reward which the child follows during any discomfort as proposed by Sigmund Freud. During initial stages of cognitive development, the curiosity and reward realm are dominant as the child explores his environment. The information gathered through the curiosity realm is then encoded as perceptual memory in the reward and punishment realms [31]. This memory in turn is reinforced on every encounter with similar situations and strengthens the reward and punishment realms. The child behaviour to a situation is then governed by perceptual or conceptual memory based on inputs from both the realms [32]. In adults, the curiosity realm is activated on failure to obtain reward or punishment based inputs from previous experiences in any particular situation. Developmental studies show dynamic maturation of brain circuits involved in motivation and cognitive processes from infancy to adulthood [33]. Studies have been conducted showing change in sensitivity to reward based cues thereby suggesting influence of motivation on cognition during adolescent years [34]. Based on their findings of gambling task Cauffman et al. propose steady increased sensitivity to rewards from late childhood to adolescence that subsequently declines from late adolescence to adulthood [35]. Punishment based decision making on the other hand is based on one or more prior experiences with an aversive outcome [36]. Hence, the sensitivity to punishment is likely to be more in late adulthood and elderly. Shimp et al. [37] in a recent study using animal models suggest that reward related decision making associated with a risk of being punished is influenced more by the punishment than the reward. Based on these previous findings and logical propositions, it may very well be suggested that behaviour is an outcome of computational processing of reward, punishment and curiosity. While curiosity dominates infancy, reward greatly influences behaviour during childhood and adolescence and calculated likelihood of punishment and reward through wisdom governs behaviour in late adulthood and elderly.

Reward and Punishment are Decisive Factors for Memory Consolidation

Information obtained through various sensory inputs is encoded as memory through formation of synapses in different regions of the brain. However, the brain does not convert all the information it obtains into memory. Discarding information which the brain considers as irrelevant is an important aspect of cognitive processing. The formation of memory can also be correlated to its relevance for a reward or punishment. Only those information which are explicitly or implicitly relevant for a reward or a punishment are encoded as memory while others are discarded and do not get registered. Attention is known to play a key facilitator in acquisition and consolidation of conscious memories. Reward or punishment in turn acts as the guiding force for attention. A recent study by Blank et al. [38] showed that EEG components discriminating punishment levels appeared later in a trial when compared to sensory evidence related components. The amplitude of the punishment components was predictive of the behavioural improvement induced by punishment indicating the influence of punishment on motivation and attention. Acquisition of information by focused attention or through overt orienting towards an event or stimuli is decided by the brain based on its relevance for certain reward or punishment. As eloquently discussed by Okon-Singer [12], anxiety and inhibitive behaviour often emerges early in development due to early experience based influence on childhood attentional biases to threat [39,40]. Kessel et al. [41] provide crucial evidence in this regard showing that temperamentally inhibited children allocate more attention to aversive cues which is reduced in children who are encouraged and appreciated for positive behaviour. Ned Block [42] proposed two states of consciousness viz., phenomenal consciousness comprising of raw experiences and access consciousness wherein information in our minds is accessible for verbal report, reasoning, and the control of behaviour. Consolidation of information acquired during sub-consciousness or phenomenal consciousness, but in an inattentive state, into memory is also dependent on the association of the information with reward or punishment. Whether such information is encoded into memory or not is probably dependent on the extent of its association with a reward or a punishment. In other words there may be a reward or punishment threshold signal and information above the threshold signal is encoded as memory while those below it are omitted and forgotten. However, determining the role of reward and punishment threshold in memory consolidation could be an interesting area for further research.

Physiological State of the Brain can Influence Cognitive Processing Between Realms

While decades of research has resulted in identifying particular brain regions with specific cognitive domains, physiological or pathological changes in these regions have been shown to effect multiple cognitive domains. There is burgeoning evidence and a growing consensus on importance of distributed neural circuits for psychological constructs of cognition and emotion in recent years thereby marking a transition from neo-phrenology to a network centric [43-45]. Hence, understanding cognitive processing of the brain requires a more integrative approach of crosstalk between brain regions. In light of information on robust functional connectivity between brain regions that lack direct functional connectivity [46,47] the probability of neurons forming dynamic networks encoding information as reward specific or punishment specific connections in different regions of the brain cannot be definitively denied. This encoded conceptual knowledge in turn can influence perception [48] and decision making [49] Schacter [50] has explicitly explained the reward or punishment bias influence of adaptive constructive processes on memory. Similarly, Schacter et al. [51] in their constructive episodic simulation hypothesis propose that episodic memory supports the construction of predictive future events. Szpunar and Schacter further observed that increased plausibility of the future event was associated with rewarding (positive) or punishing (negative) emotional events [52]. Based on the integrate-and-fire-attractor network model of [53] it may very well be proposed that neural networks of both the reward and punishment realms related to an event may be simultaneously activated and the network generating stronger potentials determines whether the ensuing behaviour is to obtain a reward or avert a punishment. This could provide an explanation to the observed overlapping cognitive domain deficits in neurological and neurodegenerative disorders that effect otherwise unrelated brain areas which are not directly connected. A physiological problem in any of the brain region would surely alter the encoded information related to reward or punishment in that specific region and thereby influence the overall signal strength of the reward, punishment or curiosity realms which is the decisive factor for cognitive processing and ensuing behaviour. This hypothesis however needs to be debated and validated through future experiments on correlation of behaviour with activation intensity of reward, punishment and curiosity networks.

Biasness Towards a Realm during Cognitive Processing Influences Personality Traits

Downplaying the pathological aspects of a person's life in favour of the healthy aspects to create a better personality has been a major objective of Humanistic psychologists [54]. One of the core principles of Humanistic psychology as proposed by James Bugental is 'human beings are intentional, aim at goals, are aware that they cause future events, and seek meaning, value and creativity' [55,56]. This aspect of human behaviour may very well be governed by the cognitive processing involving the three realms. Obtaining a reward, averting a punishment or gaining information out of curiosity forms the goal of an individual, which he tries to creatively achieve by predicting future events. Each of these events is decided through reasoning based on past experiences and their association with reward or punishment. Decision making could be reward driven, punishment driven or through wisdom that assigns a value to both rewards and punishments associated with similar situations [23]. These aspects of relative contribution of the three realms viz., reward punishment and curiosity towards decision making for ensuing greatly influences an individual's personality trait. While biasness towards reward realm could result in Extraversion, dominance of curiosity realm could lead to Openness and increased activity in punishment realm could lead to Neuroticism [57,58]. Wisdom based balanced cognitive processing involving all the three realms on the other hand could result in Conscientiousness.

Conclusion

The proposed three realm hypothesis may prima facie appear to be a simplistic approach of attributing the much diversified aspects of ensuing human behaviour to cognitive processing between reward, punishment and curiosity. However, the hypothesis does explain several unanswered questions like why is reward and punishment circuit co-localized in the brain or why are different neurodegenerative disorders associated with similar cognitive anomalies. Since an ensuing behaviour is an outcome of relative signal strength of the three realms, it also strengthens the Humanistic approach of reinforcing specific reward circuits or suppressing specific punishment circuits to create a positive personality or overcome traumatic experiences. The hypothesis also supports integrative network centric approach rather than neo-phrenological region specific interpretation of human cognition and behaviour by proposing interregional crosstalk between brain regions within each realm and subsequent cognitive processing between the realms. Validation of the hypothesis however requires a concerted effort of neuroscientists, pharmacologists and psychologists.

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