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Neurological explanations of decision making in humans: A review

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Abstract

The present review paper focuses on neurological perspective of decision making which plays a major role in our daily life. Our success or failure heavily depends up on the decision we make. So, there is a strong connection between decision making and successful life. Decision making is one of the cognitive aspects that give high load to our brain. In processing decisions, neurons and blood oxygen levels play major role. The author tried to explore various brain regions that involved in decision making process in the light of previous research findings. The author has reviewed 50 research papers/dissertations/documents/ review reports and other sources. Most of the researches used brain mapping techniques to explain possible reasons behind decision making. The conceptual understandings of the review have been presented in the following sections. The author came across various types of decision making such as perceptual decision making, social decision making, economic decision making in relation to different brain regions like parietal cortex, medial premotor cortex. These aspects have been discussed and highlighted in the upcoming sections.

Keywords: Neuroimaging; Decision Making; FMRI; Parietal Cortex; Medial Premotor Cortex

1. Introduction

Neuroscience has been gaining attention of brain researches that would help us reaching some valid scientific conclusion on how people make decisions. Ultimately, those decisions turn into economic models of humans. Many neuroimaging techniques came into existence one after other. Basically, neuroimaging is a quantitative technique that studies structure and functions of central nervous system in an objective way scientifically. The central nervous system includes brain and spinal cord. It is not only limited to medical field, but comes under multidisciplinary studies. Human brain is a complex and highly sophisticated organ. Up to some extent, Neuroimaging techniques help in understanding complex procedures of cognitive functions such as decision making, problem solving, and emotions and so on. Decision making is also said to a complex cognitive process where human selects a best option out of other possible alternative solutions.

1.1. Brief Historical Accounts of Neuroimaging Techniques

Angelo Mosso (1846-1910), Italian neuroscientist, the first one for his 'human circulation balance', that measured redistribution of blood during emotional and intellectual activity in non-invasively. Later, Walter Dandy (1918), the American neurosurgeon developed the technique of ventriculography for studying air in one or both lateral ventricles of the brain [1]. He also introduced a technique known as pneumoencephalography to demonstrate cerebrospinal fluid compartments. Cerebral angiography was introduced in 1927 by Egas Moniz to study normal and abnormal vessels in and around brain (2). Cormack and Hounsfield (1970) who won Nobel Prize for Physiology or Medicine in 1979 for

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their outstanding contribution of CT/CAT (Computerized Axial Tomography) for diagnostic and research purposes of brain[3]. With the advancements of radio ligands, SPECT (Single-Photon Emission Computed Tomography) and PET (Positron Emission Tomography) which are of highly radiation in nature were introduced in early 1980's. During the same era, MRI introduced for clinical purposes by Peter Mansfield and Paul Lauterbur, who won Nobel Prize for Physiology or Medicine in 2003[4]. Sooner Functional Magnetic Resonance Imaging (fMRI) was born in 1990's, since then is has been dominating in the field of brain mapping due it its lack of exposure to radiation and low invasiveness.

1.2. Research trends on neuroimaging techniques associated decision making

Haruno & Kawato 2006 computed the specific brain area by using fMRI in which RPE (Reward Prediction Error) and SPE (State Prediction Error) likely to occur [5]. These areas are taught to be prominent in decision making. They concluded that reward prediction process was involved in frontal P3 whereas frontal N1 influenced State Prediction Process.

1.3. Types of decision making

In the following section Social Decision Making, Perceptual decision making and economic decision making are extensively elaborated with reference to neuroimaging techniques. FMRI result shows that the rTPJ (Tempo-Parietal Junction) is claiming to be important region for pro-social behaviour. Morishima et al., (2012) stated that altruism is associated with rTPJ where grey matter increase was seen [6] while Zanon et al., (2014) observed pro-social decision-making when the rTPJ activity was high .Other techniques known as TMS (Transcranial Magnetic Stimulation) and tDCS (Transcranial Direct Current Stimulation) are the NIBS (Non Invasive Brain Stimulation) techniques are also used in establishing linkage between rTJP activity and social decision making [7]. NIBS techniques are widely helpful in evaluating behavioural impact on various tasks by stimulating. Nitsche and Paulus (2000); Pellicciari et al., (2013); Lauro et al., (2014); Pisoni et al., (2017) explained temporarily modulations of neuronal excitability [8,9,10,11]and thus function by using tDCS technique in which electrodes are sent through low voltage currents with an external, battery operated stimulator into the specific regions of the brain says Dayan et al., [12]. Soutschek et al., (2016); Hill et al., (2017) also used TMS in the field of neuro-economics to demonstrate the role of rTJP to establish link between pro-social decision making and mental modeling [13, 14].

1.3.1. Neuroeconomics

May be similar to game theory, or Ultimatum Game (UG) is an experiment able practice where two participant get together to split available wealth or prize money. It is a mathematical strategy of social decision making as reported by Polezzi et al., (2008) from the perspective of proposer, it was beneficial to offer minimum amount and receiving player may reject treating it as unfair [15]. So, here decision making plays a key role. However, social decision-making is a complex process in the UG, revealed fMRI. Rilling et al., (2008) observed that negative emotional arousal and cognitive processing in the anterior insula (AI) and dorsolateral prefrontal cortex (DLPFC) for unfair offers. They have predicted offer rejection as AI response magnitude was proportional to the degree of perceived unfairness [16]. Irrational impulse to reject unfair offers was due to top-down cognitive control appeared in DLPFC (Rilling et al., 2008). Knoch et al., 2006, 2008) concluded that there is a relationship between right DLPFC and decrease rates of unfair offer rejection during UG gameplay [17, 18,19]. However, but the rTPJ has not been studied in this experiment. Laura F. Blair et al., (2018) in their paper titled 'No Change in Social Decision-Making Following Transcranial Direct Current Stimulation of the Right Tempo-parietal Junction' studied the effects of anodal tDCS to the rTPJ on social decision-making using The Ultimatum Game: A computerized version of the UG was developed using E-Prime software (Version: 2.0 SP1, Build: 2.0.10.353).UG results shows that no significant difference in either the total number or response reaction time of unfair offer rejections , therefore rTPJ is not involved in social decision-making [20]. However, these findings are inconsistent with earlier report of high level rTPJ activity during UG gameplay (Rilling et al., 2004; Halko et al., 2009; Guo et al., 2013;). Possible explanation, the rTPJ heavily involved in mentalizing process while in the UG [21, 22, 23]. Again these findings are also focusing on complex neurobiology (Jeurissen et al., 2014) of social decision-making [24], and can-not be restricted to unitary element (Frith and Singer, 2008) of social cognition [25]. Moreover, social decision making is not only limited to rTJP but other regions of the brain too involved in the UG decision making. Sanfey et al., (2003) stated that negative emotional responses to unfair offers were influenced by AI whereas executive control was relied on DLPFC to reject those proposals due to economically irrational impulses [26]. So it can be said, UG was not enough to explain rTJP effects on social decision making. To add some more strength, Baumgartner et al., (2013) demonstrated rTJP inhibition preceded by decrease of social defectors due to parochial punishment through TMS [27]. Corradi-Dell'Acqua et al., (2013) concluded emotional resentment due to poor treatment on a personal level caused rejection of unfair offer rather than pro social intension in UG [28]. Predicting Decisions in Human Social Interactions Using Real-Time fMRI and Pattern Classification Maurice H et al.,(2011) studied on 27 healthy male subjects (23–28 years, mean: 24.761.6 years) with normal or corrected to normal vision approved by the local ethics committee of the Medical Faculty of the

University of Magdeburg. Predefined actual offers were given by computer for 12s orderly which allowed controllability in offers during scanning and rtfMRI and realtime pattern classification were used to measure brain activity and analysis. Time given for splitting amount was 2s. A questionnaire was distributed after the experiment to all participants in which they can express doubts over their playing partner and emotional state, decision behaviour regarding time and fairness. They conclude that BOLD measurements of brain activity were influencing to accept or reject an offer. In the ultimatum game, regions such as AI, VS, and LOFC, are said to be strong determinants as they are affecting emotional self-regulation and reward processing for adjustment of behaviour. These areas said to play key role from highly acceptance to rejection of an offer when the offer was 70:30. They have considered the three important brain regions such as basal ganglia, orbitofrontal cortex and parietal cortex to explain PDM (Perceptual Decision Making) that deals with detection, discrimination and categorization of noisy information as well as EDM (Economic Decision Making) in which observers choose options depends upon their past reinforcements. They found the role of parietal cortex in encoding the expected value of a decision apart from integration of sensory evidence. They have also added categorization of perceptual information might be done by striatum and OFC though regions play prominent role in value guided choices. On the basis of findings, they tried to develop general framework which might help us understanding decision making process in humans and other primates [29]. There are two main frameworks known as psychological frameworks and framework of neurological approaches. In this review, author considers neurological approaches of decision making only.

2. Neural approaches

In the primate, three vital regions are associated with decision making with regard to visual stimuli (i) dorsal stream cortical circuits, such as the parietal and premotor cortices, (ii) the striatum and related circuitry of the basal ganglia, and (iii) the medial and lateral OFC along with anterior cingulate cortex (ACC) and prefrontal cortex (PFC) as they also play important roles in decision-making. For instance, Rushworth and Behrens, (2008) conclude that the ACC might help in learning the value of actions [30], action selection was done by PFC as reported briefly by Koechlin and Summerfield, [31].Role of medial premotor cortex and parietal/premotor in the decision process, with a specific focus on how each region might contribute to the processing and integration of perception and reward

2.1. Medial premotor cortex

Content-specific beta activity is a key indicator during decision-making. As reported by Donner et al. (2009), A decision making of motor plans were accumulated and updated through courses of lateralized beta activity in motor cortex (right panel) and visual motion detection takes (left panel)place in effector-selective beta activity in humans. Invibrotactile discrimination task, binary decision outcome along with error trials were seen prior to motor response in monkey's medial premotor cortex of beta power modulation [32]. Similar findings reported in B in humans by Herding et al. [33] related to per stimulus class for correct and incorrect trials separately sorted by f2-f1 difference by Haegens et al. [34]. With regard to Beta-band oscillations in decision making, Kaiser et al., (2007); Zhang et al.,(2008); Bidet-Caulet et al., (2012) concluded that decision making is associated with sensory beta effects through motor response when choices are to be whispered [35, 36, 37]. Traditionally, motor preparation is seen in decision making with regard to beta oscillations. For instance, in serial processing, on the basis of sensory input higher order areas reach a decision then effector-specific motor plan takes place. Beta oscillations, whatsoever may or may not be associated to a specific motor plan, it still needs to be researched more.

2.2. Parietal Cortex

Friedman-Hill et al., (1995) stated that bilateral damage of parietal cortex lead to inability of integrate information of multiple spaces for providing accurate judgement of similarity or dissimilarity [38]. Similar finding were also reported by Treisman and Gelade (1980) regarding combination of various visual features is done in parietal cortex [39]. These finding were supported along with saccadic eye movement by Gottlieb and Balan [40]. In another study by Xu and Chun, (2006) parietal blood oxygen (BOLD) was seen increasing that indicates detection of change in sequential arrays during visual short term memory maintenance by neuroimaging studies of parietal cortex [41]. In addition, SSM (Serial Sampling Models) assumes that once criterial evidences are reached, decision is made. It was strengthened by findings of Gold and Shadlen (2007) that says an appropriate response is generated when evidence integration reached its threshold after sensory motor control thereby decisions are made [42]. Recently, Law and Gold (2008); Kahnt et al., (2011) demonstrated more plastic changes in parietal and pre frontal regions then in sensory cortex with regard to perceptual performance on psychophysical task like random-kinetogram and as per prediction error signal, visuo-parietal connections weights are gradually updated, thus explained trajectory of learning with the help of reinforcement learning schemes [43, 44]. These findings added some more strength to feed-back mediated learning and perceptual decision making. Kahnt et al., (2011) questioned on how prediction error is calculated [45]? Whether was it depends on processing subsequent reward at subcortical area or is computed at cortex? The much attention was paid toward outcome based perceptual decision as reported by Platt and Glimcher (1999) [46]; Rorie et al., (2010) where parietal neuron firing was seen increasing at or before the moment of stimulus onset, similarities reported in premotor cortex also [47]. Results are consistent of Fleming et al., (2010); Summerfield and Koechlin, (2010) on signal detection where BOLD signal in the lateral parietal cortex is associated with reward mediated bias shown in fMRI studies [48, 49]. These repeated results might help in understanding parietal cortex directions on providing reward driven options. One interesting report says parietal signal easily adapts to react the changing expected value with available options quoted by Sugrue et al., 2005 [50].

2.3. Sum Up

From the above discussion, it can be understood that medial premotor cortex involved in decision making of motor plans and it is also playing a key role in visual detection tasks. If we talk about parietal cortex, it can been seen playing huge role in combining sensory information thereby helping for action. Obviously, those actions are turned into decisions as well. Parietal signals are influenced by reinforcement learning mechanisms. It may be understood that decision making was biased by relative reward of other perceptual alternatives. These are also assumed to be affected by expected value or changing expected value, means as the value changes it influences our decision making process. Further, parietal neurons strongly influence choice relevant response, reward guided visuo- motor learning and faster accumulation most practiced choices. In the above discussion, the entire discussion was revolving around medial premotor cortex and parietal cortex. There are other brain regions that could involve decision making process in humans. The brain regions such as OFC (Orbitofrontal Cortex) and The Basal Ganglia Nuclei and so on are also assumed to be playing major role in decision making humans. So, the review of such studies may be extended in future for more analysis.

3. Conclusion

Researches in the field of neuroscience have reached such a level, where one can easily understand what is happening inside the brain up to great extent. Earlier, there were no such technological developments as they are today. Technology made it possible to going deep into each and every minute parts of the brain especially neuroimaging techniques like fMRI without radiation exposure. India, not behind to developed countries while applying these technologies for the purpose of diagnosis and research. Further, it may be helpful in classroom teaching. Teachers can improve themselves while teaching subjects like brain based learning, neuroscience and cognitive sciences. It can certainly beneficial for the teachers deeper understanding of various brain regions in relation to decision making process in humans.

Compliance with ethical standards

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