A NEURAL APPROACH TO DECISION MAKING UNDER UNCERTAINTY AND RISK

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***Abstract*—** The human brain is illustrated as the most complex object in the universe. From solving mathematics problems to choosing between coffee or tea at breakfast, the human brain makes thousands of decisions on a daily basis mostly under uncertainty, ambiguity or risk. Within its complex structure decision making processes play a significant role while activating many cortices, including but not limited to the orbital frontal cortex and the amygdala. On the other hand, decision making is similarly a complicated concept where uncertainty and risk are differentiated both theoretically in decision theory and anatomically in the human brain. Decisions are evaluated in the orbital frontal cortex and the ventrolateral prefrontal cortex with either value-based thinking or heuristic thinking. By uniting decision theory and the neural basis of decision making, we have learned how the human brain evaluates the available options and the possible outcomes and consequently reacts to the stimuli.

***Keywords*—** *decision making, uncertainty, risk, orbital frontal cortex, amygdala, dopamine system*

1. INTRODUCTION

AS it is defined in the Cambridge Dictionary, a decision is "a choice that you make about something after thinking about several possibilities''. Our lives consist of thousands of decisions we make every single day, whether to learn biology or history or simply to decide between wearing sneakers and heels. For something that affects our daily lives so much, we had very little information about it for a long time. After trying the solve the mystery behind the human brain, scientists began to wonder about the cognitive process of decision making. Decision making is described as a cognitive course of action due to the mental and logical thinking behind it. The progression of making a choice is a conscious action with various alternatives and consequently the desired outcome. But where does this mysterious process take place, and how does our brain respond to external stimulus and react accordingly?
Decision making isn't just a neurobiological process but rather a philosophical course of action as well. Therefore, one must first understand the philosophy behind it in order to comprehend the information about its cognitive neuroscience later on.

The human brain processes the stimulus and encodes it under two different types of decision making: value-based and perceptual. Value-based decision making is recognized by its subjectivity and its basis of preference. Under value-based decision making the outcome depends on chance, whereas under perceptual decision making it is determined by the choice, reward or penalty. Another difference between these two is the correctness of the situation. By value-based decision making, no outside factor determines the correctness of the situation, on the other hand, perceptual decision making is based on observations and objective criterion which defines the correctness of the response. Perceptual decision making has been the focus of psychological research whilst the attempt to discover the mysterious human brain. The word perceptual is defined as the objective principle that determines the correctness of the outcome. This implies that only one correct response exists. What happens when the decision maker is put in a position of uncertainty or risk, and what is the difference between these two? [1-9]

2. THE DIFFERENCES BETWEEN UNCERTAINTY AND RISK

Any decision can be risky, uncertain or ambiguous, and these will most definitely affect the decision maker. When the decision maker has plenty of information about a situation, he/she makes the decision under certainty and therefore has the opportunity to choose the best alternative. On the other hand, the decision can be made under uncertainty, in which the decision maker has to search for information in order to act in a specific way. In addition to this, the ambiguity of the situation, which is when the decision maker has incomplete information about a situation's probability distributions, the outcome may make a distinction. This indicates that the level of information available to the decision maker is also a factor during decision making. Moreover, when the decision is made under conflict or risk, the decision maker has to predict the alternatives and the outcomes.

Furthermore, one must distinguish the difference between risk and uncertainty. A decision is described as risky when the options are well-specified or transparent outcome probabilities are presented, therefore, the decision maker can estimate the optimal response. In addition to this, under uncertainty, options and consequently outcomes depend on outside factors and the decision maker must calculate in vagueness, imprecision, and subjectivity. Several dissimilarities can be identified between risk and uncertainty. Simply, in risk-based decision making the decision maker losses or wins something worthy but under uncertainty future events or outcomes are unknown. Additionally, risk can be controlled, whereas uncertainty is uncontrollable, in other words, it is beyond the control of the person. Nevertheless, the choice made for a solution under risk may not be the best under uncertainty. Moreover, the cognitive processes observed are different under risk and uncertainty, value-based statistical thinking and heuristic thinking, respectively. As the Swiss mathematician Bernoulli stated, people do not weigh options by their objective value but rather by their utility or moral value. Consequently, risk-based decision making is better understood and easier to distinguish by decision theorists [9-18].

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3. THE ELLSBERG PARADOX

With his thesis *Risk, Ambiguity and Decision*, the man behind the leak of Pentagon papers influenced decision theory and behavioral economics remarkably. Daniel Ellsberg created the Ellsberg paradox, which explained how people make decisions under ambiguity or uncertainty. Generally, it has been discovered that people choose bad situations compared to uncertainty because they are risk averse but don't want to face uncertainty. Risk aversion is when people aim to refrain costly errors while avoiding aiming high and settling for mediocre results. Additionally, people tend to choose safety over joy considering one doesn't have control over change. But most importantly, people are twice as upset when they lose compared to when they win.

The Ellsberg Paradox is a comprehensive experiment to observe and understand risk- and ambiguity-aversion and subsequently decision making. They are two urns, containing 100 balls each, present in the experiment. The first urn holds 50 white and 50 black balls, and the player wins $100 with the correct bet. On the other side, the second urn contains 100 balls with an unknown ratio of white balls to black balls. When the probability of the tendency of choosing from the first urn or the ambiguous second urn is observed generally people have chosen from the riskier urn in comparison to the ambiguous urn. In other words, P (ambiguous white balls) < P(risk white balls) and P(ambiguous black balls)< P(risk black balls). People are willing to bet on the urn where the ball ratio is known and has a risky outcome than the ambiguous urn. However, these inequalities indicate a contradiction due to the fact that the probabilities of black and white balls for each urn must sum to 1, where 1= P (ambiguous black) + P (ambiguous white) < P (risk black) + P (risk white) = 1. This evidences the Ellsberg paradox, but the paradox can be solved by stating that the probabilities of the events are subjective and based on ambiguous outcomes.

The paradox has shown that people choose the urn with measurable risk compared to the urn with unmeasurable risk. This can be described as uncertainty or ambiguity aversion, which activates the fear system and consequently the amygdala. On the other hand, risk aversion can be noticed, which demonstrates the objective or subjective probability to get the reward. This implies the reward system and activates the striatum. The value and probability are evaluated in two different parts of the brain which are functionally and anatomically not united. The neurobiological aspect of decision making will be discussed in the following heading [19-25].

4. THE NEURAL BASIS OF DECISION MAKING

We have previously discussed the theoretical definition of decision making and the differences between decision making under risk and uncertainty and substantiated these with the Ellsberg Paradox. Now we will take a neural approach to decision making, in which we will primarily focus on the dopamine system, the amygdala and the orbital frontal cortex (OFC).

First of all, in the dopamine system, the neurotransmitter dopamine is produced, specifically in the midbrain. Dopamine is the primary substrate for the representation of decision utility. In addition to this, dopamine stimulates the action of liking without wanting, where one doesn't act but shows enjoyment after acquiring the reward. This is also called incentive salience, in other words, a motivational ''wanting'' feature given by the brain. Furthermore, this alters the brains neural representations, for instance, it transforms a neutral or cold incentive to an attractive or desired incentive. This can be described as grab attention, whereas within the dopamine system a stimulus is transformed into an attraction and it is consequently neurally manipulated.

Another neural basis of decision making takes place in the amygdala. The amygdala is a subcortical structure responsible for the production of fear responses and understanding the connection between stimulus and these responses. In the amygdala, the negative outcomes are represented, and the experienced losses are handled. Neuroimaging has shown that the amygdala is active during awareness of losses. Moreover, we can use the Ellsberg Paradox experiment to understand the importance of the amygdala. It has been observed that control patients exhibit expectant response after practice, like choosing the less risky or positive expected outcome, compared to patients with amygdala lesions which do not learn to do this. In addition to this, the amygdala mediates fear conditioning and enables the person to exhibit fearful facial expressions. Patients with amygdala lesions fail to show any expression regarding their emotion, such as fear. Additionally, not only negative outcomes are represented in the amygdala but also the information concerning gains may also be encoded.

The most significant part of the brain where decisions are made, and the outcomes of those decisions are weighed is the orbital frontal cortex (OFC). The information about the probability of rewarding outcomes is used as well as the signaling of reward probability. In the OFC the predicted outcomes are mentally simulated, in which hypothetical or imagined outcomes are experienced. Interestingly, regret is also generated in the OFC. In addition to this, when a factor changes about the stimulus, the OFC helps by making an estimate in order to provide a reward.

There are two types of information regarding the time of the information being learned, newly-learned information and previously experienced information which may also be called the Pavlovian conditioning in this matter. Pavlovian conditioning can be described as the passive learning of neural conditioned stimulus and subsequently rewarding or punishing outcomes. The OFC is not necessary for such Pavlovian conditioning, for instance for a previously experienced behavior which is pre-computed without combining new information. In comparison, the OFC is required for making predictions on newly-learned information and the original learning with new information.

On another note, research has been conducted concerning OFC damage which in our case, one identifies the risky choices but chooses them anyway without displaying anxiety. People with OFC damage shows no bodily or emotional signal, which makes them choose the risky or the poor choice. For instance, people with OFC damage tend to choose riskier options without any anticipatory skin response in experiments like Iowa Gambling Task. OFC damage can also be seen in real life decisions, which serve severe impairments intellectually and on traditional neuropsychology measures. Furthermore, people with OFC damage can be categorized as acquired sociopath, which makes them engage in high risk behaviors with short

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term rewards and likely negative outcomes for the decision maker's wellbeing. Additionally, the ventrolateral prefrontal cortex (VLPFC) is related with response inhibition and goal-appropriate response [26-27].

5. CONCLUSION

In conclusion, decision making is one of the most significant cognitive aspects that affects our lives on a daily basis. Whilst living in a stressful environment due to the modern world, one is forced to encounter several moments of decision making under risk and uncertainty every day. Decision making under risk and uncertainty show differences not only theoretically but also anatomically in the human brain. Primarily the orbital frontal cortex and likewise the dopamine system and the amygdala are responsible for decision making on a biological basis. Although plentiful is to be known concerning the human brain and specifically decision making, today we can understand how a stimulus is processed and a conclusion is made regarding an outcome.

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BIOGRAPHIES

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