Neuroeconomics-Oriented Psychology: a New Approach for the Study of Mental Diseases

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ABSTRACT:

Neuroeconomics is a recent approach to understand brain activity which has been developed as an alternative to the classical sensorimotor model of deterministic reflex theory. Neuroeconomics analysis is based in principles of Ecological Biology and Modern Economics, utilizing concepts of Bayesian statistics like probability and relative utility to explain behavior elicited by an environmental stimulus. In this article we show how principles of Neuroeconomics can be applied to clinical-pathological cases in order to represent these as failure in the process of maximizing utility. Two practical examples will be given, the first representing persecution delirium of schizophrenia as a disturb in the variable of posterior probability and the second correlating apathy of depressive disorders with a disturb in expected utility. Through this paper the authors emphasize the benefits of such an interdisciplinary approach and point out the directions for future investigation in this promising area between Neuroeconomics and psychiatry.

INTRODUCTION

Human psychology can be understood as the scientific endevour of studying and explaining human behavior and comportamental patterns. In this view, it is of extreme importance to understand architectural and functional aspects of human mind, as well as its correlation with external behavior.

Therefore, we believe theoretical psychology must be embased in true assortments about biological function of human mind in order to represent in a correct manner biological substrates of normal and pathological behaviors. It is in this context that we propose ourselves to analyze the practical implications for clinical psychology, the fact that human minds encodes in a very concrete biological, even synoptically level, economical concepts such as event probability and expected utility**.**

This new endevour of understanding brain mechanisms that are responsible for evaluative processes and choice behavior has been called of Neuroeconomics. By emphasizing the behavioral mechanisms and neural signals that mediate decision making under conditions of uncertainty, these emergent discipline has proposed itself to study neurobiology of choice behavior. It is still early to predict all the impact such an interdisciplinary way of studying cognition may have in diverse fields of neuroscience and psychology. Nevertheless, some interisland results have already initiated to appear, with important discoveries about neural process which mediates decision and choice and its motivating factors.

In this paper the author delineates some implications of such Neuroeconomical approach to clinical psychology and the study of altered behaviors in psychiatric disorders. The authors emphasize the practical consequences and scientific repercussions of the correlation of concepts currently used in game theory and economics science, such as event probability and expected utility, with psychopathological entities used to describe symptoms of psychiatric disorders, such as apathy and persecution delirium. Finally we present some of interessant studies on Neuroeconomics and point out the directions for future investigation in this promising area.

HISTORY OF CLASSICAL DETERMINISM

Since Descartes proposal of understanding behavior as deterministic responses to sensory stimulus, the leading conceptual view in neurophysiology has been the classical reflex theory. Descartes believed that all behavior, even the most complex ones, could be explained by mechanistic reflex like mechanisms. [1] This view is intensively correlated with premises of Cartesian ontology [2] which proposes to understand the world as a spectacularly complex clockwork which could be completely studied, explained and described by lawful physical principles.

This philosophical ideas were not new and most of them could be found in texts of Greeks Epicurus and Democritus, whom argued that the world was composed entirely of matter and causal interactions among this matter, must, in principle, account for all physical events. This way, if all the events that take place in the universe are the product of tiny particles colliding which each other according to simple physical laws, then the behavior must also be the product of these material collisions, and therefore, human attitudes would be, in this deterministic world, totally predictable. And thus, our sense that human behavior is unpredictable, even volitional, would be, as well as free will, only an illusion.

These deterministic ideas acquired during renaissance a distinct honor place, being considered by philosophers as the logical consequence of a scientific interpretation of the world. The Scottish philosopher David Hume [3] suggested that all human and animal action could be reduced to a complex series of deterministic interactions and that deterministic mathematical tools of the scientific revolution should be the right tools to analyze operations of human mind.

This deterministic way of thinking is very well illustrated by LaPlace idea of a perfect mind. [4] He argued that if someone which porsuited all possible information about the present world, in other words, if someone knew all the positions and velocities of physical particles of the actual world, then this person should be capable of preview all future states of this particles, and therefore, all the future events.

The neurophysiological approach based in this deterministic view of the world was the reflex theory, which postulated that sensorial stimulus acting on nervous system would elicit a motor behavior which could be fully predicted. Brain and analogous structures would be essentially passive, serving as the conduct through which impulses and forces could be transmitted from sensory afferents to motor efferents pathways.

In this topic we must mention the importance of the eighteen century English physiologist Charles Scoot Sherrington [5] whose work combined Descartes` model with a logical-analytical process which would form the core of the theory of the biological basis of deterministic behaviors. Sherrington's principles influenced the way of viewing neurophysiology for more than two centuries. Other important support to biological basis of behavior came with the works of the Russian Ivan Pavlov [6] which seemed to suggest that all behavior were deterministic and that the calculus of reflexes would be an adequate system for describing possible deterministic behavior.

THE BIRTH OF NEUROECONOMICS

While deterministic psychophysicists and sensory physiologists traditionally emphasize the effects of sensory stimuli on decision-making, cognitive psychologists and economists have long known that decision-making is strongly influenced by an organism's prior experience or beliefs concerning the 'value' of alternative choices

Among the first critics against the simplicity of reflex theory bases explanations was the English biologist Grahan Brown and the german physiologist Von Holst. [7] These scientists believed that there was enough empirical evidence to believe that the nervous system did more than simply conduction of sensory stimulus. They argued that the nervous system could actually generate its own activity. Working from yet another starting point, a second group of anti-reflexive neurobiologists have argued that while the reflex seems a good model for many simple behaviors, if you examine those behaviors in detail you find that they are organized around well-defined goals rather than being loose conglomeration of local and independent reflexes. Among these scientists we may citate the names of the Viennese physiologists Paul Weiss [8] and the Russian cyberneticist Nikolai Bernstein [9].

Nevertheless, the main contributor to the creation of a new alternative approach to deterministic reflex bases theory was the English computer scientist David Marr. [11] Marr seems to have been struck early on by the idea that formal computational studies of the nervous system were the only way to achieve a deep understanding of brain functions. In a famous paper published in 1976 Marr and Poggio [12] argued that instead of isolating a tiny piece of behavior, figuring out what “definite nervous path produced that behavior, and trying to build a theory of the brain out of these tiny pieces, one should start from an overview, trying first to understand the computational goal which the neurobiological system and its architecture was attempting to accomplish One should began from the top by describing what the whole system was trying to do, as formally and mathematically as possible, and then begin to ask how the biological hardware achieved that goal or computation. In Marr`s own words: “To understand the relationship between behavior and brain one has to begin by defining the function, or computational goal, of a complete behavior. Only then can a neuroscientist determine how the brain achieves that goal”.

In this tentative of describe a biological system based in its computational goals, Marr and colleagues found that economics concepts from statistical theory like probability, expected utility and optimal responses were much more useful than classical mathematical tools. These new approach to understand brain through description based in modern economic theory and behavioral ecology was the beginning of a new born theoretical research line called Neuroeconomics.

The knowledge in Neuroeconomics has exponentially growed since 70s decade, and recent works have experimentally showed that some of the areas of brain can be optimally described by economical tools. Of special interest is the work of Glimcher and col. About the role of posterior parietal cortex, more specifically Brodmmann`s region 7, known as LIP area, in visual saccade movements. [13] [14] these researchers had demonstrated that classical concepts of sensory and motor areas were not capable to give an explanation to patterns of neuronal activation of area LIP observed in laboratory experiments. Historically, while Goldberg and col. [15] proposed to describe area LIP as having a role in motor planning, and therefore, an intentional character, the group of Anderson and col. [16] tried to describe are LIP as an sensory association area, having, therefore an attentional character. Nevertheless, neither Goldberg nor Andersen interpretations could afford with perfection to empirical results of experiments, which, in some aspect tended to favor one view and in other aspects tended to favor the other. It seemed that the philosophical ground of interpretations of the experiments were failing.

It was in this context that Glimcher et col. proposed a new approach to area LIP problem based in classical economical concepts. The most interessant is that this economical approach were able to describe perfectly all the aspects of experiments, proving to be optimal tolls to describe some brain functions. These scientists demonstrated that neuronal activity in area LIP were intrinsically correlated with two economical variables, probability of some future event to occur and the expected value or utility of this occurrence. These results suggested that the variables which have been used by economists, psychologists and ecologists from a long time ago were someway useful to describe the saccadic behavior elicited by LIP area activity.

Other promising line of experiments in neuroeconomics, which have already demonstrated consistent and interessant results, is the study of sensorimotor systems in terms of utility functions. [25] The basis of such experiments relies in the fact that every sensorimotor system has choose between different actions. The practical occurrence such actions will depend on two components—the cost associated with performing an action and the desirability of the outcome. Through the analysis of the variability and predictability of these actions a curve of utility function can be constructed. (Figure 1)

These utility function used by sensorimotor system can be practically assessed by measuring the indifference curves for human subjects experiencing short pulses of force. In sensorimotor control, utility functions that depend on several variables occur frequently. Consider, for example, unpacking a car after a snowboarding vacation. We could carry all the suitcases at the same time, reducing the time to unpack but maximizing the weight we have to lift concurrently. At the other extreme we could transport each item individually, which would minimize the magnitude of the force required at the expense of a long unpacking duration. The chosen solution is likely to lie somewhere between these two extremes and may re.ect an optimal decision based on a utility function that depends on duration and magnitude of the forces. Once a utility function is specified, the decision problem becomes one of solving an optimal control problem, finding the actions that maximize the utility. A number of studies in the field of optimal sensorimotor control have proposed loss functions (the negative of utility function) and derived the optimal actions given these proposed loss functions. For example, the minimum jerk model, [10] [24] (Hogan 1984; Flash and Hogan 1985) suggests that people minimize the average squared jerk of the hand (third derivative of position) when making reaching movements. Alternative models have suggested that during reaching people try to minimize the variation of endpoint errors that arise from noise on the motor commands [57], [29] (Harris and Wolpert 1998 and Todorov and Jordan 2002).

In the sequence we expose how this neuroeconomical approach can be extended to interpretation of psychological features of psychiatry disorders, providing a mathematical description of pathological behavior. Two examples will be given, both demonstrating how psychiatric syndromes can be understood as a failure in the task of maximization of utility function, leading to an altered and suboptimal behavior. Afterwards we provide the theoric basis for experiments which should be conducted in order to correlate the theoretical results from economic theory with empirical data from neurophysiology.

PSYCHIATRY AND NEUROECONOMICS

The neuroeconomical approach is based in the assumption that evolutionary processes have selected advantageous behaviors and that action of nervous system could be understood as the biological result of the these evolutionary selection. The goal of the nervous system, in evolutionary terms, could be described as the action of making decisions that proportionate maximum benefits to the organism. In this way human mind could be said to encode in a very concrete biological, even synaptical level, economical concepts used in evoluationary ecology to describe the process of decision making such as event probability and expected utility.

For this classical economical tools of Expected-value Theory would provide a clear mathematical method for analysis of brain function. Its laws could be used to combine probabilities of future outcomes with the gain they offer to organism in order to estimate a value for certain choices and thus, predict, the animal behavior.

The final goal of human mind can be said to be, in an economical view, to evaluate which decisions provide the maximal expected utility. The total value of the expected utility (EX) of an event can be understood as the amount of final benefits of determinate decision and can be mathematically determinated by the multiplication of the event probability (EP) and the event utility (EU). For determination of the total expected utility of an action which implies more than one event, it is necessary to multiply the expected utility (EX) of each event for its respective event probability (EP). Mathematically we have:

$$E\ EX_1^n$$

EX(n) = (EP1 x EU1) + (EP1 x EU1) + ... + (EPn x EUn)

We give some practical example to illustrate these concepts. Imagine someone who wants to invest 100 dollars in the stock market. There are two classes of papers. The first class has a probability of 30% of giving rentability 50 dollars in one month and 70% of give a rentability of 20 dollars in the same period. The second class of papers has a probability of 10% of give rentability 90 dollars in one month and a probability of 90% of give rentability 5 dollars. How could anyone compute these values in order to discover which class of papers offer the best benefits?

One way is to multiplicate events utility (EU) by its event probability (EP) and discover which class of papers proportionate the greater expected utility. (EX)

In this way we have:

EX = EU x EP

In the first case we would have

Expected Utility of event 1 (EX1) = 30% x 50 + 70% x 20 = 29

In the second case we would have

Expected utility of event 2 (EX2) = 10% x 90 + 90% x 10 = 18

As we can see, the first class of papers proportionate the great expected utility and, therefore and is the best option for our business man.

Once understood the role of event utility and event probability in determining expected utility we can detain ourselves for just a while and analyze some of the experiments which first used neuroeconomical tolls in order to describe animal behavior in face of a task of choice and reward.

EYE MOVEMENT AND REWARD EXPERIMENTS

The expected utility of some event is in practice determined through a statistical approach, considering the event utility of prior similar events in the past and determining the mean value of utility that can be expected from any of possible outcomes.

Let us explain this with a short example:

First let’s imagine the following experiment: a monkey is posed in front of a white screen and suddenly spot of light appears right in the middle of the screen. If the monkey look to the left, they receive 10 ml of grape fruit juice (which they love) in 50% of the time; in the other 50% they receive 5ml. If monkey looks to the right 1ml of juice is given in 90% of the events and 20 ml is given in 10% of the times.

In this simple situations, expected utility (EX1) for looking to the left (event 1) would be described as the product of expected utility of the first occurrence (EU 1a) which is 10 ml multiplied by its probability of occurrence 50% plus expected the expected utility for the other possible occurrence (EU 1b) which is 5 ml multiplied by its possibility of occurrence (EP 1b) which is 50%.

In a mathemaematical representation t:

EX1 = EU 1a x EP1a + EU 1b x EP 1b

EX1 = 50% x 10ml + 50% x 5ml = 7,5 ml

This will give an total expected utility for event 1 (looking to the left) of 7,5 ml

In the same way the expected utility for looking to the right (event 2) can be described as the product of expected utility of the first occurrence (EU 2a) which is 4 ml multiplied by its probability of occurrence 50% plus expected the expected utility for the other possible occurrence (EU 1b) which is 1 ml multiplied by its possibility of occurrence (EP 1b) which is 50% .

EX2 = EU 2a x EP2a + EU 2b x EP 2b EX

EX1 = 50% x 4ml + 50% x 1ml = 2,5 ml

This will give an total expected utility for event 2 (looking to the right) of 1,5 ml

This is just the way that economical tolls would describe the behavior of the monkeys if they acted in an optimal way in order to maximize utilization, that is, receive more juice.

The interessant is that this is exactly what happens in empirical experiments. If the previously calculated expected for looking to left is 7,5 and to right is 2,5, the animal submitted to these task, choose in 75% of the times the first alternative (with the expected utility of 7,5 ml) and in 25% the second alternative (with expected utility with 2,5 ml). In an unknown way the brain apparatus of the monkey encoded the expected utility of each event and determined the choices with basis in it.

The most interesting is that experiments [13] have not only demonstrated that behavior of monkey is optimal and can be described in terms of expected utility, but were also capable to isolate some cluster of neurons in cerebral cortex of these monkey which responsible for intentional movements and which firing rates incredibly follows exactly such 7,5/2,5 proportion. In other words, these experiments discovered the biological substrate of such encoded expected utility which were first theoretically predicted, empirically confirmed by experiments and finally neurophysiologically recorded as frequency of firing of cells in cerebral cortex

These results demonstrated that animal sensorimotor behavior can be described as an optimal economical task of choicing between two alternatives based in its final expected utility (in these case to receive more juice). These experiments also showed that is possible to correlate the firing of some neurons in cerebral cortex of the monkeys with these values expected utility. The neuroeconomical tolls were here not only useful to predict the occurrence of behavior in a choice task, but its elements (in this case expected utility) provided a mathematical representation of events which occurs in cerebral cortex during the performance of the studied behavior..

Based in our clinical and research activities with psychopathology of psychiatric diseases, we intend demonstrate that is possible to extend the use of neuroeconomical approach to the study of human behavior and its disturbs. For this we propose to practical examples of how psychopathological features of two psychiatric disorders (apathy of depressive disorders and persecution delirium in schizophrenia) can be mathematically described by use of same tolls of Expected-value and Probability Theory previously exposed.

In our analysis we will show how persecution delirium can be understood as a disruption of event probability, and depressive apathy as a case of depreciation of values for event utility. Our purpose is to show these symptoms can be understood as an disruption in optimal behavior predicted by expected-value theory, providing this way an example of how useful neuroeconomical the tolls can be in description and understanding of psychiatric syndromes.

The key components of this research program is similar that of previous studies: first, we want to showing that behavior (in our case, pathological ones) is under the control of value computations emerging from an human effort to evaluate sensorial data and maximize utility function. Second, we perform a modeling of behavioral data to gain insight into the decision variables in the brain that might specify these kind of behaviors (in our cases, the event probability and expected event utility) and third, we construct the theoretical basis of electrophysiological experiments (with techniques of fMRI and PET-Scan) which should be conducted in order to determine whether and how the hypothesized decision variables are actually encoded by specific neural systems. [22]

PERSECUTION DELIRIUM AND THE BAYES THEOREM

Bayes theorem is the statistic-mathematical method to describe the possibility of some event to occur based in probability of another given event which already occurred. [17] In practical terms, Bayes theorem gives us a value of the probability of occurrence of some event w given the probability that another event y occurred (Pw/y), multiplying probability of occurrence of y given that w occurred (Py/w) plus probability of occurrence of w

(Pw), divided by the probability of occurrence of y (Py).

In mathematical terms:

$$P(w/y) = \frac{P(y/w) \times P(w)}{P(y)}$$

Eq. No 1

Could Bayes theorem, a toll of economic mathematics be anyway useful for description of persecution delirium present in schizophrenic syndromes? We believe yes. But first, we present what is currently know about persecution delirium in psychiatric science.

Persecution delirium is a form of delusion. Classical definitions define delusion that they were as a false belief about reality. [13] Held with unusual conviction, whose absurdity was manifest to others and which were not amenable to logic. People with persecutory delirium selectively attend to threatening information and jump to conclusions on the basis of insufficient information, attributing negative events to external personal causes, and misinterpretating others' intentions, motivations, or states of mind.

In the sequence we provide the mathematical description in terms of probability theory which could afford for a general example of a persecutory delirium. Let’s suppose the event w as being the situation in which the subject is really under persecuted and in danger, and y the signals or tips of being persecuted, for example the fact that someone is walking behind him in the street. We know “a priori” that in the internal, subjective evaluation of psychotic patients, the probability of being persecuted once someone is walking behind P(w/y) is extremely high. In other words if the patient see someone walking behind him (the event y occurs) the patient feels as being persecuted (the event w). In such psychiatric patients the brain seems to act poorly in the task of evaluate probabilities of occurrence of events, acting in a suboptimal pathological manner, which gives to the patient a strong sensation of being persecuted and, therefore, elicite reactive afraid behavior.

But we can go further in our analysis. If expected probability (P) of being persecuted (event w) given that someone is walking behind in the street (cue y) (mathematically: P (w/y)) is too high, then, it must be due to disruption in some of the members of the second part of equation 1. Which one could be the responsible? Let see the first term of the second half of the equation, the probability of y given that w occurred (P (y/w)) which describes the probability of the presence of cue (y) once someone is really persecuted (under event w). Let's give, for example, the value 50% to P(y/w), in the case we imagine that in 50% of the persecutions it can be really found someone walking behind the person (we call "back-persecutors"), and in the other 50% of persecutions cases, there is none behind in this cases the persecutor is maybe is not physically behind the person, but in front, walking in the opposite direction along the street, or maybe just observing from a distant point, for example (we call these "non-back persecutors").

Could we suppose that an elevation (P (y/w) and consequently in the subjective probability of being persecuted (P (w/y)) is the best analytical description of the problem faced by the patient? In these, in the patient mind, there would be an abnormal high probability of back-persecutors (those who walk behind) in comparison to our mean value of half to half proportion present in the general population. Does a schizophrenic patient have such an incontrollable and firm conviction that persecutors are always behind and never in front? These does not seems to be the case. Schizophrenia really seems to lead to false beliefs, but not of these type.

From analysis of patient's behavior and discourse it seems more rational to suppose that mistakes of patient beliefs are not in the location from where come persecutors, but about the differentiation of normal followers and persecutors.

Let's, thus, examine the second term of the equation, P(y), in our case, the probability of finding someone walking behind the street. We can say that this term has a relative high value, mainly in conturbated streets of our superpopulated cities. Nevertheless, although the probability of finding someone walking behind him (p(y) is very high to the patient, it is also high for the normal subject and it is not probable that schizophrenic patients have a propense to think that all people want to walk behind him, as in a Indian row. (note here that the term P(y) is in the denominator, and, this way, in order to expect a high P(w/y) which is present in the persecution delirium P(y) we should suppose that the probability of finding someone walking behind him (p(y) would have to be lower in schizophrenic patients in relation to normal people and not higher. Nevertheless these does not seems to be the case, once the opposite belief (that no-one likes to walk behind him) is also inadequate to describe patients beliefs.)

It only rests for us the last term of the equation: P(w): the probability of being persecuted. And exactly here is the problem. P(w) or the general probability of being persecuted is, in patient analysis, very high, as a result of his unfounded beliefs, while for normal people P(w) usually stays low, unless the person might have committed any crime.

This lead us to a situation high values of P (w/y) are unexpected high value of P(w), while P (y/w) and P (y) seems to be unaffected by disease. (these are some examples about the second step of our endevour: the way theoretical analysis around neuroeconomical variables involved in the studied situation should be preceded).

As previous described expected utility for visual saccades is biologically encoded by specific cluster of neurons in area LIP. We could therefore, with a good empirical base, suppose that other forms of expect expected utility are also biologically encoded. In fact, other authors (Hemsley and Garety) [26] have already that Bayes's decision-making theorem can be useful as a theoretical basis for examining reasoning biases in deluded subjects. [27]

Studies from affective neuroscience suggest for example, that hyperactivation of amygdale is associated with fear-like and anxiety components of schizophrenic patients. Excessive activation of amygdale in these patients was also associated with hypervigillance, particularly toward threat-related cues. [21] Attention to threatening material relevant to self differentially also activates a more dorsal region of the left inferior frontal gyrus (BA 44).

Neurophysiological studies with functional magnetic resonance imaging have also demonstrated that people with persecutory delusions regard ambiguous data in the social domain as self-relevant and selectively attend to threatening information. In determining self-relevance, the deluded subjects showed a marked absence of rostral–ventral anterior cingulate activation together with increased posterior cingulate gyrus activation in comparison to the normal subjects. Abnormalities of cingulate gyrus activation while determining self-relevance suggest impaired self-reflection in the persecutory deluded state, which may contribute to persecutory belief formation and maintenance. [61] A positron emission tomography (PET) study of a group of patients with chronic schizophrenia (99) demonstrated, for example, significant positive correlations between the reality distortion dimension and regional blood flow (rCBF in left frontal (lateral prefrontal cortex), ventral striated, and temporal (superior temporal gyrus, parahippocampal) areas. A PET study of unmedicated patients with schizophrenia (a mixture of never-treated and drug-free patients) (100) demonstrated a significant positive correlation between the reality distortion dimension and left-sided temporal activity. A single photon emission computed tomography (SPECT) study of unmedicated patients with schizophrenia (a mixture of never-treated and drug-free patients) (101) showed strong positive correlations between the reality distortion dimension and the left striated area but strong negative correlations with left temporal areas. A further SPECT study of never-treated patients with schizophrenia (102) showed strong negative correlations between a "delusions" score and left frontal and medial temporal rCBF. All these data have highlighted the importance of the medial temporal and ventral striated limbic areas in delusion formation.

Future experiments in neuroconomics should search for pathological functioning of such neuronal area in psychotic patients, and further correlation of empirical data with variables of neuroeconomical mathematical analysis. In this way, correlation between measurements firing rates in the area and curves of event probability for perception of dangerous events would provide an important advance in study of persecution delirium in schizophrenic patients. A feasible practical model of such a experiment would be the exposure of both patients and control group to a movie where someone is walking on the street and there is someone behind him and asked them to try to analyze if the person is being persecuted or not. The theoretical predictions would expect that schizophrenic patient would more often than normal subjects classifying the person in the movie as a persecutor. While this task if performed, some kind of brain monitorization (in this case a less invasive techniques like Positron emission tomography can or functional Magnetic

Resonance Images –fMRI-) trying to detect any abnormal working, and respective firing rates, of specific brain areas involved in danger perception and theory of mind (the term used in neuroscience to describe the capacity of correctly inferring .someone's intention).

Through a neuroeconomical approach we could hypothesize the following questions? Could these hypervigillance be described by a classical probabilistic function P(w) of an event w y. What are the necessary and sufficient characteristics related to this treated-related cues which define an event as being an event w? (in mathematical terms it would correspond to define the dominance and image of the function P (w). What is the graphical representation of such probabilistic function? How such functions behave in relation to other variables involved in Bayesian theorem Bayesian theorem (the previous occurrence of a similar event for example, or the presence of distraction variables). What is the temporal evolution of such probabilistic function during progression of the mental disease and which are the changes which occur in its pattern during use of anti-psychotic drugs?

Many other questions could be formulated, and we believe that such mathematical and conceptual analysis in neuroeconomic terms may provide real and consistent benefits in the scientific effort to describe understand and represent the particularities and nuances of the complex mental phenomena involved in such psychiatric disorders.

In the sequence, we present a second example of how neuroeconomical tools could help clinical psychology and psychiatry to better understand pathological mental conditions. This time, we will deal with a very important symptom in psychiatric syndromes, apathy, classically associated with depressive disorders but also a component of other psychiatric pictures such as Alzheimer disease, vascular dementia and Huntington disease.

APATHY AND EXPECTED-VALUE THEORY

The essential meaning of apathy is lack of motivation. Recently specific criteria for diagnosing the syndrome of apathy and scales for the practical evaluation of apathy as a continuous variable has been suggested (the Apathy

Evaluation Scale, which provides reliable and valid measures of diminished motivation in diverse clinical populations). The neural mechanisms of apathy are postulated to involve the brainstem and forebrain circuits that mediate goal-directed behavior. The functions of these circuits provide a model for suggested classification of apathy syndromes into cognitive, sensory, motor, and affective subtypes. Nevertheless, apart of their particularities, all of these subtypes of apathy have a common component, which can be understood in terms of lack of attention (manifested, for example as absence of motor or cognitive behavior). [21] One good definition of attention was that given by the psychologist William James in the beginning of XIX century: [18] “Attention is that process by which the speed or accuracy of normal sensory processing is enhanced, an enhancement that leads to increase of focus in the sensory world and may be manifested as new active behavior”.

It is important to note that apathy here is not only an absence of motor behavior (as in plegic patients, for example) but an absence of active behavior which is profoundly correlated with lack of attention to sensorial world around. This apparent disinterest, almost like a disdain for the external world, its inputs and the outputs, being the real cause of diminished motor output. Could we maybe characterize this picture in terms of any neuroeconomical tolls?

For over a century experimental economists have characterized the decisions people make based on the concept of a utility function. This function increases with increasing desirability of the outcome, and decrease with the increasing of cost associated with performance of tasks that generates the outcome. For classical economic theory, people are assumed, to make decisions so as to maximize utility, in other words, to receive the maximum of benefits with lowest cost possible. When utility depends on several variables, indifference curves that represent outcomes with identical utility that are therefore equally desirable arise. Whereas in economics utility is studied in terms of goods and services, the sensorimotor system may also have utility functions defining the desirability of various outcomes of behavior. [25] (figure 1).

As we saw before the goal of human actions can be understood as to maximizate expected utility (EX), which can be mathematically represented as the result of the multiplication of event probability (EP) and event utility (EU):

$$EX = EP \times EU \quad \text{(eq. 2)}$$

Attention can be economically understood as a resource, which can be allocated to different external objects. This way, each moment the person is posed face to the task of distributes this attention according to expected utility of the event. The more desirable the result of an event (greater the expected utility) more attention will be distributed to such event In the same way, the higher cost, less interesant will be the action, and lower the value of expected utility.

We can suppose, then, that attention has a linear correlation with expected utility. (Of course, the degree of this correlation in a particular situation will depend on other factors, as subject beliefs and states, which can only be evaluated with empiric experiments). The higher the expected utility of some action, more attention it will elicit in the organism and the result of it is that more cognitive resources (perceptive or motor) are allocated in order to execute this task.

Although attention depends also on other variables (like the ability of the subject in such a task – so that new tasks demand more attention that old ones) we will here suppose them to be constant and focus in relation between attention and expected utility and its relation to apathic behaviour.

Note here that we are considering only the second term of the equation, the event utility of an action (EU). Nevertheless, the decision also depends on event probability, in other words, the probability of the occurrence of desired results once allocated the necessary attention and resources. This way, even an action with a very high event utility will be a low final expected utility if the probability of occurrence of such event is low. As an example we have the case of someone who gambles. In this case the event utility is very high once cost form performing the action is low (just little cents) and the outcome is very desirable (the premium is very high). Nevertheless the final expected utility of the event is still little (EX), so that the majority of people do not do buy these tickets. This fact occurs because even allocated the necessary resources for the action (in this case the money for the ticket) the probability of occurrence of the desirable event (EP) is low.

We can therefore perceive that both event probability and event utility are factors that determines the final expected utility and, as consequence, the occurrence of the behaviour.

As already mentioned the relations between these variables may be much more complex, once we suppose attention as a resource that can be represented by continuous instead of all-or-nothing variables. These can explain why the values obtained in practical economics experiments do not usually follow linear and regular relationships.

Once understood the role of event probability and event utility and its relation to final expected utility and the occurrence of an action, let's turn our attention back to the psychological symptom of apathy. Could it be defined in neuroeconomical terms?

We could suppose that for apathic patients, the neural mechanisms underlying the process of choicing between possible future events seems to be somehow disturbed, once, no internal or external action is capable of gather even a little piece of attention. In other words, the patient is unable to use the prediction of future benefits of an event in order to make a bias toward the future occurrence of this desired event. We could say that the equation of expected utility must be somehow altered in these patients' mind. But would it possible to know analyze with more detail and mathematically this disturb? Could we also find a specific brain area encoding this disturbed equation? We may try, as done before for persecution delirium, through an analytic-conceptual exercise raise some hypothesis which can, in a second moment, be tested.

In the case of apathy we could say that not only expected utility for some events, but expected utility as a hole seems to be reduced. This lead us to one of two possible situations: one of the second terms of equation 2 must be decreased, either event probability (EP) or event utility (EU)

If the event probability of some event is low, the subjective feeling would be that as such event was interessant, although almost impossible to occur. Although theoretically possible, it is difficult to imagine how it would be, to have all events probability low. Which would be psychological internal experience for someone who experiences this? Would the person have a feeling that nothing would occur? That sounds a little strange and does not seem to correlate with the feelings reported by apathic patients. Additionally, it is difficult to correlate such hypothetical low event probability with a disturb in any specific known neuronal cluster of human brain

The second option, in order to have a low expected utility (EX), would be to have a low event utility (EU). As we saw, in the case of apathy, event utility of all events should be low, not only event utility of some specific event. This seems to correlate more nearly with sensation experienced by patients with apathy. When expected utility for all events is low, there is no special interest toward one or another event. In such situation no attention would be elicited by specific sensorial events, and, therefore, there would be a lack of intentional and planned motor actions, which is exactly the observed behavior in apathic patients. Once expected utility can be represented mathematically by a utility function, we could demonstrate the following relation:

$A = \lim EX (x_n) \text{ -> } 0$

Being A – apathy

$EX (x_n)$ – the generic utility function for n-th event x.

But which would be the benefits of what we have done? Is it not the same, to employ a philosophical-linguistic term as apathy or a neuroeconomical term as event utility? Well, the benefits achieved until here are that through this procedure, we were able to represent psychiatric symptom (apathy) as a mathematical event (the tendency of function utility values of all events to approximate of zero), which can be more easily manipulated in terms of a mathematical analysis of the empirical data and its relation (the second step of hour heuristic task)

But the benefits of such an approach are still greater. We could search, in a third step, for the biological systems underlying such decisional process. In the specific case of apathy such search could focus in forebrain reward systems which mediates the linking between a future prevision of pleasant outcome and the activation of cerebral areas responsible for the allocation of the resources involved in bringing about such outcome.

From an experimental neuroscientific point of view, it is well known that the circuitry of motivated behavior involves a combination of behavior specific regions in the hypothalamus as well as a general reward system running from midbrain to forebrain and including important components of several frontal-subcortical circuits. Catecholaminergic systems, particularly the mesolimbic dopaminergic system, are key modulators of motivated behaviors. [57] Other neuronal system deeply involved in this decisional process is the medial prefrontal cortex, in particular the anterior paracingulate cortex. The action of pre-frontal cortex can be understood as to maintain the representation of goals and the means to acquire them. [30] It is already know from behavioural neuroscience experiments that patients with depression present decreased bilateral or predominantly left-sided activation of medial pre-frontal cortex. [19] [20] [28] Behavioral experiments suggest that anticipation of increasing monetary gains activates a subcortical region of the ventral striatum in a magnitude-proportional manneris accompanied by feelings characterized by increasing arousal and positive valence.

After the employment of neuroeconomical variables to description of the problem and the localization of candidates areas responsible for biologically encode such terms, some questions could, them, be raised. Is it possible to quantify the magnitude of changes in expected utility equation observed in psychiatric patients with apathy when compared to normal healthy subjects? Could these modifications be descripted in arithmetical terms or through a graphic of utility function? Which is the response of these changes in utility function during treatment with antidepressive drugs? Which other variables (for example the presence of bad thoughts) could possibly interact with apathy? Could it also be described in neuroeconomical terms and related to specific brain areas? (Neurophysiological studies have demonstrated, for example, that activation of amygdale occurs when negative outcomes are predicted. Other authors have shown that there is a raise in amygdale activation during depressive disease, leading to an increase in frequency and intensity of negative feelings. [23] Could we demonstrate biologically the interaction of these areas and correspondent variables during psychiatric disease?

As we saw before the empirical endevour in Neuroeconomics has already begun for the research of visual-attentional and motor performance. This empirical embasement of such neuroeconomical theoretical analysis of psychiatry should certainly the ultimate objective to be persecuted, and only then, one might see all the final benefits and implications of such new way of dealing with mental disease.

As mentioned before, our intention is not to provide a complete theory of a psychiatry based in neuroeconomical approach, but to emphasize the benefits for psychology and of this revolutionary approach, providing some practical examples of the essential steps of such scientific research program would evolve.

CONCLUSION

Neuroeconomics provide conceptual tools which have proved to be of great value for analysis of brain and behavior. This article showed how this promising approach could be useful not only to describe normal behavior, but also extended to the study of pathological psychiatry symptoms and syndromes. Along the article we described the process of birth of Neuroeconomics as an alternative approach to classic reflex theory. We also presented and discussed some of the first experiments in Neuroeconomics, related to description of animal behavior in terms of Expected-Value Theory during visual saccadic movements and sensorimotor actions. Finally, we describe how neuroeconomical tolls could be used to describe mathematically two entities of psychopathology of psychiatric disorders: persecution delirium of schizophrenia and apathy of patients with depressive disorder. We sincerely expect that, at the end of this small journey through this still unexplored field of Neuroeconomics, we were able to increase reader's interest in this fascinating scientific approach, encouraging future theoretical and empirical research, and providing the first steps in direction of a Neuroeconomics oriented Psychopathology.

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