International Journal of User-Driven Healthcare
Volume 7 • Issue 1 • January-June 2017

Homo Neuroeconomicus:
A Review of Functional Magnetic Resonance Imaging of Game Trials on Economic Choice

Torben Larsen, Institute of Public Health, University of Southern Denmark, Odense C, Denmark

ABSTRACT

This paper discusses the development of a neuroeconomic model of decision-making (DM). The method used was a review of functional Magnetic Resonance Imaging of game trials on economic choice. Key centers in economic DM are Ventromedial Prefrontal Cortex, Dorsolateral Prefrontal Cortex, Frontopolar Cortex, Orbitofrontal Cortex, Anterior Cingulate Cortex, Amygdala and Ventral Tegmentum. The interaction of these centers determines individual risk-preference (NeM). The validity of NeM is consolidated by lesion-studies. NeM shows that relaxation exercises are complementary to physical fitness in the maintenance of mental health. Further, NeM explains the effect of "Early home-supported discharge" and how chess games support the learning of mathematics.

KEYWORDS

Bounded Rationality, Economic Choice, Gender Difference, Meditation, Neurocybernetics, Neuroeconomics, Risk-Aversion, Risk-Loving, User-Driven

1. INTRODUCTION

In 1955, Herbert Simon introduced the neoclassical paradigm of bounded (or imperfect) rationality (BR) in economic decision-making (DM). Simon realized that in practical life, rational decisions are limited by 1) insufficient information, 2) insufficient personal skills, and 3) shortage of time. Today, BR is challenged by economic psychology as introduced by (Kahnemann and Tversky, 1979). Neuroeconomics is a new transdisciplinary field of neuroscience, behavioral economics and cognitive psychology developed around new hypersensitive brain scanners as functional magnetic resonance imaging (fMRI). Early reviews were focused on how neuroscience could inform economics (Camerer et al., 2005), neuroeconomic research from the economics point of view (Kenning and Plassman, 2005), specific neurocenters relevant to economic decision-making (Loewenstein et al., 2006), and social decision-making (Sanfey, 2008). A recent neuroeconomic review identifies integration of reward seeking (RSS) and cognitive executive control (ES) as crucial to economic DM (Farb, 2013). RSS is a mesolimbic dopamine system originating in Striatum, passing the Midbrain and Anterior Cingulate Cortex (ACC) towards Orbitofrontal Cortex (OFC). ES is centered in Dorsolateral PFC (dlPFC) and is served by the Frontopolar Cortex (FPC) as well as posterior cortices as the visuospatial sketchpad in Intraparietal Sulcus (IPS) and semantic memories in Superior Temporal Sulcus.

A neuroreview assesses the schism between BR and cognitive psychology from the economics point of view (Camerer, 2008): Most economists think that neural evidence is unnecessary holding BR

DOI: 10.4018/IJUDH.2017010104

as the central normative position. Other economists share the skepticism among cognitive psychologists and neuroscientists about how rapidly new techniques like fMRI will yield operational conclusions. Some economists do have a cautious optimism about the option value of neuroeconomics. Addressing this cautious optimism, the present study aims to synthesize BR and psychological coping developing a neuroeconomic model of DM.

2. MATERIALS AND METHOD

Neuroeconomics is not yet a medical search term (MESH) in PubMed. Searching for "Neurueconomics, decision making and fMRI" finds 63 studies, out of which only Sanfey et al. (2003) is a primary trial on an economic choice. However, the reviews cited above, reference other relevant trials (registered in PubMed) as listed in Table 1.

The following seven neurocenters are extracted from Table 1 for construction of a Neuroeconomic model in Section 3:

1) vmPFC, 2) dlPFC, 3) FPC, 4) OFC, 5) ACC, 6) Am and 7) VT\

Table 1. Primary fMRI-trials on economic choice

Author	Purpose	Method	Center
Sanfey/Rilling (2003)	The neural base of emotional and cognitive processes in economic choice	fMRI of ultimatum game (UG) distributing a monetary reward	dlPFC and ACC
McLure et al. (2004)	The neural base of Intertemporal choices (IC)	fMRI of participants offered a choice between rewards at different points of time	ACC, Am[1] and dlPFC
Daw et al. (2006)	The neural base of switching: explorative vs. exploitative economic choices	fMRI of healthy subjects performing a 'four-armed bandit' task involving repeated choices between 4 slot machines	FPC-IPS or dlPFC
Goel et al. (2006)	The role of Prefrontal Hemispheric specialization in problem solving	Inference tasks were administered to 4 groups: Subjects dominated by the left PFC (dlPFC) with/-out brain injury and 2 other groups dominated by right PFC (FPC) with/-out injury	Dominance of dlPFC
Li et al. 2017	Neural correlates to cognitive Error	fMRI of 143 subjects performing a gain/loss framing task with data from >8000 studies	dlPFC and Amygdala (Am)
Erk et al. (2002)	Neural base of symbols (cars) of wealth/dominance	fMRI of differential responses viewing photographs of limousines, sports cars and small cars	Ventral Tegmentum (VT)
Singer (2006)	The neural base of empathy	Review of PET and fMRI-studies of 'Mind Reading' respective empathy	ACC
Camille et al. (2004)	The neural base of regret	fMRI manipulating a simple gambling task on 'counterfactual thinking' to subjects with normal respective injured Orbitofrontal Cortex	OFC
Levy/Glimcher (2012)	The neural base of valuation system	Meta-analysis of 13 fMRI-studies of monetary reward choices	vmPFC - OFC
Hare et al. (2014)	Rationality of DM in IC	fMRI of ventromedial PFC (vmPFC) respective dorsolateral PFC (dlPFC) in IC	vmPFC and dlPFC

3. RESULTS

3.1. fMRI Studies of General Economic Choice

1. Economic DM is investigated in the Ultimatum Game (UG), where one person offers another person a prize, e.g. 100 EURO, if he agrees with a third person on the sharing of this prize (Sanfey and Rilling, 2004). The UG is an economic choice because it (1) involves preferences for a reward and (2) requires cognitive reasoning on the best decision within a budget restriction (100 EURO). The UG is reproduced a number of times, showing that dlPFC (ES) and ACC/Insula (RSS) are activated simultaneously: ACC/Insula dichotomizes the transmission of signals towards the Frontal Cortex: emotions transmit to the OFC and saliency signals to dlPFC (Mohanty et al., 2007). In broad terms, this confirms the classical Homo Economicus optimizing the combination of preferences (formed in RSS) with budget restrictions (worked out by ES) (Pareto, 1906). A meta-analysis of 37 studies of UG find that on average the proposer offers 40% of the pie to the responder (Oosterbeek et al., 2004). Offers below 20% are mostly rejected and in all 16% of the offers are rejected;
2. Intertemporal Choice (IC) offers a group of persons a choice between rewards at different points of time. IC has a rational choice as that in accordance with the borrowing rate in the financial system. Respondents to IC divide in a group of rationalists dominated by dlPFC and a subgroup of risk-averters preferring a halving of their reward as paid instantly instead of waiting a year (McClure et al., 2004). The risk-averters are identified by Am indicating hyper activation of the fear network also comprising ACC/Insula and OFC. Despite methodological shortcomings in the study of intertemporal choice, evidence exists in favor of a two-component (Quasi-Hyperbolic) model of intertemporal choice referring to the subsystems centering, respectively, dlPFC and Am. A later fMRI-study of prosocial DM finds an analogue subgrouping of participants: one group with strong cognitive control dominated by dlPFC and another group of group-oriented subjects dominated by the fear network centering Am (Declerck et al. 2013; Fermin et al. 2016). Over-activation of Am is associated with the serotonin transporter (5-HTTLPR) in a meta-analysis (Munafo etal., 2008). Over-activation of Am constitutes Social Anxiety Disorder (Bruhl et al., 2014) wherefore the border between a normal risk-aversion and Social Anxiety Disorder is a gray zone;
3. A game trial within the field of reinforcement learning investigates a switch between normal exploitative choices and extraordinary explorative choices[9]. The subjects performed a 'four-armed bandit' task involving repeated choices between four slot machines paying out points (to be exchanged for money) around four different means randomly and independently changing from trial to trial. Exploration appears when subjects choose another slot than the one with the highest expected mean (the subjective experience behind these choices were described during a post-task interview). The simultaneous fMRI documents increased activity in Frontopolar Cortex (FPC) and IPS (centering the visuospatial sketchpad) during explorative choices (Daw et al., 2006). Further, FPC differentiates entrepreneurs managing their own venture from managers without venture experience in a controlled, non-randomized trial (Laurie-Martinez et al., 2014). Managing entrepreneurs made more efficient decisions than non-entrepreneur management. In summary, complementarity exists within ES between sequencing by dlPFC (Robertson et al., 2007) and association by FPC (Green et al. 2006; Bochin and Buckley 2015; Ryals et al., 2016);
4. A study (MRI) examines hemispheric specialization and DM during conditions of resolving certain, respective uncertain inferences (Goel et al., 2006). The results provide compelling evidence for hemispheric specialization for reasoning in PFC where the right PFC has a critical role to play about incompletely specified situations (ambiguity) which is typical to economic DM. This role involves the maintenance of ambiguous mental representations that temper premature over-interpretation by the left hemisphere. This special fallacy of left hemispheric

(dlPFC) dominance is explained as an over-imposed goal-direction blocking interhemispheric communication due to serial processing (with limited capacity) in the left lateral FPC (Koechlin and Hyafil, 2007). This cognitive fallacy is shown to appear far more frequent than fear-related biases (Li et al., 2017);

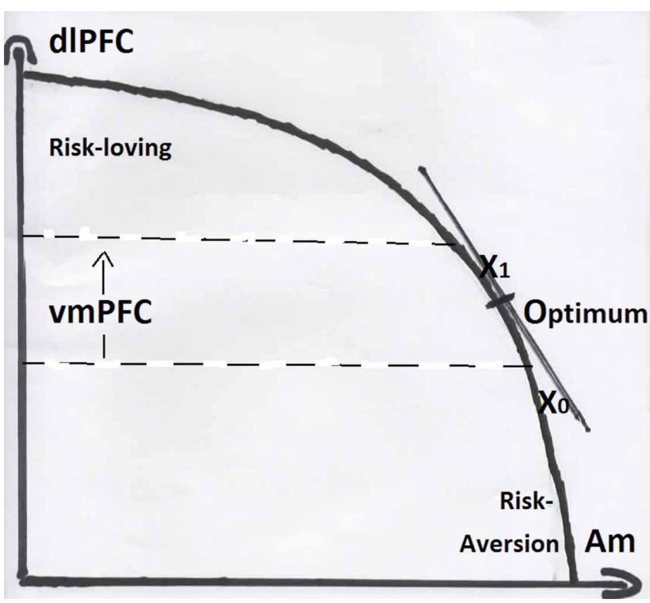
5. Classical economic man is a sovereign decision-maker as prototyped by Robinson Crusoe. BR does not change this pattern as his adaption of social attitudes in institutional settings is explained as individualist career moves. More studies contradict sovereign individual economic choices:
   a. The promotion effect on consumer goods of associated status symbols e.g. athletes are well-known in marketing. The extra cognition by neuroeconomics is to specify VT in the basal pro-reptile brain as dominant in this influence (Erk et al., 2002);
   b. Empathy and solidarity originate at the pro-mammal brain level (ACC). These qualities rely on a "mirror"-function meaning that our response to the pain of other people is nearly as strong as to pain originated in our own body (Singer, 2007);
   c. Regret as a technical term for conscientiousness is rooted in OFC at the Neomammal brain level (Camille and Corricello, 2004).

3.2. A Neuroeconomic Model

Koechlin and Hyafil (2007) has simulated the higher center of reintegration of RSS (VT, ACC, Am, OFC and FPC) and ES (dlPFC and FPC) in a neurocomputational model, where FPC as overlapping center sets our top-goal (or top-reward) in a pending, top-down relationship with vmPFC activating dlPFC (Oya et al, 2007). Basically, vmPFC inhibits OFC enabling graduation of reward-seeking as a bottom-up mechanism of integration (Beer et al., 2007). Levy and Glimcher (2013) identifies the vmPFC-OFC-complex as a value system constantly updating the expected utility. The integration process is illustrated in Figure 1.

The intrinsic imbibition of RSS is reflected by Am as the X-axis. For simplicity Am is indicated by the variability of the heart rate (HRV) (Thayer et al., 2012). The intrinsic state of ES – the balance of associations (FPC) and sequencing (dlPFC) – is indicated by the intensity of lateralized cortical control in the prefrontal EEG (Papousek and Schulter, 2002). The basic relationship between RSS

Figure 1. Neuroeconomic model of decision-making (NeM)



and ES is substitutional in economic terms or antagonistic in neurological terms: Arousal arising from RSS (Thalamus) is inversely related to Frontal attention by vmPFC (Portas et al. 1998; Olbrich et al. 2009). The minimal prediction error - or "Optimum" - is in such concave substitution relation the point where the first derivative has the value -1. The dominance of Am is characterized by risk-aversion (Bruhl et al., 2014) while the dominance of dlPFC implicates a risk-loving that threatens sound judgement (Goel et al., 2006). Gain/Loss-games show that decision-errors due to a dominance of dlPFC or goal-directed behavior are more frequent than errors due to risk-aversive behavior (Li et al., 2017). The case of optimization requires, that emotional control by vmPFC enabling a relative strengthening of dlPFC - indicated by the vertical shift from X_0 to X_1 - is sufficient to overcome an initial imbalance by economic reasoning.

The risk-preference (NeM) is operated as "Willingness to take risks in general" in a representative survey on 'risk attitudes' with 20,000 respondents (Dohmen et al., 2012). The survey demonstrates that a simple question on 'General risk attitude' to be answered on a scale from 0 through 10 has a fairly good explanation of individual performance. The coefficients of correlation (r) on important life domains are: 1) Car driving (r = 0.49), 2) Financial matters (r = 0.50), 3) Careers (r = 0.61), 4) Sports/leisure (r = 0.56), and 5) Health (r = 0.48).

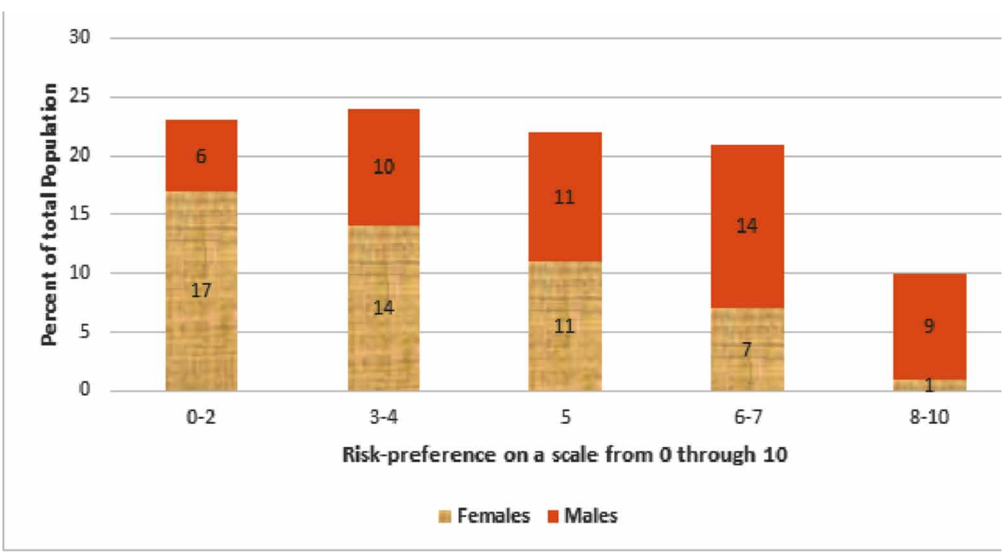
A number of factors affect the 'General risk attitude', however, the single far most important factor is gender as females are much more risk-averse than males. Also, the wiring of the brain shows gender differences (Ingalhalifar, 2014). Figure 2 shows the distribution of 'General risk attitude' in the adult population (18+). The total distribution is right skewed due to a very strong right-skewedness of females' 'General risk attitude', while nearly symmetrical around "Rationality" for males. The median of females' 'General risk attitude' is a moderate risk-aversion level, where economic decisions are made communicating with other rather than strictly rational.

4. DISCUSSION

4.1. Validity of NeM as Decision-Making Model

NeM identifies brain regions that are evidenced to be active in core fMRI-experiments with economic choice. However, more brain regions have different functions in different contexts. In order to insure

Figure 2. Social distribution of general risk-preference



the reverse function, that the associated function appears when that identified region is active, lesion studies are relevant to complement interpretations of fMRI (Xue et al., 2010):

- Lesions in vmPFC reduce the consistency of DM in accordance with the assigned role as over-all center of cognitive integration (Camille and Griffith, 2011);
- A neurological review develops the classical concept from lesions in OFC (inhibitory control) into a role across reward domains in forming and “updating the expected value of specific outcomes” (Rudebeck and Murray, 2015);
- A study of patients with lesions in dlPFC provides key evidence for the necessity of dlPFC in the manipulation of verbal and spatial knowledge (Barbey et al., 2013);
- Using an animal model, localized lesions to the FPC of nonhuman primates selectively impair the ability of the animal to learn rapidly about novel objects and rules (Green et al., 2006);
- The ACC or pro-mammal Cortex is the root of emotions as pro-reptiles without a significant ACC are ruled by behavioral instincts according to McLean (Cory and Gardner (Eds), 2002);
- Subcortical nodes as Am and VT should not need further explanation as they are well-known to neurophysiology.

In-all, evidence exists on the reversal validity of all distributed center functions in NeM. The interaction of these centers constitutes a risk-preference function as presented in Figure 1. Moreover, the forward correlation from risk-preference to neural activity is investigated (Rudorf et al., 2012): Subjects were grouped into risk-averters and risk-seekers according to the risk preference they revealed in a simple lottery task. This fMRI-study confirms the main assumption of Figure 1 that the internal inhibition of RSS is strong in risk-averters and weak in risk-lovers.

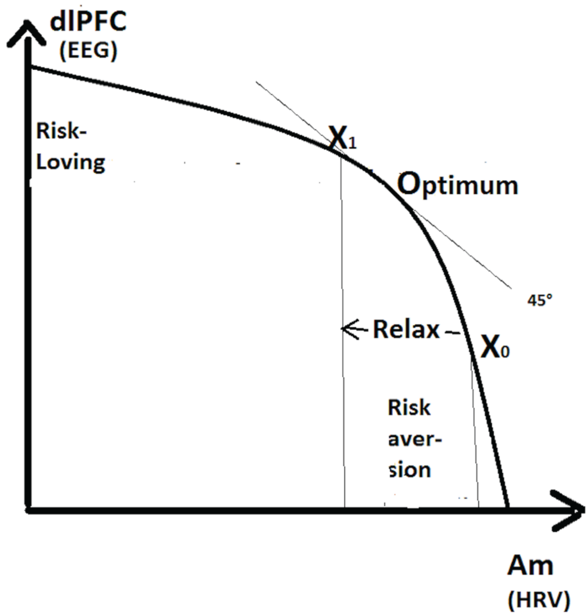
4.2. Neuroeconomic Training

NeM establishes a 2-way relationship between mental phenomena and neural substrates. This opens a new window for ‘objective’ mental training in the sense that neural processes are targeted to improve subjective qualities. In this way, traditional problems of “transference” between coach and client may be avoided. Neuroeconomic training respects personal integrity as other positivist training which is of special relevance for use in user-driven healthcare.

4.2.1. Relaxation Exercise

The crucial question is what type of neural training is relevant to strengthen subjective DM? NeM identifies self-control or endurance by vmPFC as crucial to mental health (Hare et al., 2014). The health effect of improved endurance by regular physical exercise is documented (Oaten and Cheng, 2006). Specific to emotional biases in DM risk-aversion builds up in the fear network centering Am. Moderate fear is conducive to cognition (Optimum), while strong emotional stress leads to maladaptation (Bruhl et al., 2014). Relaxing the fear network (Am) is hypothesized to facilitate cognition as illustrated by a horizontal shift in Figure 3. Already, a review with meta-analysis of the effectiveness of various relaxation techniques towards anxiety finds a significant effect (Manzoni et al., 2008). Despite severe male stress responses (Wang et al., 2007), the practice of relaxation exercises is very unequal distributed among genders. Yoga Asanas (physical relaxation techniques) are very popular among women in the industrialized world, but rare among men. Mental or logical relaxation in the format of meditation techniques is practiced only by a small minority – equally distributed on males and females - in the risk-loving part of the risk-preference spectrum (Hurk et al., 2011). Historically, the access to relaxation procedures as yoga and meditation are conditioned by some degree of belief which represents a strong barrier to rationalist males. Based on NeM, rationalist men may benefit from stress

Figure 3. Cognition by relaxation



management by complementary use of physical fitness and meditative relaxation independent of historical belief systems.

Promoting the status of alternative, user-driven relaxation exercises inspired by classical yoga and meditation to complementary healthcare implicates new challenges: What's the best relaxation procedure? How should the dissemination of such complementary health interventions be organized? To what extent may modern biofeedback technology improve the effectiveness of classical relaxation techniques?

4.2.2. Chess Morals

Regarding moderation of uncontrolled risk-loving as general maturation problem for youngsters – the most frequent DM-error (Li et al., 2017) - appropriate means are less obvious. A line of research inspired by Benjamin Franklin (1779) focuses on chess training as this ancient game demands interaction of basic qualities of the brain as sequencing (dlPFC), exploration (FPC) and self-control (vmPFC). A review concludes that chess training has a moderate but significant positive effect on mathematical skills among children at the primary school level (Bart, 2014). According to the Danish Association of School Chess, now, 200+ studies exist of the effect of chess instruction in early primary school on concentration, learning, reading and mathematics. A study substituted a weekly lesson in mathematics with chess instruction in primary school grades 1-3. Looking at subgroups, significant positive effects were found for native children, but not for children of immigrants (Gumede and Rosholm, 2015).

Despite the promising beginning in the introduction of chess at an early stage of primary school, there is still much to do in the development of chess as a broad tool for decision-making training. For example, is it common among advanced chess players to use computer analysis of their games. Such programs are able to identify poor chess-decisions as “Misinterpretations” and “Overlookings”. So, in combination with cheap computer programs young chess players may gain crucial self-recognition on the subjective conditions of “Misinterpretations” and “Overlookings”.

4.2.3. Early Home-Supported Discharge (EHSD)

When patients move from a hospital clinic to domicile their blood pressure declines 5-7 mmHg (Verberk et al., 2005). Following NeM (Figure 3) such Limbic relaxation may empower the cognitive function in the same way as do relaxation exercises. Actually, home-based rehabilitation is object to a number of research projects. Especially stroke patients have a large risk of severe disablement as nearly 30% may have poor outcome (PO) – dies or become disabled – by 6 months follow-up after admission. The Cochrain Trialists have reviewed a series of RCT on Early Home-supported Discharge (EHSD) as compared to usual care for patients suffering from stroke (Langhorne et al., 2005). The meta-analysis demonstrates a significant reduction in PO while traditional hospital measures as Barthél Index or Functional Independence Measure only show non-significant tendencies. In all, this indicates that the primary effect of EHSD is rather better psychological coping than somatic training as hypothesized from NeM.

Further, integrated programs of physical exercise and cognitive relaxation (meditation) may together benefit cardiac patients. An integrated mind/body approach to cardiac rehabilitation studied during a 3-month program 637 patients with coronary artery disease. As an outcome, this program gave a significant improvement for patients considered to be at "higher risk" level for cardiac events (Casey et al., 2009).

4.3. Related Models of Decision-Making

NeM as illustrated in Figure 1 is essentially a neural rooting of the vision of classical Homo Economicus (Pareto, 1906) as operated in the Neoclassical paradigm (BR) (Simon, 1955). In summary, NeM consolidates in one side BR as the central theorem of behavioral economics (Simon, 1955). On the other side are the borders of BR identified - not just as "Gray Zones" – but as different value-systems: Group-oriented risk-averters bordering anxiety disorders respective Risk-lovers challenging conventional wisdom. Related models of DM as advanced by applied psychology respective neurobiology are discussed below.

4.3.1. NeM and Behavioral Psychology

Luo and Yu (2015) models human choice as integration of emotion and cognition. In the typical case, the outcome is rational choices. "Reduced Cognition" is associated with strong fear (Am). When emotions are out of cognitive control, a state of "Exaggerated Emotions" appears ruled by intuition. The state of "Exaggerated Emotions" should not be confounded with the state of "Risk-loving" in NeM. Risk-lovers are characterized by low emotional inhibition and relative strong cognitive function. As such, Risk-lovers are a subgroup of persons with "Exaggerated Emotions".

Luo and Yu (2015) propose emotion regulation by cognitive measures (dlPFC) as attention deployment, cognitive change and response modulation to stabilize "Exaggerated Emotions". In comparison, NeM proposes improved mental health by user-driven neurophysiological measures as physical fitness, relaxation exercise, diet and understanding of NeM to persons with a normal mental health.

4.3.2. NeM and the Neurobiological Model

Ernst et al. (2006) propose a triadic model of the neurobiology of motivated behavior in adolescence. In this model vmPFC centers cognitive integration parallel to NeM. Further, Am serves the intralimbic inhibition parallel to NeM. However, Nucleus Accumbens (NAc) represents - as the third pillar - an intralimbic counter pole to Am. A subsequent study of animal behavior identifies the NAc core as crucial to the association of a cue stimuli with another reward, than the specific one in Paulovian-instrumental Transfer (General PIT). At the level of goal-directed human behavior. The authors hypothesize that complacency is a general PIT-fallacy explaining the cognitive error identified by Goel et al. (2006).

ACKNOWLEDGMENT

The project is financed by the European Commission FP7-Homecare project (Grant no. 222954). For special consultancy regarding multidisciplinary collaboration, I'm thankful to members of the International Institute of Advanced Studies and Cybernetics (IIAS), especially George Lasker (President of IIAS), Kensei Hiwaki (Professor of Economics) and Helmut Sauer (MD). Neuroeconomic Model (NeM) is awarded at Intersymp17 in Baden- Baden.

Disclosure Statement

The author declares that no competing financial or non-financial interest exists.

REFERENCES

Barbey, A. K., Koenigs, M., & Grafman, J. (2013). Dorsolateral Prefrontal Contributions to Human Working Memory. *Cortex*, *49*(5), 1195–1205. doi:10.1016/j.cortex.2012.05.022 PMID:22789779

Bart, W. M. (2014). On the effect of chess training on scholastic achievement. *Frontiers in Psychology*, *5*(762), 1–3. PMID:25152737

Beer, J. S., Knight, R. T., & DEsposito, M. (2007). Controlling the integration of emotion and cognition. *Psych Sci*, *17*(5), 448–453. doi:10.1111/j.1467-9280.2006.01726.x PMID:16683934

Boschin, E. A., & Buckley, M. J. (2015). Differential contributions of dorsolateral and frontopolar cortices to working memory processes in the primate. *Frontiers in Systems Neuroscience*, *9*(144), 1–8. PMID:26578901

Bruhl, A. B., Delsignore, A., Komossa, K., & Weidt, S. (2014). Neuroimaging in social anxiety disorder-a meta-analytic review resulting in a new neurofunctional model. *Neuroscience and Biobehavioral Reviews*, *47*, 260–280. doi:10.1016/j.neubiorev.2014.08.003 PMID:25124509

Camerer, C., Loewenstein, G., & Prelec, D. (2005). Neuroeconomics: How Neuroscience Can Inform Economics. *JEcoLit*, *43*, 9–64.

Camerer, C. F. (2008). Neuroeconomics: Opening the Gray Box. *Neuron*, *60*(3), 416–419. doi:10.1016/j.neuron.2008.10.027 PMID:18995815

Camille, N., & Corricello, G. (2004). The involvement of the orbitofrontal cortex in regret. *Sci*, *304*(5674), 1167–1170. doi:10.1126/science.1094550 PMID:15155951

Camille, N., Griffiths, C. A., Vo, K., Fellows, L. K., & Kable, J. W. (2011). Ventromedial frontal lobe damage disrupts value Maximization in humans. *The Journal of Neuroscience*, *31*(20), 7527–7532. doi:10.1523/JNEUROSCI.6527-10.2011 PMID:21593337

Cartoni, E., Puglisi-Allegra, S., & Baldassarre, G. (2013). The three principles of action: A Paulovian-instrumental transfer hypothesis. *Frontiers in Behavioral Neuroscience*, *7*(153), 1–11. PMID:23423702

Casey, A., Chang, B. H., Huddleston, J., Virani, N., Benson, H., & Dusek, J. A. (2009). A model for integrating a mind/body approach to cardiac rehabilitation: outcomes and correlators. *Journal of Cardiopulmonary Rehabilitation and Prevention*, *29*(4), 230–238. doi:10.1097/HCR.0b013e3181a33352 PMID:19451830

Cory, G. A., & Gardner, R., Jr. (Eds.). (2002). The evolutionary neuroethology of Paul McLean.

Daw, N. D., ODoherty, J. P., Dayan, P., Seymour, B., & Dolan, R. J. (2006). Cortical substrates for exploratory decisions in humans. *Nature*, *441*(7095), 876–879. doi:10.1038/nature04766 PMID:16778890

Declerck, C. H., Boone, C., & Emonds, G. (2013). When do people cooperate? The neuroeconomics of prosocial decision making. *Brain and Cognition*, *81*(1), 95–117. doi:10.1016/j.bandc.2012.09.009 PMID:23174433

Dohmen, T., Falk, A., Huffman, D., Sunde, U., Schupp, J., & Wagner, G. G. (2012). Individual Risk Attitudes: Measurement, Determinants and Behavioral Consequences. *Journal of the European Economic Association*, *9*(3), 522-550.

Langhorne, P., Taylor, G., Murray, G., Dennis, M., Anderson, C., Bautz-Holter, E., ... & Rodgers, H. (2005). Early supported discharge services for stroke patients: An individual patient data and meta-analysis. *Lancet*, *365*, 505–506. doi:10.1016/S0140-6736(05)70274-9

Erk, S., Spitzer, M., Wunderlich, A. P., Galley, L., & Walter, H. (2002). Cultural Objects modulate reward circuitry. *Neureport*, *13*(18), 2499–2503. doi:10.1097/00001756-200212200-00024 PMID:12499856

Ernst, M., Pine, D. S., & Hardin, M. (2006). Triadic model of the neurobiology of motivated behavior in adolescence. *Psychological Medicine*, *36*(3), 299–312. doi:10.1017/S0033291705005891 PMID:16472412

Farb, N. A. S. (2013). Can Neuroimaging inform economic theories of decision-making? *Neurosci and Neuroecon*, *2*, 1–10. doi:10.2147/NAN.S39339

Fermin, A. S., Sakagami, M., Kiyonari, T., Li, Y., Matsumoto, Y., & Yamagishi, T. (2016): Representation of economic preferences in the structure and function of the amygdala and prefrontal cortex.

Franklin, B. (1779). *On the Morals of Chess*. Yale University Press.

Laureiro-Martínez, D., Canessa, N., Brusoni, S., Zollo, M., Hare, T., Alemanno, F., & Cappa, S. F. (2014). Frontopolar Cortex decision-making efficiency: Comparing brain activity of experts with different professional background during an exploration-exploitation task. Frontiers in human neuroscience, *7*, 1–10.

Goel, V., Tierney, M., Sheesley, L., Bartolo, A., Vartanian, O., & Grafman, J. (2006). Hemispheric specialization in human prefrontal cortex for resolving certain and uncertain inferences. *Cerebral Cortex, 17*(10), 2245-2250.

Green, A. E., Fugelsang, J. A., Kraemer, D. J. M., Shamosh, N. A., & Dunbar, K. N. (2006). Frontopolar cortex mediates abstract integration in analogy. *Brain Research*, *1096*(1), 125–137. doi:10.1016/j.brainres.2006.04.024 PMID:16750818

Gumede, K., & Rosholm, M. (2015). Your move: The effect of Chess on Mathematics Test Scores. Institute for the Study of Labor, Bonn, Germany.

Hare, T. A., Hakimi, S., & Rangel, A. (2014). Activity in dlPFC and its effective connectivity to vmPFC Are associated with temporal discounting. *Frontiers in Neuroscience*, *8*(50), 1–15. PMID:24478622

Kahnemann, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, *47*(2), 263–291. doi:10.2307/1914185

Kenning, P., & Plassmann, H. (2005). Neuroeconomics: An overview from an economic perspective. *Br Res Bul*, *67*(5), 343–354. doi:10.1016/j.brainresbull.2005.07.006 PMID:16216680

Koechlin, E., & Hyafil, A. (2007). Anterior Prefrontal Function and the Limits of Human Decision-Making. *Science*, *318*(5850), 594–598. doi:10.1126/science.1142995 PMID:17962551

Levy, D. J., & Glimcher, P. W. (2012). The root of all value: A neural common currency for choice. *Curr Op. Neurosci*, *22*(6), 1027–1038.

Loewenstein, G., Rick, S., & Cohen, J. D. (2008). Neuroeconomics. *Annual Review of Psychology*, *59*(1), 647–672. doi:10.1146/annurev.psych.59.103006.093710 PMID:17883335

Luo, J., & Yu, R. (2015). Follow the heart or the head? The interactive influence model of emotion and cognition. *Frontiers in Psychology*, *6*, 573. doi:10.3389/fpsyg.2015.00573 PMID:25999889

Manzoni, G. M., Pagnini, F., Castelnuovo, G., & Molinari, E. (2008). Relaxation training for anxiety: A ten-years systematic review with meta-analysis. *BMC Psychiatry*, *8*(1), 41. doi:10.1186/1471-244X-8-41 PMID:18518981

McClure, S. M., & Laibson, D. I., Loewenstein, G., & Cohen, J. D. (2004). Delayed monetary rewards separate neural systems value immediate and delayed monetary rewards. *Science*, *306*(5695), 503–507. doi:10.1126/science.1100907 PMID:15486304

Mohanty, A., Engels, A. S., Herrington, J. D., Heller, W., Ringo Ho, M.-H., Banich, M. T., & Miller, G. A. et al. (2007). Differential engagement of anterior cingulate cortex subdivisions for cognitive and emotional function. *Psychophys*, *44*(3), 343–351. doi:10.1111/j.1469-8986.2007.00515.x PMID:17433093

Munafo, M. R., Brown, S. M., & Hariri, A. R. (2008). Serotonin Transporter (5-HTTLPR) Genotype and Amygdala Activation: A Meta-Analysis. *Biological Psychiatry*, *63*(9), 852–859. doi:10.1016/j.biopsych.2007.08.016 PMID:17949693

Oaten, M., & Cheng, K. (2006). Longitudinal gains in self-regulation from regular physical exercise. *British Journal of Health Psychology*, *11*(4), 717–733. doi:10.1348/135910706X96481 PMID:17032494

Olbrich, S., Mulert, C., Karch, S., Trenner, M., Leicht, G., Pogarell, O., & Hegerl, U. (2009). EEG-vigilance and BOLD effect during Simultaneous EEG/fMRI measurement. *NeuroImage*, *45*(2), 319–332. doi:10.1016/j.neuroimage.2008.11.014 PMID:19110062

Oosterbeek, H., Sloof, R., & van deKuilen, G. (2004). Cultural Differences in Ultimatum Game Experiments: Evidence from a Meta-Analysis. *Experiment Econ*, *7*(2), 171–188. doi:10.1023/B:EXEC.0000026978.14316.74

Oya, H., Adolphs, R., Kawasaki, H., Bechara, A., Damasio, A., & Howard, M. A. (2005). Electrophysiological correlates of reward prediction error in the human prefrontal cortex. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(3), 8351–8356. doi:10.1073/pnas.0500899102 PMID:15928095

Papousek, I., & Schulter, G. (2002). Brain asymmetry and stress: New perspectives in psychophysio logically oriented psychosomatic research. *Psychologische Beiträge*, *44*, 535–544.

Pareto, D. (1906). *Manual of Political Economy*. Lausanne.

Portas, C. M., & Rees, G., Howseman, A. M., Josephs, O., Turner, R., & Frith, C. D. (1998). A specific role for the thalamus in mediating the interaction of attention and arousal in humans. *The Journal of Neuroscience*, 18(*21)*, 8979–8989. PMID:9787003

Li, R., Smith, D. V., Clithero, J. A., Venkatraman, V., Carter, R. M., & Huettel, S. A. (2017). Reason's Enemy Is Not Emotion: Engagement of Cognitive Control Networks Explains Biases in Gain/Loss Framing. *The Journal of Neuroscience, 37(13), 3588-3598.* PMID:28264981

Robertson, E. M., Tormos, J. M., Maeda, F., & Pascual-Leone, A. (2007). The Role of the Dorsolateral Prefrontal Cortex during Sequence Learning is Specific for Spatial Information. *Cerebr. Cort.*, *11*(7), 628–645. doi:10.1093/cercor/11.7.628 PMID:11415965

Rudebeck, P. H., & Murray, E. A. (2015). The orbitofrontal oracle: Cortical mechanisms for the prediction and evaluation of specific behavioral outcomes. *Neuron*, *84*(6), 1143–1156. doi:10.1016/j.neuron.2014.10.049 PMID:25521376

Rudorf, S., Preuschoff, K., & Weber, B. (2012). Neural Correlates of Anticipation Risk Reflect Risk Preferences. *The Journal of Neuroscience*, *32*(47), 1683–1692. doi:10.1523/JNEUROSCI.4235-11.2012 PMID:23175822

Ryals, A. J., Rogers, L. M., Gross, E. Z., Polnaszek, K. L., & Voss, J. L. (2016). Associative recognition memory awareness improved by theta-burst stimulation of frontopolar cortex. *Cerebr Cortex*, *26*(3), 1200–1210. doi:10.1093/cercor/bhu311 PMID:25577574

Sanfey, A. G. (2007). Social Decision-Making: Insights from Game Theory and Neuroscience. *Sci*, *318*(5850), 598–602. doi:10.1126/science.1142996 PMID:17962552

Sanfey, A. G., & Rilling, J. K. (2007). The neural base of economic decision-making in the ultimatum game. *Sci*, *30*, 1755–1758.

Ingalhalikar, M., Smith, A., Parker, D., Satterthwaite, T. D., Elliott, M. A., Ruparel, K., ... & Verma, R. (2014). Sex differences in the structural connectome of the human brain. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(2), 823–828. doi:10.1073/pnas.1316909110 PMID:24297904

Simon, H. A. (1955). A Behavioral Model of Rational Choice. *The Quarterly Journal of Economics*, *69*(1), 99–118. doi:10.2307/1884852

Singer, T. (2006). The neuronal basis and ontogeny of empathy and mind reading: Review of literature and implications for future res. *Neuroscience and Biobehavioral Reviews*, *30*(6), 855–863. doi:10.1016/j.neubiorev.2006.06.011 PMID:16904182

Thayer, J. F., Åhs, F., Fredrikson, M., Sollers, J. J. III, & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience and Biobehavioral Reviews*, *36*(2), 747–756. doi:10.1016/j.neubiorev.2011.11.009 PMID:22178086

van den Hurk, P. A., Wingens, T., Giommi, F., Barendregt, H. P., Speckens, A. E., & van Schie, H. T. (2011). On the relationship between the practice of meditation and personality – an exploratory analysis of the mediating role of mindfulness skills. *Mindfulness*, *2*(3), 194-200.

Verberk, W.J., Kroon, A.A. et al (2005): Home Blood Pressure Measurement. A Systematic Review. *Journal of the American College of Cardiology* 46(5:743-61.

Wang, J., Korczykowski, M., & Rao, H., Fan, Y., Pluta, J., Gur, R. C., ... & Detre, J. A. (2007). Gender difference in neural response to psychological stress. *SCAN*, *2*, 227–233. PMID:17873968

Xue, G., Chen, C., Lu, Z., & Dong, Q. (2010). Brain Imaging Techniques and Their Applications in Decision-Making Research. *Xin Li Xue Bao*, *52*(1), 120–137. PMID:20376329

Torben Larson received an MSc Egon from University of Aarhus and a Degree in Strategic Management from University of Maryland / Tietgenskolen Dk. Torben has broad experience in regional planning of healthcare with Academic Awards from 1) Association of Hospital Managers in Norway, Lundbeck Fonden Dk and MIE96. He is a former Chief Consultant in Apples Healthcare Research at University of Southern Denmark. This included leadership of an EU-sponsored research project in Integrate Homecare. He has been involved with various courses and conferences and has written research papers in neuroeconomics, meditation and Biofeedback.