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An Analysis of Deductive Reasoning: A Review Supported by Neuro-Physiological Evidences

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Deductive reasoning is the cognitive ability to search for new information on the basis of the information already given. With the advancement of different neurological techniques it is possible to understand neural activities during deductive reasoning in details. Review based literature helps in understanding area wise activation during deductive reasoning. However, the possible cognitive roles of those activated areas were not clearly described in the literature. This paper attempts to address primitive cognitive functions that are involved in deductive reasoning by means of identifying the possible role of brain regions during deductive reasoning. Majority of studies indicate that other cognitive functions are inherent in deductive reasoning.

Keywords: Deductive Reasoning, Cognitive Functioning, Neurophysiology, Activated Brain Area

Reasoning is an essential component of cognition. It may be discussed under two broad categories: deductive and inductive reasoning. In this paper we would focus on deductive reasoning. Unlike inductive reasoning, deductive reasoning basically deals with the information (premises), which is already given. The conclusion is to be drawn on the basis of that information. An inference is considered valid if and only if the conclusion by virtue of some rules comes from the premises. If the conclusion is not accepted by the common sense view, it does not affect the validity of the inference. For example, All smart people are reasonable, All politicians are smart people. Therefore, all politicians are reasonable.

Someone may consider it as an invalid conclusion because his/her commonsense view may prevent him/her to consider tht conclusion as a valid one. This kind of subjective interpretation comes in the way of rule following (Evans, 2002; Goel, 2007). Since individual belief plays an important role in concluding the presented information as premise. Tht belief bias is a good evidence for manipulation of stored information in deductive reasoning, which needs to be investigated. Apart from belief bias, there are several other factors with which deductive reasoning may be concerned. Review indicates the experiment conducted in the study of deductive reasoning often uses different kinds of stimulus or task variables. Most of the experiment based on deductive reasoning was conducted by using task variables, which varied in terms of presentation, mode of stimulus and instructional variation. For example, contextual knowledge, familiarity or non-familiarity of the stimulus (Goel, Markele, & Grafman, 2004), certainty or uncertainty of task (Politzer & Bourmaud, 2002), nature of task (Chadha & Booth, 2012) may influence deductive reasoning. In deductive reasoning the reasoner draws the right conclusion in a more precise and appropriate way. Thus, investigating deductive reasoning amounts to, scientifically validating particular information from alternative available information.

Neurophysiological assessment of deductive reasoning

For understanding cognitive processes in the brain during deductive reasoning, neurological processes are taken into consideration. Three of the major neurological techniques are popular namely EEG, PET scan and fMRI study (Goel, 2007; Prado, Chadha, & Booth, 2010). The advantages of the neurological techniques are useful for several reasons (Anu, Lavelle, & Cacioppo, 2009):

- It provides region specific information in the brain excluding noises (especially in EEG)
- It provides high chance of reliability because it shows quantitative records
- Through fMRI we get thre3 dimensional images. One of the advantages of 3-dimensional fMRI studies is that it provides information about functioning of the entire brain by its pattern of dynamic blood flow in the brain. The new fMRI techniques can monitor changes in neural activities within few seconds. It helps in the analysis of the neural pathways from where activities initially take place. Another important aspect of fMRI technique is that it provides a sophisticated method, which helps in further interpretation and modeling of data.

In more recent experiments repetitive Transcranial Magnetic Stimulation (rTMS) (Christoff, et al., 2012) has been used in deductive reasoning study.

Problem with the neurophysiological experiments:

With the advancement of more technological tools it is easier to understand the neural activities in a much sophisticated way. It is difficult to predict conclusively the exact set of neurons that are active during deductive reasoning. Deductive reasoning depends on several factors. In the earlier meta-analysis by Goel (2007) and Prado Henst, & Noveck. (2010) it is shown how neural activity during deductive reasoning changes in accordance with the nature of premises. In those attempts they tried to provide a guideline regarding deductive reasoning and neurological explanation by using corresponding neuroscience literature. Categorical reasoning, complex reasoning and transitive inferences are paid more attention on 2007 review by Goel. After four years, in 2011 another attempt was made by Prado Chada & Booth to find out brain network for deductive reasoning involving categorical, relational and propositional statements. Essentially this attempt was also based on review of corresponding literature since May 2007 to September 2010. There was a difference in the nature of data processing in the second meta-analysis by Prado et al (2011). He used both qualitative and quantitative methods for data processing whereas Goal had used only the qualitative survey method. Overall findings highlighted brain wise activities in deductive reasoning.

Purpose of the present review:

The difficulties with the earlier findings as mentioned by Goal (2007) and Prado et al (2011) is thatethe findings basically focus on region wise activation during deductive reasoning task. Both Goal (2007) and Prado et al (2011) reviewed neurocognitive framework with variation of types of premises such as categorical, propositional, relational etc. However, the explanation is incomplete if the specific role of those areas is not explored during deductive reasoning process. Specific brain regions are being discussed in the following paragraphs. There have been high probabilities of activation of those numerous regions due to maintenance of other cognitive functions such as attending stimulus, recognizing words, executing and monitoring etc. These cognitive functions help in successful fulfillment of deductive reasoning. Specific brain region are being discussed in the following paragraph.

Thus, the initial purpose of this article is to identify brain wise different activity during deductive reasoning with the help of the recent neurological review based evidences. At the same time we try to identify other cognitive activities in relation with deductive reasoning, whichd activate the brain region due to deductive reasoning. Some other cognitive processes also take place during deductive reasoning tasks on those chosen areas. Those are also mentioned in brief.

Processes of Deductive reasoning evident by neurophysiological experiments:

Deductive reasoning is not merely one singular process. There are neurological sub processes underlying the different phases in deductive reasoning (Fangmeier, Knauff, Ruff, & Sloutsky, 2006).The first phase of this sub process is known as premise processing phase. In this phase the premises are presented. The working memory and attentional mechanism is essentially involved in maintaining the information, which is presented or which is going to be presented (in sequential trails). Here, the reasoner has to hold the information as either in a form of letter stimuli or spatial sequential task (according to the design of the study, either verbal or spatial information is to be processed). The next step is called premise integration phase. Here, the reasoner along with the first stimulus received other stimuli. Thus, here reasoner has to integrate stimulus from two successive steps. In the final step, the subjects select the right conclusion. In most of the neurophysiological studies the multiple choice type information are given and the subject has to answer either true or false by pressing keys. Neurological evidences revealed that premise processing phase is related to the bilateral cortical structure in the occipital temporal cortex (OTC). Those areas are involved in visual working memory, imaging and corresponded to the ventral 'what' stream. Thus, it indicates that the reasoner uses his/her knowledge to construct a visual spatial model to understand the information conveyed through the premises. Another important issue is that those stimuli that are easy to visualize facilitate the activity for integration during a reasoning task. Thus, memory may be involved in premise integration phase.

In the integration phase, the reasoner constructs a single integrated model of the presented stimulus. So the premises are not scattered as separate entities in working memory. The executive functioning helps the reasoner to integrate the information to draw a certain conclusion. The activation of the anterior prefrontal cortex and the anterior cingulate cortex during this stage of reasoning supports integration process. The Anterior Prefrontal Cortex is involved in relational integration during reasoning and maintenance of multiple relations simultaneously. This integration and maintenance of information actually facilities the executive control of information in deductive reasoning.

Neurological evidence from the transitive inferences or three-term-series problems (Fangmeier, Knauff, Ruff, & Sloutsky, 2006) also indicate tha, presentation of first premise does not produce any neural activities (except temporal-occipital lobe, which is due to semantic analysis and visual presentation task), it gradually starts after presentation of second premise and the process continues up to selection of conclusion (Moreno & Diana, 2009). In the validation phase, the conclusion is verified specially if it's in multiple choice or optional form. During this phase, activation in the right prefrontal cortex and lateral prefrontal cortex helps in spatial processing especially when the nature of task is related with spatial processing. The working memory and integration of sensory information helps in the modality of independent conclusion drawing (Fangmeier, Knauff, Ruff, & Sloutsky, 2006).

Cognitive activities related with deductive reasoning:

From the literature we highlighted three main cognitive processes in deductive reasoning. The primary cognitive activities that are noticed during reasoning are memory, language and attention.

Memory: Several kinds of memory are involved during deductive reasoning. Depending upon the task designed by the experimenter, it has been observed from fMRI that in deductive reasoning task either visuospatial or spatial memory processing is involved. The findings highlighted possible role of working memory in deductive reasoning. Another possible reason to focus on the working memory is that popular models of deductive reasoning, namely Mental Model Theory (MMT) or Rule Based Approach (RBA), both of which can be explained through working memory models. It is either visuospatial processing (in case of deductive reasoning experiment conducted with language or verbal medium) or spatial memories (in case of non-language, spatial task) are involved in deductive reasoning. In the study conducted by Goel and Dolan (2004) it was highlighted that bilateral activation of superior and inferior parietal lobes, dorsal superior frontal cortex and right superior and middle frontal gyri, widely implicated in visual spatial processing caused by modulation of deductive reasoning task for an unfamiliar situation. It was assumed by the experimenter that an unfamiliar situation activated more on visuospatial memory than a familiar situation. In this experiment, the right inferior temporal gyrus, posterior hippocampus and para-hippocampal gyrus are activated. This activation is caused by deductive reasoning task due to familiar situation. This activation significantly highlighted the function of spatial memory during deductive reasoning task performance. Another important function is executive control that helps to maintain information in working memory. Rebecca Paulin & Stern (2007) found that deductive reasoning reflects an interaction between cortical areas and the caudate nucleus. This caudate nucleus actually controls the executive functioning during deductive reasoning. Thus, working memory activation during deductive reasoning is evident and supported by different neurological experimentation.

Language: The language is an essential component of deductive reasoning. However, in case of deductive reasoning language becomes a part of semantic memory, that is, declarative form of Long Term Memory (LTM). In declarative memory participants are able to carry forward the information that is already stored in LTM. The semantic memory is actually accessed in deductive reasoning. For example, Sloman (1996) conducted a study to experimentally find out the systems of deductive reasoning. Researchers find out that conceptually familiar and coherent information, that is, semantic information are processed by language areas of the brain mainly left frontal-temporal systems. On the other hand, unfamiliar, non-conceptual or incoherent materials in deductive reasoning are processed by bilateral parietal lobes, indicating activation of visuospatial systems of working memory.

Attention: Depending on the experimenter design, the deductive reasoning can be explained by attention. For example, in many deductive reasoning studies on symbolic cueing task was applied. The symbolic cueing test is conducted by presenting a visuay stimulus and the participants were asked to respone as soon as possible followed by the appearance of the stimulusion the screen. By endogenous attention we mean the voluntary involvement of participants toward specific aspects of the environment in accordance with their interest and goal (Breedlove, Watson & Rosenzweig, 2010). This kind of experiment is common in deductive reasoning where the experimenter designed the study independent of language and related with the directional changes of the stimulus. The fMRI evidence for three stage model of deductive reasoning conducted by Frangmeier et al. (2006), it is observed that in deductive reasoning task the participants paid attention to the positional shift of the premise in first two successive stages. It is also important to mention her, that the encoding phase of the stimulus is not possible without attention.

Theories studied during neurological experiments of deductive reasoning:

There are two conjectures for deductive reasoning. One is the rule based approach and the other, mental model based approach. The distinctive features of those two approaches are basically focused on the processes of deductive reasoning. We consider the popular models of deductive reasoning with reference to the neurological experiments that have been conducted. The Rule Based Approach (RBA) postulates reasoning governed by underlying knowledge of inferential rules in closed form or logical term. Essentially rule based approach considers deductive reasoning related with linguistic or syntactic nature of premises. Hypothetically,r RBA deductive reasoning is related to activation of the right hemisphere (Rips, 1994). On the contrary, Mental Model Theory (MMT) postulates that reasoner has internal competence knowledge, that is, the reasoner had inherent capacity to comprehend the underlying mechanism of deductive reasoning task. This knowledge is required to construct and search alternative scenarios (counter examples). The internal representations of arguments proved the structural properties of the world (spatial relation for example). Thus, it is involved with the visuospatial system of the brain. This visuospatial system is hypothetically related with the activation of left frontal and temporal lobe regions (Johnson-Laird, & Byrne, 1991) of the brain.

Although, both the theories have different approaches, that is, reasoning is either governed by linguistic areas of the brain or by visuospatial areas, the findings suggests different stories. Other than language areas and visuospatial areas, different areas of the brain are found, which are affected during reasoning (Moreno & Diana, 2009; Reverberi, et al 2012). Several areas typically are responsible for other cognitive functioning and are also activated during reasoning. For example, hippocampus (essentially related with memory function) is activated in reasoning task (Goel, Markale, & Grafman, 2004). Another important area in middle frontal gyrus called cingulate is activated during reasoning (Fangmeier et al 2006). The cingulate is related to several cognitive processes like active manipulation of stimulus. The role of cingulate is also well known for the executive function, which is essentially related with working memory (Salvadore, et al 2010). In the three step neurological analysis of deductive reasoning it was also found that both occipital-temporal areas (assumed by MMT) are initially activated during reasoning, but it spreads throughout the brain as the reasoning process continues (Fangmeier et al., 2006). Activation of several areas like cingulate, hippocampus or temporal lobes in more or less all kinds of reasoning task essentially leads to the conjecture that reasoning may not be governed by a single cognitive factor. It might require several other cognitive functions like working memory, semantic memory or even attentional processes.

The neurophysiology and other cognitive process during deductive reasoning:

Deductive reasoning and activation of Basal Ganglia: The basal ganglia are collection of subcortical neuronal groups in the forebrain located beneath the anterior portion of the lateral ventricles. The basal ganglia have a significant role in the control of movement. The three main subdivisions of basal ganglia are globus pallidus, caudate nucleus, and putamen. The basal ganglia, sub-thalamic nucleus, and substantia nigra participate in circuits with the cortex and thalamus to mediate aspects of motor control, as well as cognitive functions such as short term memory process of the dorsolateral prefrontal cortex, and some executive functions (involvement of high control of behavior).

Activation in the subcortical structure like basal ganglia is common in the neurological investigation for deductive reasoning. The meta-analysis by Prado et al (2011) highlighted the function of basal ganglia in categorical argument. Goel (2007) in his review based investigation found activities of basal ganglia in several areas of reasoning like transitivity in deductive reasoning, categorical deductive reasoning and on complex deductive reasoning. Recent investigations by Liu, et al (2012) it has been identified that activities in basal ganglion is due to complex conditional reasoning. Most focused investigation by Rebecca, Poulin, and Stern (2007) explain the requirement of basal ganglion on deductive reasoning to make a connection between cortical areas and caudate body, in which caudated body support both reasoning and working memory. The executive function of reasoning is conducted by the head of caudate. The role of executive function is to deduce and apply a sequence of rule. In case of mental models the sequence of rule is inbuilt in the human system and in case of rule based approach rules are learned to carryout reasoning task. Thus, both working memory and LTM gets involved in the learning rules. The investigation also revealed that basal ganglia make a circuit in reasoning task with activated part of caudate, putamen and globus pallidus. The role of putamen in planning (Elsinger, Harrington, & Rao, 2006) and motor execution (Monchi, Petrides, Strafella., Worsley, & Doyon, 2006) was reported. These planning and execution are required for deductive reasoning in self-governing responses (Elsinger, Harrington & Rao, 2006). Globus pallidus was identified as in selection and updating of information with working memory (Tinaz, Schendan, Schon, & Stern, 2006). Successive updating of information is essential for deductive reasoning to maintain sequences. Not only for the complex reasoning task engagement of caudate is also found in both low and high load reasoning condition (Moreno & Diana, 2009). The caudate was found involved in two crucial steps of deductive reasoning such as integration of the premises and conclusion generalization. Thus, basal ganglion plays an important role in deductive reasoning. The basal ganglion is also involved in many other functions of human behavior. Basal ganglion is important in neuroendocrine control, motivation and reward (Claudio, Alexander & Charles, 2012). It is possible that there is involvement of those functions in deductive reasoning. Especially the role of neurotransmitters (activation initially mediated by basal ganglion) such as function of dopamine and serotonin were not well recognized in reasoning. Stollstorff (2010) had made an attempt to explain the role of basal ganglion in human reasoning, but the study was limited only on genetic influence on reasoning. Actually basal ganglion is the store house of different neurotransmitters, namely dopamine, serotonin etc. From the neurophysiological evidences activation in basal ganglion during reasoning is observed. basal ganglion is the key source of neurotransmitters, those neurotransmitters may also take part in human reasoning. Thus, from the analysis of the role of basal ganglion it may be suggested that human deductive reasoning is closely related with working memory activities.

Deductive reasoning and activation of frontal lobe: The most obvious anatomical differences between primates and other mammal is that primates have large frontal lobe. Frontal lobe is activated in almost every study with deductive reasoning. In more precise and well defined experiments several other areas are mentioned with specific task. The areas are right pre frontal cortex (Fragmenier, et al 2006; Brzezicka, et al 2011), left-fronto lateral cortex (Reverberi et al 2010), left inferior lateral frontal (BA44/45) and superior medial frontal (Reverberi, et al 2012), inferior frontal gyrus (Prado, Mutreja, & Bopth, 2012) etc. Several areas of frontal lobe are more active depending on the nature of premise. Prado et al (2011) have shown that meta-analysis in left frontal gyrus gets activated due to categorical arguments and medial frontal gyrus due to propositional reasoning.

In a more recent experiment by Reverberi, et al (2010) it has been observed that the nature of activation in brain is related with the nature of premise change.

The main activated areas in frontal lobe, which are found in recent experiments are described below:

Inferior frontal gyrus: Goel & Dolan (2004) in their study found that left inferior frontal gyrus is typically activated in deductive reasoning rather than inductive reasoning. The left inferior frontal gyrus was found important for language production and verbal comprehension. The most popular 'Broca's area is associated with left inferior gyrus. Persons with damage in Broca's area are found to have non fluent aphasia, which indicate speech is notably difficult to produce comparing with Wernicke's aphasia (Fauci, 1998). In a study, Prado et al. (2012) claim that left inferior gyrus and posterior cortex are involved in verbal processing.

Another role of inferior frontal gyrus was found by Adam, Trevor, Robbins, and Russell, (2004) related with go/no go task. In the go/no go tasks participants have to inhibit their responses on a particular stimulus like a red signal.

Activation of middle Frontal gyrus in inhibitory process was assumed by Liu et al. (2012). In their falsification process of conditional statement it was found that the middle frontal gyrus differentiated relevant information from the irrelevant one. It may be predicted tha, during deductive reasoning task inferior frontal gyrus involved in verbal processing and middle frontal gyrus helps to inhibit irrelevant information.

Rostrolateral prefrontal corte: (RLPFC): In the deductive reasoning relationn premises plays an important role for searching the appropriate conclusion. The Rostrolateral prefrontal cortex is assumed to play a crucial role in understanding of relational aspect of reasoning task (Wendelken, & Bunge, 2010). Wendelken et al. (2010) had claim that RLPFCs evaluate the analogies and compare relational structure.

The right RLPFC is sensitive to increasing relational processing whereas left RLPFC is engaged only when participants consider the higher order relationship, which is already given (Silvia, et al 2001). Thus, Rostrolateral prefrontal cortex plays a significant role in understanding the relational aspect among the premises.

Prefrontal cortex: In the anterior part of the frontal lobe another important area is known as prefrontal lobe. The frontal lobe is more effective in motor control, planning and executive behavior. Thus, the main function of this area is to integrate information. The prefrontal cortex may be anatomically divided into the following areas namely

i) The dorsolateral prefrontal cortex, which is related with working memory function

ii) Orbitofrontal cortex, which maintains interconnectivity

iii) Anterior cingulate, related with working memory and executive control

iv) Medial frontal region

Among the four areas cingulate plays an important role in deductive reasoning. The possible activities may be executive control (Wang et al 2005) or working memory (Lenartowicz, & McIntosh, 2005). Cingulate somehow is also related to the attention and initiatioen of an action (Bryden, Johnson, Tobia, Kashtelyan & Roesch, 2011).

Conclusion

Deductive reasoning apparently is not just drawing conclusion from the premises. Deductive reasoning involves much more subtle functions. Neuroscience has ensured the areas of activation in the brain during deductive reasoning. It is important to note that memory and reasoning involve common mechanisms, which is supported by functional neuroimaging studies (Henson, 2006). There is thus, an interaction between memory and reasoning, which was not made explicit in the neurological papers. The neuroscience papers discussed above considered deductive reasoning to be primarily task based. We on the other hand, observed other cognitive functions like memory, attention, executive function and language taking place simultaneously during deductive reasoning on the basis of the activated brain regions. Kahneman (2011) suggests that a division between faster and slower cognitive process is more effective than the traditional division between memory and reasoning. A faster process is one that depends upon generalization, familiarity and association and a slower process depends on recollection and rule following (Evan, Rotello, & Hayes, 2012). The first involves core component of memory and the secondf is reasoning. Our suggestion would be that there cannot be exclusive activation in the brain for deductive reasoning. Deductive reasoning is a higher order cognitive process, which is founded on certain primitive cognitive processes.

Implication for further research:

It is a known fact that in disorders like Parkinson's disease, Huntington's disease, Cerebral Palsy etc. activation in basal ganglion is affected. In those diseases failure in reasoning is a common symptom. This leads to the assumption that along with memory, reasoning too, is affected. However, we can come to conclusive evidence after precise neurophysiological studies by using PET, EEG or fMRI. Moreover, it may be conjecture, that activation of basal ganglion in deductive reasoning play an important role by changing neurochemical elements in the nervous system. Here too, neurophysiological explanation is required. Language and reasoning have some relation specially in maintaining the sequences in the reasoning task. This indicates that language may also be affected during impairment of reasoning. From the behavioural point of view an effective experimental design can be furthere framed to find the link between language and reasoning.

References

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends in cognitive sciences, 8*(4), 170-177.

Aue, T., Lavelle, LA., & Cacioppo, JT. (2009). Great Expectations: What can fMRI Research Tell Us about Psychological Phenomena, *International Journal of Psychophysiology, 73*(1),10-16

Breedlove, S. M., Watson, N.V., Rosenzweig, RM. (2010). *Biological psychology: an introduction to behavioral, cognitive, and clinical neuroscience.* Sixth edition. Sinauer Associates, Inc. Publishers

Bryden, DW., Johnson, EE., Tobia, SC., Kashtelyan, V., & Roesch, MR. (2011). Attention for Learning Signals in Anterior Cingulate Cortex. *The Journal of Neuroscience, 31*(50), 18266-18274.

Brzezicka, A., Sedek, G., Marchewka, A., Gola, M., Jednoróg, K., Królickim L., & Wróbel, A. (2011). The Role of the Right Prefrontal and Bilateral Parietal Cortex in Four Term Transitive Reasoning: An fMRI Study with Abstract Linear Syllogism Tasks. *Acta NeurobiolExp (Wars). 71*(4), 479-95.

Bunge, SA.Helskog, EH., & Wendelken, C. (2009). Left, but not Right, Rostrolateral Prefrontal Cortex Meets a Stringent Test of the Relational Integration Hypothesis. *Neuroimage, 46*(1), 338-342.

Christoff, K., Prabhakaran, V., Dorfman, J., Zhao, Z., Kroger, JK., Holyoak. KJ, & Gabrieli, JD., (2012). Rostrolateral Prefrontal Cortex Involvement in Relational Integration During Reasoning, *NeuroImage, 14*(5),1136-49.I-doi:10.1006/nimg.2001.0922

Claudio, DC., Alexander, GA., & Charles, DB. (2012). The Role of the Basal Ganglia in Motivational Behavior, *Rev Neuroscience, 23* (5-6), 747-767

Elsinger, CL., Harrington, DL., & Rao, SM. (2006). From Preparation to Online Control: Reappraisal of Neural Circuitry Mediating Internally Generated and Externally Guided Actions, *NeuroImage, 31*(3), 1177–1187.

Evan, H., Rotello, CM. & Hayes, BK. (2012). Relations Between Memory and Reasoning, *Psychology of Learning and Motivation, 57*, 57-101.

Evans, JS. (2002). Logic and Human Reasoning: An Assessment of Deductive Paradigm, *Psychol Bull, 128*(6), 978-96.

Fangmeier, T., Knauff, M., Ruff, CC., & Sloutsky, V. (2006). fMRI Evidence for a Three Stage of Deduction Reasoning, *J Cognitive Neuroscience,18*(3), 320-334.

Fauci (1998). The Dominant Inferior Frontal Convolution. *Harrison's Principles of Internal Medicine*, 14th Edition, Companion Handbook, p.1055

Gazzaniga M., Richard B., Ivry RB. & George RM, (2002). *Cognitive Neuroscience: The Biology of the Mind*. Second Edition,.449-557

Goel, V., (2007). Anatomy of Deductive Reasoning, *Trends in Cognitive Sciences, 11*(10), 435–441

Goel, V., & Dolan, RJ (2004). Differential Involvement of Left Prefrontal Cortex in Inductive and Deductive Reasoning, *Cognition, 93*(3), 109-121.

Goel, V., Makale, M., & Grafman, J., (2004). The Hippocampal System Mediates Logical Reasoning about Familiar Spatial Environment, *Journal of Cognitive Neuroscience 16*(4), 654-664

Henson, RN, (2006). Forward Inference in Functional Neuroimaging: Dissociations vs. Associations. *Trends in Cognitive Science,10*, 64-69

Johnson-Laird PN., & Byrne RMJ. (1991). *Deduction.* Hove, UK, and Hillsdale, NJ: Lawrence Erlbaum Associates

Kahneman, D. (2011). *Thinking. Fast and Slow*, New York: Farrar, Straus, and Giroux.

Lenartowicz, A., & Mclntosh, A.R., (2005). The Role of Anterior Cingulate Cortex in Working Memory is Shaped by Functional Connectivity, *Journal of Cognitive Neuroscience, 17*(7), 1026–1042.

Liu J., Zhang M., Jou J., Wu X., Li W. & Qiu J. (2012). Neural Bases Of Falsification In Conditional Proposition Testing: Evidence From An fMRI study, I*nternational Journal of Psychophysiology, 85*(2), 249-256.

Monchi, O., Petrides, M., Strafella, AP., Worsley, KJ., & Doyon, J,(2006). Functional Role of the Basal Ganglia in the Planning and Execution of Actions, *Neurol. 59*(2), 257–264.

Moreno R. & Diana HJ, (2009). The Dynamics of Deductive Reasoning: An fMRI Investigation, *Neuropsychologia, 47*, 949-961.

Politzer, G., & Bourmaud, G., (2002). Deductive reasoning from uncertain conditionals. *J Psychol. 93* (3), pp.345-81.

Politzer, G., & Mud, G. (2002). Deductive Reasoning from Uncertain Conditionals, *British Journal of Psychology, 93*, 354-381.

Prado, J., Henst, JB., & Noveck, IA., (2010). Recomposing a Fragmented Literature: How Conditional and Relational Arguments Engage Different Neural systems for Deductive Reasoning, *Neuroimage, 51* (3) pp.1213-1221

Prado, J., Mutreja, R., & Booth, JR. (2012). Fractionating the Neural Substrates of Transitive Reasoning: Task-Dependent Contributions of Spatial and Verbal Representations, *Cerebral Cortex, 23*(3),499-507

Prado, J., Chadha, A., & Booth., JR. (2011). The Brain Network for Deductive Reasoning: A Quantitative Meta-analysis of 28 Neuroimaging Studies, *Journal of Cognitive Neuroscience, 23*(11), 3483–3497

Rebecca, JM., Poulin, RM., & Stern, CE (2007). An fMRI Investigation of the Role of the Basal Ganglia in Reasoning. *Brain Research, 1142*, 146-158.

Reverberi, C., Bonatti, LL., Frackowiak, RS., Paulesu, E., Cherubini, P., & Macaluso, E.(2012). Large Scale Brain Activations Predict Reasoning Profile, *Neuroimage, 59*(2), 1752-1764.

Reverberi, C., Cherubini, P., Frackowiak, RS., Caltagirone, C., Paulesu, E., & Macaluso, E. (2010). Conditional and Syllogistic Deductive Tasks Dissociate Functionally During Premise

Integration, *Hum Brain Map. 31*(9) pp.1430-1445.

Ribs, L.J. (1994). *The Psychology of Proof: Deductive Reasoning in Human Thinking*. Cambridge, MA: MIT Press.

Salvadore, G., Cornwell, BR., Sambataro, F., Latov, D., Colon-Rosario, V., Carver, F., Holroyd, T., Diaz Granados, N., Machado-Vieira, R., Grillon, C., Drevets, WC., & Zarate, CA Jr. (2010). Anterior Cingulate Desynchronization and Functional Connectivity with the Amygdala during a Working Memory Task Predict Rapid Antidepressant Response to Ketamine. *Neuropsychopharmacology, 35*(7), 1415-1422

Silvia, A., Bunge, SA., Kevin, N., Ochsner, KN., John, E., Desmond, JE., Gary, H., Glover, GH., & Gabrieli, DE. (2001). *Prefrontal Regions Involved in Keeping Information in and out of Mind, Brain, 124* (10), 2074-2086.

Sloman, S.A. (1996). The empirical case for two systems of reasoning. *Psychological bulletin, 119*(1), 3.

Stollstorff, ML. (2010). Modulation of Reasoning Bias and Brain Activation by Serotonin Transporter Genotype and Emotional Content, *Neuroimage, 59*(2),1752-1764. doi: 10.1016/j. neuroimage.2011.08.027.

Tinaz, S., Schendan, HE., Schon, K. & Stern, CE., (2006). Evidence for the Importance of Basal Ganglia Output Nuclei in Semantic Event Sequencing: an fMRI study, *Brain Res.1067* (1), 239–249.

Wendelken, C., & Bunge, SA. , (2010). Transitive Inference: Distinct Contributions of Rostrolateral Prefrontal Cortex and the Hippocampus, *Journal of Cognitive Neuroscience, 22*, (5), 837-847.

Wang, K., Fan, J., Dong, Y., Wang, CQ., Lee, TM., & Posner MI. (2005). Selective Impairment of Attentional Networks of Orienting and Executive Control in Schizophrenia. *Schizophrenia Research 78*(2-3), 235-241.

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