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neuroscience and decision making

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This paper reviews the cognitive neuroscience of decision making and summarizes a talk given by the author at a SOL-UK workshop entitled 'Improving the Decision-Taking Process in Institutions' and held at the London School of Economics on 23rd June, 2006.

An operational definition of decision making is discussed as it relates to neuroscientific research and application. Neuroanatomical and cortico- subcortical as well as cortico-cortical connections between brain structures are then reviewed as they relate to the decision making process. Finally, while biased toward the individual level of analysis, extrapolations to the larger group environment are also discussed.

What is decision making?

As it relates to neuroscientific research, decision making may be operationally defined according to the type of decision that one is facing. Thus, decision making may involve logical analysis in situations of certainty or it may take the form of a cost-benefit analysis in situations of uncertainty. In situations of certainty, the likelihood of most individuals making a clear choice is relatively high; however, when decisions involve a cost-benefit analysis and uncertainty, there is more variability and individual difference in outcome. Thus, the type of decision making process may lead to different outcomes and different cognitive operations.

Decision making involves a series of cognitive operations that cascade from a judgement about familiarity. One of the overarching aspects of decision making involves discriminating incoming stimuli as to whether it is new and therefore requires online cognitive processes (i.e., an uncertain situation) or whether it is familiar, often cued by perceptual information, and therefore requires a more habitual action (i.e., a situation of certainty) (Gazzaniga, Ivry, Mangun, & Phelps, 2002). For example, when driving along a familiar route to work, typically the incoming stimuli are familiar (e.g., local grocery store on the corner, bus stop or traffic light) and require little to no additional processing. However, if there is an accident or a traffic light malfunction causing a detour, this new information must be processed and decided upon for action to occur leading to arrival at work. Thus, situations of uncertainty often stem from novel incoming stimuli and require additional cognitive processing for decision making.

A variety of cognitive processes are needed to integrate novel incoming stimuli for decision making in situations of uncertainty. For example, when considering options about novel stimuli that is, when conducting cost-benefit analyses, individuals must demonstrate flexibility in planning to account for various outcomes, constantly monitor incoming information as it relates to the ultimate goal-state or decision and evaluate the risk-reward ratio for various decision making options (Gazzaniga et al., 2002). These cognitive operations occur concurrently and often under specific time constraints.

Additionally, an individual often considers past experience and values as well as future outcomes of the decision as part of the basis for that decision. Thus, there is a certain degree of individuality that contributes to decision making, particularly when one considers the emotional influences on the decision making process.

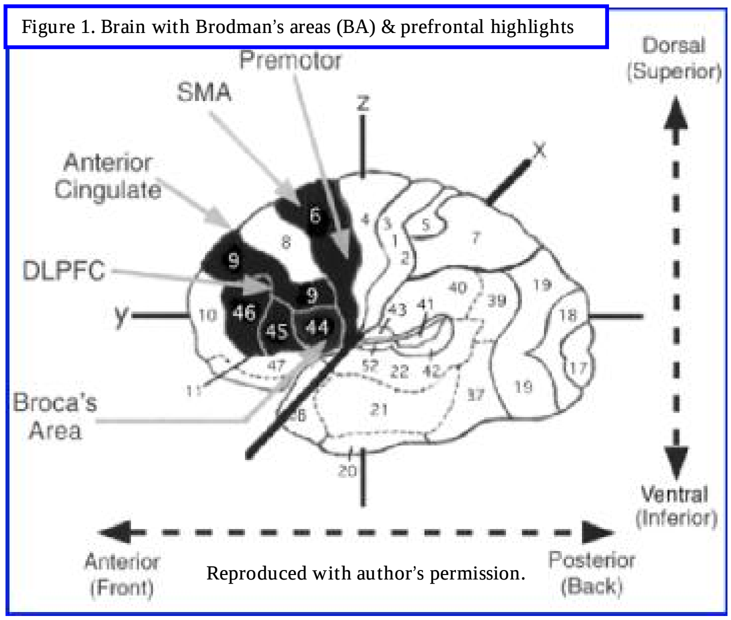
It has long been acknowledged that emotions influence decision making. Internal cues as well as external contextual information can positively or negatively impact the emotional state surrounding the decision making process. It has even been proposed that to pretend reasoning and emotion are separate cognitive domains may be obscuring a key element of the decision making process (Bechara, Damasio, & Damasio, 2000; Damasio, 1996). In fact, decision making may be guided by the emotional evaluation of an action's consequences given that individuals must be able to provide a common metric for evaluating choices and making a decision. For some researchers, this metric is the somatic marker (Bechara et al., 2000; Damasio, 1996) in which bodily sensations imply a link to physiological experience and emotion that influences the cognitive operations of decision making.

The interaction between physiology, emotion and cognition during decision making is best exemplified with the Iowa Card Task which requires cost-benefit analyses in a situation of uncertainty. During this task, individuals are presented with four decks of cards and given a loan of $2000. They are told to pick cards with the object of winning as much money as possible or, alternatively, avoiding losing as much money as possible. They are told that some decks are worse than others but not which ones and they can win if they avoid the worst decks (Bechara et al., 2000). Under normal conditions, individuals will learn to avoid the decks that have the biggest monetary rewards but also the biggest losses in favor of the decks that provide small but consistent monetary rewards in conjunction with small and sporadic losses. Using galvanic skin response measurements of micro-sweating, researchers discovered that this 'advantageous' decision making and the learning process behind it occurs before individuals can verbally explain their card choices. Thus, before being able to verbalize which are the 'advantageous' and 'disadvantageous' decks, individuals are picking from the 'advantageous' decks and showing elevated levels of micro-sweating suggestive of negative emotions immediately before picking from the 'disadvantageous' decks (Bechara et al., 2000; Bechara, Damasio, Tranel, & Damasio, 1997). Thus, studies using the Iowa Card Task would suggest that while cognitive operations are essential to decision making, emotional and physiological influences on these processes are also present.

Neuroanatomical substrates of decision making

Several brain structures have been identified as integral to the decision making process particularly the orbitofrontal cortex and the anterior cingulate. The orbitofrontal cortex (OFC; BA47 & 11) within the prefrontal cortex (see Figure 1) is responsible for processing, evaluating and filtering social and emotional information for appropriate decision making abilities (Elliott, Dolan, & Frith, 2000). It is seen to be involved because of on-line rapid evaluation of stimulus-reinforcement associations, that is, learning to link a stimulus and action with its reinforcing properties. In addition, the anterior cingulate cortex (see Figure 1) controls and selects appropriate behavior as well as monitors errors and incorrect responses of the organism (van Veen & Carter, 2002). Across both lesion

Figure 1. Brain with Brodman's areas (BA) & prefrontal highlights



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studies (e.g., Bechara & Damasio, 2002; Bechara et al., 1997) and neuroimaging studies (e.g., Lamar, Yousem, & Resnick, 2004) in normal adult populations, these regions appear integral to successful decision making. However, other regions within the prefrontal cortex are also involved in the decision making process.

The OFC and anterior cingulate cortex act in concert with other prefrontal regions, particularly the dorsolateral prefrontal cortex (DLPFC) and the posterior medial frontal cortex to monitor errors and make appropriate choices during decision making. Thus, the DLPFC (see Figure 1) is involved indirectly with decision making through its neural connections to the orbitofrontal and anterior cingulate cortices as well as directly with its own cognitive contributions to the decision making process. Cohen and colleagues (Cohen, Heller, & Ranganath, 2005) demonstrated that the DLPFC selects information for working memory, planning and flexibility as it relates to the decision making process. Thus, there is an analysis of cost-benefit acted out in working memory as mediated by the DLPFC. In addition, the DLPFC and the posterior medial frontal cortex are implicated in the goal directed behaviors of information integration and ongoing performance monitoring, respectively (Hogan, Vargha-Khadem, Saunders, Kirkham, & Baldeweg, 2006). These regions are connected to each other as well as other regions of brain through a series of cortico-subcortical and cortico-cortical connections.

Basal ganglia-thalamocortical circuits (BGTC) and frontoparietal networks are implicated in aspects of decision making through their neural associations suggesting that decision making is not solely relegated to the prefrontal cortex. For example, the BGTC involving the OFC connects this region with the thalamus and ventromedial caudate, each of which have connections throughout brain. Likewise, the BGTC involving the DLPFC connects this region with the thalamus as well as dorsolateral regions of the caudate. The frontoparietal network is cited as important in directing attention toward relevant information as opposed to irrelevant information during goal-related decision making processes (Chelazzi & Corbetta, 2000; Kastner & Ungerleider, 2000). Thus, decision making evokes multiple brain regions and multiple networks for completion.

Assessing decision making

In addition to understanding the basics regarding the cognitive and neuroanatomical underpinnings of decision making, it is important to consider contributing factors such as expertise, age and sex when attempting to assess decision making at the individual or group level. Individuals with different levels of expertise will approach the decision making process very differently; that is, their cognitive and neuroanatomical contributions will differ. For example, from a cognitive perspective, physics experts use a ‘working forwards’ strategy to solve problems, making decisions using the information given in the problem to derive a solution. In contrast, neophytes to physics typically employ a ‘working backwards’ strategy in which they start from the perceived goal state or decision and back track toward a solution (Larkin, McDermott, Simon, & Simon, 1980). Neuroanatomically, experts are seen to have alterations in key regions of brain associated with their area of expertise. Thus, London black cab drivers who are required to learn and memorize London streets show a different degree of hippocampal volume distribution when compared to ordinary drivers (Maguire et al., 2000). The hippocampus is intimately connected with learning and memory. Thus, with expertise come differences in the function and structure of brain regions required for decision making and task completion.

In addition to expertise, age and sex also impact decision making. With age come changes in the recruitment of specific brain regions for task completion during decision making. Thus, older adults will often compensate for age-related declines in prefrontal structure and function by recruiting additional prefrontal regions (Grady et al., 1998) as well as more posterior regions of brain (Lamar et al., 2004) during the decision making process regardless of sex. Sex does, however, impact aspects of decision making. For example, during the Iowa Card Task, men usually determine the more ‘advantageous’ decks at a faster rate than women (Bolla, Eldreth, Matochik, & Cadet, 2004; Reavis & Overman, 2001) suggesting a bias toward men for faster decision making in situations of uncertainty and limited feedback. While not to be exploited, aspects of age and sex should be considered when attempting to investigate the decision making process.

Judgement of risk and reward also impacts decision making particularly in situations of active uncertainty. Active uncertainty, or constantly changing levels of risk, may be conceptualized as a dynamic state of risk-reward ratios. For example, dynamic risk may be seen during a task in which participants are instructed they could win 30 points if a yellow star is under one of four red squares but they could win 70 points if the yellow star is under one of the two blue square (Rogers et al., 1999). The risk-reward ratio, here at 4:2, constantly changed, e.g., 30 points if under one of five, 70 points if under one of one (5:1), but the larger reward was always associated with the least likely outcome. Interestingly, participants were less likely to pick the most likely outcome when the reward was diminished, i.e., 10 points versus 90 on a 4:2 risk-reward ratio, even though the deliberation time was longer to making their decision. This suggests that although participants were well aware of the risk under such extreme ratios, they continued to take the larger risk given the possible, albeit unlikely, larger reward (Rogers et al., 1999). Thus, risk-reward ratios impact the decision making process and should be considered when attempting to evaluate this process in a dynamic environment.

Decision making, the corporate environment and SOL-UK

Decision making involves complex cognitive and emotional processing as well as judgements of risk and reward. Scientists have identified several regions of the brain associated with the decision making process. Furthermore, several aspects of the individual as well as the environment may impact decision making. Determining the role, if any, for specific aspects of the decision making process within a corporate environment may allow for the enhancement of more advantageous aspects of the decision making process. Ultimately, such knowledge may benefit the group decision making process and long term operations by taking some of the uncertainty out of decision making in a corporate environment. The challenge for SOL-UK, however, is to consider how best to address these issues given the expertise in business, technology and science its members possess; a challenge this multi-disciplinary group are sure to meet and exceed.

Melissa Lamar, September 2006

References

Bechara, A., & Damasio, H. (2002). Decision-making and addiction (part I): impaired activation of somatic states in substance dependent individuals when pondering decisions with negative future consequences. *Neuropsychologia, 40*(10), 1675-1689.

Bechara, A., Damasio, H., & Damasio, A. R. (2000). Emotion, decision making and the orbitofrontal cortex. *Cereb Cortex, 10*(3), 295-307.

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science, 275*(5304), 1293-1295.

Bolla, K. I., Eldreth, D. A., Matochik, J. A., & Cadet, J. L. (2004). Sex-related differences in a gambling task and its neurological correlates. *Cereb Cortex, 14*(11), 1226-1232.

Chelazzi, L., & Corbetta, M. (2000). Cortical mechanisms of visuospatial attention in the primate brain. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 667-686). Cambridge, MA: MIT Press.

Cohen, M. X., Heller, A. S., & Ranganath, C. (2005). Functional connectivity with anterior cingulate and orbitofrontal cortices during decision-making. *Brain Res Cogn Brain Res, 23*(1), 61-70.

Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philos Trans R Soc Lond B Biol Sci, 351*(1346), 1413-1420.

Elliott, R., Dolan, R. J., & Frith, C. D. (2000). Dissociable functions in the medial and lateral orbitofrontal cortex: evidence from human neuroimaging studies. *Cereb Cortex, 10*(3), 308-317.

Gazzaniga, M. S., Ivry, R. B., Mangun, G. R., & Phelps, E. A. (2002). Emotion. In M. S.

Gazzaniga, R. B. Ivry & G. R. Mangun (Eds.), *Cognitive Neuroscience: The Biology of the Mind* (2nd ed., pp. 537-576). New York: W.W. Norton & Company.

Grady, C. L., McIntosh, A. R., Bookstein, F., Horwitz, B., Rapoport, S. I., & Haxby, J. V. (1998). Age-related changes in regional cerebral blood flow during working memory for faces. *Neuroimage, 8*(4), 409-425.

Hogan, A. M., Vargha-Khadem, F., Saunders, D. E., Kirkham, F. J., & Baldeweg, T. (2006). Impact of frontal white matter lesions on performance monitoring: ERP evidence for cortical disconnection. *Brain, 129*(Pt 8), 2177-2188.

Kastner, S., & Ungerleider, L. G. (2000). Mechanisms of visual attention in the human cortex. *Annu Rev Neurosci, 23*, 315-341.

Lamar, M., Yousem, D. M., & Resnick, S. M. (2004). Age differences in orbitofrontal activation: an fMRI investigation of delayed match and nonmatch to sample. *Neuroimage, 21*(4), 1368-1376.
Larkin, J., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Models of competence in solving physics problems. *Cognitive Science, 4*, 317-345.

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S., et al. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proc Natl Acad Sci U S A, 97*(8), 4398-4403.

Reavis, R., & Overman, W. H. (2001). Adult sex differences on a decision-making task previously shown to depend on the orbital prefrontal cortex. *Behav Neurosci, 115*(1), 196-206.

Rogers, R. D., Owen, A. M., Middleton, H. C., Williams, E. J., Pickard, J. D., Sahakian, B. J., et al. (1999). Choosing between small, likely rewards and large, unlikely rewards activates inferior and orbital prefrontal cortex. *J Neurosci, 19*(20), 9029-9038.

van Veen, V., & Carter, C. S. (2002). The anterior cingulate as a conflict monitor: fMRI and ERP studies. *Physiol Behav, 77*(4-5), 477-482.