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Divide and conquer: strategic decision areas

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Abstract

Human decisions are often strategic, but this can prove difficult to study experimentally. The board game shogi is used to investigate the functional neuroanatomy of strategic decisions, revealing different brain areas to other forms of choice.

Historians debate what moved Napoleon to attack the English at Waterloo or the Duke of Wellington to decide to hold and defend his position. By contrast, readers of this article may ponder their repeated tendency to choose chocolate cake over fruit for their teatime snack. These decisions sound very different to one another, because one has the power to shape history whereas the other can only shape one's waistline. But what remains less clear is whether they are also different in terms of the brain regions that they engage. This is because research into the neurobiology of value-based decision-making has so far primarily focussed on the latter, 'economic' form of decision over the former, 'strategic' decision. This reflects not an unwillingness amongst military generals to volunteer for neuroimaging studies but a more fundamental problem: how might one ask subjects to make strategic decisions inside the scanner whilst indexing the motivations underlying their choices?

In this month's issue of *Nature Neuroscience*, Wan *et al.* take advantage of a Japanese chess-like strategy game called shogi to investigate the neural basis of strategic reasoning1. Shogi not only has many millions of human players who have trained themselves to make rapid strategic decisions, but it also has computer algorithms that can calculate the precise value of different offensive and defensive moves. The authors scanned amateur shogi players using functional magnetic resonance imaging as they were presented with different board positions and asked to rapidly select whether an offensive or defensive approach was required. A computer algorithm was used to calculate value estimates for different possible strategies, approximating the degree to which subjects might be motivated to attack versus defend in each decision. These estimates were then regressed against neural activity as the subjects made their choice. Crucially, in contrast with moves in many other strategic games, shogi moves can be easily characterized as being part of a defensive or offensive strategy. As such, a clear dissociation could be drawn between neural activity related to the value of either form of strategy, or to the comparison of strategies. This approach complements the now

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widespread use of mathematical models to describe neural activity in the context of many different forms of decision making, such as economic decisions[2,3], social decisions[4,5] and foraging decisions[6,7] (Fig. 1).

The two kinds of intuitive strategies participants could choose, defence or attack, were found to relate to activity in three key neural structures. Firstly, posterior cingulate cortex (PCC) reflected the subjective value of offensive strategies. PCC has often been seen to activate in value-based decision tasks, but rarely (with notable exceptions[8]) has it been explicitly discussed as a decision area. Secondly, rostral anterior cingulate cortex (rACC) activated as a function of the subjective value of the defensive strategy. Intriguingly, it has recently been shown that neurons in a nearby brain region in macaque monkeys preferentially encode negative information about air puffs[9], which elicit a defensive response. In humans, rACC does not always appear in decision-making experiments, as it does not seem to directly encode subjective economic values, but it is sometimes differentially active in participants depending on their subjective bias[6]. This is consistent with it signaling the overall approach or strategy they are likely to adopt in the task, varying among people. Lastly, Wan *et al.*[1] focused on how the values of those different strategies could be compared, looking for areas encoding the relative difference between chosen and unchosen strategy values. This highlighted dorsolateral prefrontal cortex (DLPFC), which has frequently been implicated in rule- or model-based decisions[10], as well as cognitive control[11]. Using functional connectivity between these three regions, it was possible to show that DLPFC connected more strongly to PCC when subjects chose to attack, whilst DLPFC connected more strongly to rACC when subjects chose to defend.

It is notable that the decision signals were distributed across three separate brain areas, and that the comparator region lay outside of regions more traditionally associated with other forms of value-based decision making (Fig. 1). This result speaks to the idea that decisions may be realised via a distributed consensus[12,13], a viewpoint that argues that no single brain area is critical to decision making but that decisions instead emerge via competitions occurring in many brain regions. The use of a particular type of decision may lead to a particularly strong engagement of a particular neural structure, but competitions have been found in ventromedial prefrontal cortex for concrete offer comparisons[2], dorsomedial prefrontal cortex for decisions about the simulated strategy of another individual[5] and dorsal anterior cingulate cortex for comparison[3] or the value of foraging[6], to name only a few. An alternative, 'serial processing' account argues that the same mechanisms that govern simple economic comparisons between arbitrary goods are also responsible for all other value-guided choices. However, this would struggle to explain the dissociation between the comparison signal observed by Wan *et al.*[1] and those observed in other forms of choice. Moreover, the functional connectivity results of Wan *et al.*[1] suggest that, in addition to distributed competition, changes in connectivity could be crucial for understanding how flexible choices could be implemented. Similar flexible changes of connectivity have been seen in other recent studies—for example, as a function of variation in risk preferences[14] or attention to relevant attributes[13]. This gives further evidence that rapid reshaping of connectivity may help engage different decision areas as necessary.

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The strategy selection in the task did not require participants to evaluate every single potential outcome following from a strategy choice, but merely to evaluate what strategy to adopt. In fact, in separate trials where the subjects did have to select a specific move, the participants appeared to be relatively poor at rapidly choosing accurate moves (despite clear evidence that they were trying to do so). This begins to address a challenge that has been made to certain models of choice, which is that people often resort to quick and imprecise heuristics because many economic models and reinforcement learning algorithms may be too computationally expensive and time-consuming[15]. In other words, making use of heuristics may be fundamental to how we make many decisions, such as when we constrain a complex problem rapidly by choosing a certain strategy. Voluntary strategy selection can provide constraints on how subsequent decisions ought to be made, limiting the necessary number of comparisons and allowing far more rapid choices. This idea has a profound influence on how we think about choices neurally as well as behaviourally. It is essentially a decision about how we decide.

Leaving the many implications for issues of hierarchical and concurrent processes aside, another basic question remains. What distinguishes defensive and offensive moves computationally and functionally, and why does their value appear to be tracked by separate brain structures? Although the authors controlled effectively for various potential confounds, it should be possible to define different strategies in terms of their inherent computational challenges and properties. In other words, more work is needed on what computational and physiological reasons drive the clear anatomical dissociation and whether they can be considered as categorically separate from each other. It is possible that the dissociation emerged during evolution from a simpler system that evolved to make actual defensive or aggressive responses, hence relating to more action-based accounts for decision-making.

In the end, understanding Napoleon's strategic choices on the battlefield might prove very different from understanding decisions about afternoon tea, but both kinds of decision may be important in different aspects of our daily lives. By leveraging the intrinsic motivation and expertise of hobby shogi players, Wan *et al.*[1] provide a new tool with which to ask neuroscientific questions about how humans generate intrinsically motivated strategic behaviour.

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Figure 1. Many routes to a decision:

The strategic choices between attacking and defending investigated by Wan et. al.1 found a circuit encompassing rostral anterior cingulate cortex, posterior cingulate cortex and dorsolateral prefrontal cortex to interact for strategy-based decisions. Intruigingly, this circuit differs from the areas of the medial wall recruited in other forms of decision. Economic deicions *(in cyan)* have revealed comparison processes in ventromedial prefrontal cortex2 and extended activations in the pre-supplementary motor area and dorsal anterior cingulate cortex (dACC)3,13, but a portion of dACC *(in blue)* has more recently also been suggested to play an active role in making foraging decisions6. Simulated choices – those used when thinking about other individuals' behaviour – reveal a separate, more dorsomedial portion of prefrontal cortex5 (in purple). Outside the medial wall, many other cortical regions have also been suggested to play a critical role in value comparison (such as the lateral intraparietal area, for saccadic decisions). Thus, many areas may play complementary roles in different forms of comparison. (Painting: *Napoleon near Borodino* by Vasiliy Vereshagin).

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