Primer

Decision making

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Daily we encounter numerous alternative courses of action among which we must choose. These alternatives vary in complexity and consequence. Some alternatives are considered lightly, such as the way to turn on the journey home. Others require fervent deliberation, such as Hamlet's agonizing decision whether to end his life. The neural basis of decision making has been reviewed extensively [1–4], so the goal of this primer is to orient the interested reader to this growing literature with emphasis on neurophysiological work, rather than the expansive literature on functional brain imaging and neuropsychology. Another goal is to articulate the key concepts of choosing, deciding, intending and acting [5,6]. Dwelling on terminology may seem an unnecessary tangent, but science travels on its vocabulary — inconsistent and vague terms can only yield confusion. This is all the more important when the object of this scientific investigation ultimately is nothing less than human agency.

Choice

A choice is required when an organism is confronted with alternatives for which an action is required to acquire or avoid one of the alternatives because of a desire, goal or preference. In its most fundamental sense, a choice is an overt action performed in the context of alternatives for which explanations in terms of purposes can be given. Consider the options of selecting between two envelopes, A and B, containing different amounts of money (Table 1). Choice #1 is easy because it offers the guarantee of obtaining $1,000 by selecting envelope A, instead of $1 by selecting envelope B. Choice #2 requires more thought because the amount of money is unpredictable, but a suitable analysis leads to a wise choice. Choice #3 requires deliberation to contend with a paradox of choice prediction [7]. Regardless of the complexity of the alternatives, though, you must execute your choice through some action, such as grasping one of the envelopes.

Choices have particular characteristics. First, choices are evaluated as good or bad according to whether goals are achieved and consequences are as expected. Second, choices take time; a choice process evolves from a state of more or less equipotentiality immediately after the alternatives are presented to a state of commitment before the overt action is performed. Third, with prior knowledge of the alternatives and preferences, some choices can be predicted.

According to this definition, neurophysiological correlates of choice behavior are studied whenever an experimental subject has alternative responses. This has been studied, for example, with psychophysical discrimination [8] and visual search [9]. With easily distinguished alternatives and predictable reinforcements, like choice #1, the neural representation of the stimuli is resolved unambiguously, leading to an earlier and more accurate motor response. When the stimuli are more difficult to distinguish [10,11] or the reinforcement becomes less predictable [12,13], like choice #2, the neural representation of the alternative choices takes more time to resolve, and that representation can be modulated by the expected value of the choice.

Finally, although no neurophysiological studies have been conducted in the context of Newcomb's paradox, new studies are exploring situations in which the experimental subject chooses alternatives supposedly based on the actions of another agent [14]. Choices made in the context of the choices of another agent are also guided by reinforcement history, but also with some sensitivity to the strategies employed by the other agent. This progression of experimental conditions should make clear that some choices are easy and others are hard. When alternatives are vague, payoffs are unclear and stakes are high, then it seems natural to regard the subjects as making a decision before they act.

Decision

The term decision is used casually and technically in several, not entirely consistent senses. On the one hand, decision theory describes the characteristics of effective behavior in relation to expected consequences [15]. For example, the best solution to the second choice in Table 1 is to select the envelope for which the product of the probability and the monetary amount is greatest. This is the domain of decision theory and related frameworks, such as economics and game theory. A very active area of inquiry of late has employed concepts of decision theory and related disciplines in the investigation of the neural preliminaries of choice behavior [16].

Table 1. Choices based on predicted monetary reward.

	Envelope A		Envelope B	
	Condition	Payoff	Condition	Payoff
#1	100%	$1,000	100%	$1
#2	9%	$10,000	90%	$1,000
#3	100%	$1,000	If only B	$1,000,000
			If A and B	$0

Two envelopes labeled A and B are offered for you to obtain. Choice #1 is between two transparent envelopes; envelope A contains $1,000 and envelope B, $1. Choice #2 is between two opaque envelopes. Envelope A has a 9% chance of containing $10,000 and envelope B has a 90% chance of containing $1,000. Choice #3 is Newcomb's paradox. Envelope A is transparent and contains $1,000. Envelope B is opaque and will contain either $1 million or nothing. You will be given the choice of taking either B alone or A with B. Before you are presented with the envelopes, an infallible brain scan is done to predict your choice. If the prediction is that you will choose only envelope B, then $1 million is placed in it. If it is predicted that you will choose both envelope A and B, then nothing is put in envelope B.

On the other hand, we can refer to a decision as a process that results in the overt act of choosing. Such a process must have a particular architecture, but measures of outcome derived from decision theory do not uniquely specify mechanism. Decision as a process has two logically and practically distinct meanings. We must distinguish between *decide to*, which is a selection between alternative actions, and *decide that*, which is a selection between alternative categories of an image or concept. The logical distinction is easy to see. You can *decide that* falsely, but you cannot *decide to* falsely — it is not intelligible. The *decision that* envelope B always contained $1 million is false, but in what sense can you *decide* falsely *to take* envelope B? You just take it or you do not. *Decide to*, like choosing, is judged as good or bad, but not as true or false.

The fact that choices can be predicted makes it possible to choose in advance: it is intelligible to say, "I will choose envelope B when given the opportunity." This sense of choice is more related to decision. But important distinctions must be recognized between 'choose' and 'decide to'. Whereas 'choice' refers most directly to the final commitment to one among the alternative actions, 'decision' refers most directly to the deliberation preceding the action. Deliberation involves weighing the options which amounts to contrasting the characteristics of the alternatives in working memory. Such deliberation is rarely (if ever) only rational, for emotional valence influences decisions too [17].

The polarity of deciding and choosing can be highlighted by contrasting the three choices in Table 1. For any of the three, you must enact a choice by grasping an envelope (you could just point or speak to choose through symbolic actions, but some movement must occur). But it is likely that, before you can make choices #2 or #3, you must invest more effort to comprehend the alternatives, understand the differences between them and identify which would be most satisfying. The course of this deliberation reveals another defining feature of decisions that distinguishes them from choices: decisions cannot be predicted, even by the agent. If you can say what you will decide, then you will have decided.

In other words, decisions, like perceptions, just happen; introspection cannot find the source of a decision [18]. By monitoring the activity of the neurons that produce the decision as described above, however, it becomes possible to predict the choice. Morever, it is also possible to manipulate decisions by electrical stimulation [19]. But this ability to predict and manipulate choices has strict limits; most fundamentally, it requires proper experimental control of numerous extraneous variables. Thus, while it is appropriate to contemplate the ethical and legal ramifications of this technical breakthrough [20], the social fabric is unlikely to be torn by it very soon.

Choice #3 provides a useful domain in which to clarify further these ideas. It is based on the premise that a person's choice can be predicted reliably (by a brain scan perhaps). The rules of this choice are explained in Table 1. Imagine that you have observed others make this choice and that every time they took only envelope B, it contained $1 million; and every time they took both, envelope B was empty. Would you reason that the choice prediction is reliable and so choose only envelope B to become a millionaire? Or would you reason that, once the prediction was made and you are presented with the selection, the contents of the envelopes will not change, and so choose both envelopes so as not to forego the obvious $1,000? Both arguments seem sound, but they cannot both be correct, so which is wrong? Your reaction to the contents of the envelopes opened after making choice 3 may be pleasure or distress, according to whether the outcome was consistent with your intention. What did you mean to do?

Intention

The term intention is complex [21]. The disposition to perform some act is a central feature of an intention, but intention cannot be identified entirely with response preparation. A statement of intention must also answer "why was that done?". Of course, one answer might be the causal path through neurons to muscles, but this is incomplete. A satisfactory explanation must address the *reasons* for the action based on preferences, goals and beliefs. In other words, to judge whether a movement was intended, one must refer to the agent's beliefs about which action must be performed under what circumstances to bring about the desired object of the intention. A consequence of this is that intentions may not be realized; success can be judged only with reference to the description of the goal and the conditions under which it could be achieved [22]. Furthermore, a particular movement may be intentional under one description but not under another; for example, an eye may wink or blink. The neurophysiology literature has used the term intention to refer only to response preparation [23]. Until nonhuman primates can report what they meant to do, the scientific study of intentionality may be restricted to humans [24].

Action

The term action has been used above, but it is a complex concept [25]. Often one does one thing (obtain money) by doing something else (pick up an envelope). But all such descriptions of actions reduce to a *basic action* that we perform without any preliminaries, such as moving a hand (to grasp an envelope to obtain money). We cannot say how we move our hand; it just happens when we will it. The neurophysiological basis of producing basic actions such as gaze shifts and reaching are reasonably well understood [26].

Defining a body movement as an action depends on context. A purposeful action (a wink) is distinguished from a mere event (a blink) by reference to some intelligible plan, because actions are performed to achieve a goal. In other words, actions have *reasons* ("I did it for..."), but events just have *causes* ("It happened because...”). Reasons for actions are explanations in terms of purposes, that is, intentions. Thus, a particular movement may be intentional under one description but not under another. With human subjects it is possible to distinguish the brain states producing intentional versus unintentional movements [27,28].

But if all actions are caused by neurons firing and muscles contracting, how can there be any reasons for actions? Evidence for many-to-one mapping of brain states onto movements has important implications for elucidating a neural basis of intentional action [29]. If the mapping of neural activity onto movement were one-to-one, the causal basis of movements would be clear: a particular action follows necessarily from a given brain state as reliably as a reflex. While such an automatic causal process seems an adequate account of certain kinds of movements (such as blinks), it cannot provide a satisfactory account of other kinds (such as winks). Intended movements are owned (“I did”) while unintended movements are not (“it happened”). In other words, we distinguish the *cause of* from the *reason for* movements [30].

In fact, some have argued that a many-to-one mapping of neural activity onto cognition and behavior provides room for intentional reasons within neural causes [31]. If a given basic action can arise from different brain states, then the dependence of the behavior on an intention can hold in virtue of the content of the representation of the intention and not its neural realization, that is, the content which answers “why did you do that?”. Thus, a movement can be called an intentional action if and only if it originates from a cognitive state with meaningful content, and this content defines the cognitive state’s causal influence.

This analysis depends on whether the brain knows what it means to do. Recent research has shown that the medial frontal lobe registers error and success [32]. For example, in monkeys performing a task requiring the interruption of a planned action, neurons signaling errors and omission of earned reinforcement were observed in the medial frontal lobe [33]. Such signals can be used to adjust behavior and provide the basis for distinguishing “I did” from “it happened”.

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