Of all the qualities of humankind, the ability to reason stands out as our most defining characteristic. It forms the cornerstone of scientific investigation and the expansion of human knowledge. Without the ability to reason, the developments of modern medicine and of science in general would never have occurred.

Although patients with isolated impairments of reasoning can perform the simple tasks of daily life, their ability to navigate through life and the quality of their lives are often significantly diminished. Clearly, there is a need to attack impaired reasoning with the same fervor that we use to treat defects in language and other cognitive functions.

This article defines reasoning as the ability to draw conclusions from given information (premises or arguments). The conclusions reached provide new insights. Neuropsychological investigations have traditionally divided reasoning into 2 categories, deduction and induction, based on the type of relationship between the premise and the conclusion. Deductive reasoning reaches conclusions that are limited to the information contained within the original set of premises. The premises necessarily lead to one conclusion. By contrast, inductive (or probabilistic) reasoning reaches conclusions that extend beyond the original set of premises. The premises give probable support only for the conclusion drawn. Inductive reasoning creates new knowledge by using incomplete information. This article focuses primarily on deductive-reasoning studies. However, as noted later, the distinction between deduction and induction may be more artificial than real.

EXPERIMENTAL TASKS

Many early investigations into human reasoning used tasks that evaluated multiple skills. Some of these tasks, such as Raven's Progressive Matrices, require deduction but also rely on other frontal lobe abilities such as executive control and planning. Performance failure on such tasks does not necessarily indicate a deficit in reasoning. However, no single task selectively assesses reasoning; this ability requires that other cognitive skills function properly, such as comprehension of the task and the stimuli, perception, working memory, and in some cases mental imagery. In addition, most paradigms do not mirror real-life situations. Therefore, poor performance on a task may not reflect poor reasoning ability in day-to-day life, and vice versa.

Complicating matters, few measurable cognitive components of reasoning have been identified. As a consequence, relevant neuropsychological tests available today may signal that a deficit in reasoning exists but generally do not identify which aspect of reasoning is impaired. Vague definitions and the lack of units of measure also plague efforts to assess, measure, and define reasoning.

The most frequently used tool, the Wason selection task, assesses conditional reasoning. Conditional reasoning involves drawing (deductive) inferences from scenarios in which the occurrence of one event is conditioned on the occurrence of a second event. Typically, conditional relations are phrased as “If p, then
q” (eg, “If a person has not graduated from college, then he or she cannot attend medical school”). The Wason selection task requires subjects to identify what information is necessary to ascertain whether a conditional relation is true or false. For example, the examiner gives subjects 4 cards, each with a letter on one side and a number on the other. Subjects are asked to decide which of the cards they need to turn over to find out whether a certain rule is being followed, such as “If a card has an A on one side, then it must have a 4 on the other side.” Drawings of 4 cards follow, showing 4 possible cases: A (p card), B (not-p card), 4 (q card), and 7 (not-q card). The logically correct response is to select the p (A) and not-q (7) cards. However, when presented with this task, only 4% of college students selected these cards.¹ That number increased to 62.5% when the task used a familiar scenario.² For example, when given the rule “If a person is drinking beer, then the person must be older than 19 years,” normal subjects select the appropriate cards more than 60% of the time.

The gambling task assesses decision making, the ability to select a course of action. Although not a reasoning task, studies using this test have shed light on processes important for reasoning. In the task, subjects choose cards from 4 decks. Selecting cards from 2 of the decks more often results in a reward (a low immediate gain but a smaller future loss; hence, a long-term gain), and selecting from the other 2 decks more often results in a penalty (a high immediate gain but a larger future loss; hence, a long-term loss). After encountering several losses, normal subjects generate an anticipatory skin conductance response before choosing a card from a disadvantageous deck and begin to avoid choosing from those decks.

**IMAGING STUDIES**

With the advent of positron emission tomography (PET), neuroscientists have more closely scrutinized the neural basis of reasoning. Three PET imaging studies³-⁵ using syllogisms reported left prefrontal activation during both deductive and inductive tasks. Only induction produced activation of the medial prefrontal cortex. A fourth study⁶ found medial left frontal cortical activation as well as right hemispheric involvement during deduction and induction. The content of the stimuli in all 4 imaging studies, however, generally did not refer to situations with which the test subjects would have had prior experience. One possible explanation is that the left hemisphere may be more adept than the right hemisphere at reasoning when the subject is not familiar with the content of the reasoning task (content-independent reasoning), such as reasoning about abstract situations.⁷

**STUDIES IN PSYCHIATRIC PATIENTS**

Deglin and Kinsbourne⁸ asked patients with schizophrenia or bipolar disorder to solve syllogisms following electroconvulsive therapy (ECT) to either cerebral hemisphere. The syllogisms contained information that was either familiar or unfamiliar to the subjects. Prior to ECT, 86% of subjects gave a logical answer. Following right hemisphere suppression by ECT, the same percentage of subjects provided logical answers, but responses came more quickly and with greater assurance. Following left hemisphere suppression by ECT, however, 79% offered empirical answers in accordance with their own experience. In a second experiment, subjects were asked to solve syllogisms with familiar content but false premises (eg, “All trees sink in water; Balsa is a tree; Does balsa sink in water or not?”). In the control condition, two thirds of all answers were empirical. Following left hemisphere suppression by ECT, subjects rejected false premises more frequently, with empirical answers comprising almost 90% of the answers. In addition, after left hemisphere ECT, subjects rejected false premises with strong emotion. Following right hemisphere ECT, the number of logical answers almost doubled; subjects responded to false premises calmly and appeared unaffected by the absurdity of the premises. Deglin and Kinsbourne concluded that the right hemisphere uses acquired knowledge to ensure that thoughts correspond to reality. In contrast, the left hemisphere applies rules of formal logic independent of the content of the material.

**STUDIES IN PATIENTS WITH BRAIN LESIONS**

Golding⁹ evaluated responses to a Wason selection task made by patients with unilateral brain lesions (the author did not report the location of the lesions, however). Although no control subjects and only 1 subject with damage to the left hemisphere selected the p card and not-q cards (the logically correct answer), 50% of the subjects with right hemisphere damage chose both cards. Because control subjects tended to select cards that matched the items described in specific test sentences, Golding proposed that the perceptual aspects of the task interfered with the control subjects’ verbal reasoning (for example, when given the sentence “Whenever there is a circle on one half of the card, there is yellow on the other half of the card,” control subjects selected the circle or the circle and the yellow cards). According to Golding, patients who had right hemisphere damage with impaired visual processing showed superior verbal reasoning skills because of a lack of visual perceptual interference.

Adolphs et al¹⁰ administered a Wason selection task using both familiar and unfamiliar stories to patients with dorsolateral frontal lesions, those with ventromedial prefrontal lesions, and normal controls. Subjects in all 3 groups performed equally poorly when given unfamiliar stories. However, patients with dorsolateral lesions and normal subjects chose the p and not-q cards (the logically correct selections) when the story involved familiar material. In contrast, the patients with ventromedial lesions who had damage to the medial orbitofrontal cortex (5 of 6 had bilateral damage) did not show this facilitatory effect with familiar material. The authors concluded that people generally reason by analogy and retrieve past experiences, including the emotion experienced, when confronted with a familiar situation. Patients with ventromedial prefrontal lesions may fail to retrieve or appropriately use past experiences when reasoning.

To further explore the role of the ventromedial prefrontal (medial orbitofrontal) cortex (VPC) in reasoning and decision making, Bechara et al¹¹ administered a
gambling task. After several trials, normal subjects generated an anticipatory skin conductance response prior to choosing a card from the disadvantageous decks and started to avoid selecting cards from those decks. Patients with bilateral damage to the VPC failed to produce an anticipatory skin conductance response and continued to select cards from the disadvantageous decks.

Similar to their performance in laboratory studies, patients with bilateral damage to the VPC typically make real-life decisions against their best interests and fail to learn from their mistakes. However, their general intellect and other executive function abilities remain intact, and they usually retain the ability to generate options in social situations and to conceptualize the consequences of selecting a particular option.13 In the study by Bechara and colleagues, 50% of patients with damage to the VPC were able to recognize and identify the bad decks but still performed disadvantageously. Therefore, the authors posited that when presented with situations in which a decision is required, individuals generate possible responses and the probable outcomes of those responses and recall their prior experiences in similar situations. The VPC performs the latter function by activating a link between factual knowledge about the situation and the type of bioregulatory state (including the emotional state) associated with that situation based on the individual’s past experiences. When a person faces a situation similar to one previously experienced, relevant facts are generated, and the VPC activates linkages to reconstruct a previously learned factual-emotional set. The VPC facilitates a person’s ability to perform risk-benefit analyses by rejecting less appropriate responses. Patients with damage to this region of the frontal lobes do not choose advantageously because they fail to activate a bioregulatory state appropriate to the consequences of a response. Options and outcomes become essentially equal for the individual. Therefore, subjects fail to respond to future consequences and are more controlled by the immediate results. They can generate options and future outcomes but do not act on this knowledge because they fail to activate the behavioral relevance of available choices of action. Primate studies as well as PET imaging and electrophysiological studies in humans support this view.13,14

In comparison, the dorsolateral prefrontal cortex may be important for generating potential responses and their expected outcomes. Different areas of the orbitofrontal prefrontal cortex (OPC) may perform various functions important for reasoning. According to Elliott et al,15 the medial OPC (or VPC) monitors associations between stimuli, responses, and outcomes and determines whether a particular response “feels right.” The lateral OPC suppresses previously rewarded responses, allowing the individual to inhibit the current choice behavior and to modify that behavior in response to changing circumstances.

Patients with bilateral damage to the amygdala also choose disadvantageously on the gambling task16 and exhibit poor judgment and decision making in their real-life behavior.37 However, the decision-making failure is likely the result of the patients’ inability to experience the emotional attributes of a situation, whereas patients with VPC damage cannot effectively integrate all of the bioregulatory state information provided by the amygdala and other structures. In addition, damage to the amygdala or VPC likely impairs the ability to form associations between complex situations and bioregulatory states.

These reports suggest that a neural network subserving reasoning that includes the dorsolateral prefrontal cortex may identify potential responses and their expected outcomes. A second network that includes the VPC may determine the behavioral relevance of response options.

ROLE OF EACH HEMISPHERE

As described previously, both patients with brain lesions and PET imaging studies suggest that each hemisphere performs different functions pertaining to reasoning. One interpretation of these studies is that the left hemisphere may use rules to reason independent of the content of the task. Therefore, the left hemisphere would be more adept at abstract reasoning. In contrast, the right hemisphere may use past experiences (factual or emotional) and thus would be more adept when reasoning involves familiar scenarios. The ventromedial prefrontal neural network plays a role when the behavioral relevance of possible responses can aid the selection of the appropriate action.

A second hypothesis is that the right hemisphere holds representations of the emotional states associated with events experienced by the individual.18 When that individual encounters a familiar scenario, representations of related past emotional experiences are retrieved by the right hemisphere and are incorporated into the reasoning process. In the absence of or failure to activate such representations, the left hemisphere applies learned rules of logic.

Asymmetric advantages in processing based on receptive field size offer a third explanation for hemispheric differences in reasoning skills. Beeman et al19 provide evidence that large semantic receptive fields account for the right hemisphere’s role in understanding discourse and metaphor. A similar explanation may underlie hemispheric differences in reasoning. Large receptive fields in the right hemisphere would permit individuals to activate all possible relationships, local and distant, between the items in the problem to be solved. Overlap between features from the activation of multiple relationships would allow the right hemisphere to use past experience to narrow possible options; patients would arrive at the appropriate conclusion and reason by analogy. The right hemisphere would have an adaptive advantage over the left hemisphere in analogical reasoning and reasoning involving familiar situations. By comparison, the left hemisphere’s fine coding would allow individuals to focus on the main feature or event and on the local relationships between the items in the problem. As a result, the left hemisphere would have an adaptive advantage over the right hemisphere in formal logical reasoning and reasoning involving abstract content.

FUTURE DIRECTIONS

Reasoning, like the prefrontal cortex, is a primarily human trait that develops late in childhood.20 Reasoning deficits can arise from various causes. For example, im-
paired reasoning can be an initial symptom of frontal lobe dementia or the sequelae of frontal lobe stroke or head trauma. Various neurological disorders can affect regions of the brain that are important for reasoning, sometimes selectively, producing similar clinical manifestations but requiring potentially different treatments. Regardless of the cause, reasoning deficits can seriously affect patients’ ability to manage their daily affairs and to interact appropriately with others. As neurologists, we must be able to detect impaired reasoning in our patients as an indication of neurological disease, diagnose the underlying cause of that reasoning deficit, and treat both the cause and the deficit if possible.

A better understanding of the basic mechanisms and subprocesses of reasoning should make it feasible to evaluate reasoning abilities in different neurological disorders. To facilitate this process, coherent nomenclature and units of measure need to be formulated. With increasing knowledge of the specific mechanisms that mediate reasoning will come the increasing hope of developing effective pharmacological and behavioral therapies to treat reasoning deficits that result from neurological damage.

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Corresponding author and reprints: Jeffrey E. Shuren, MD, JD, Office of Policy, Planning, and Legislation, US Food and Drug Administration, HF-11, Room 14-101, 5600 Fishers Ln, Rockville, MD, 20857 (e-mail: jshuren@oc.fda.gov).

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