Unraveling the Mystery of the Frontal Lobes
Explorations in Cognitive Neuroscience
By Arthur P. Shimamura, PhD

Arthur F. Shimamura, PhD, is Professor of Psychology at the University of California, Berkeley. His research involves the study of human memory and cognition from a neuropsychological perspective. His primary focus is on the study of memory disorders in neurological patients. He is also involved in investigations of how the normal aging process affects memory and cognition. Dr. Shimamura is the author or coauthor of over 60 journal articles and book chapters and is currently Associate Editor of Psychological Bulletin and Scientific Advisor for the San Francisco Exploratorium Science Museum. Dr. Shimamura received his PhD in psychology from the University of Washington in 1982.

In 1848, Phineas Gage, a foreman for the Rutland and Burlington Railroad Company, suffered a most horrifying accident. He and his men were clearing away boulders for a new rail line with the help of explosive charges. Phineas's job was to "tamp" or compress the explosive compound into a bored hole with an iron rod. While he was tamping, the charge prematurely exploded, sending the iron rod up, like a harpoon, through Phineas's left eye socket, up into his frontal lobes, and out through the top of his skull. The rod landed 30 meters behind him. Eyewitnesses reported that Phineas never lost consciousness and, after a few minutes, rose to his feet and told bystanders that they did not need to carry him. The fact that a person could sustain such a horrendous brain trauma and appear to experience rather minimal aftereffects intrigued people, as indicated by the amount of popular press given to the incident.

Phineas survived his accident and lived for another 13 years. However, the injury to his frontal lobes produced a distinct psychological impairment that was reflected primarily in his emotional instability. Prior to the accident, Phineas was known to be a calm and respectable individual. Following his accident, he was rude, irritable, and profane. Although the accident did not appear to disrupt severely Phineas's intellectual language, or memory capacities, he could not hold his former position, because he was unable to control or suppress his emotional outbursts.

The remarkable case of Phineas Gage offers important insights into the workings of the brain. The fact that the control of emotional responses could be affected without affecting other mental capacities suggests that the brain's architecture is built in a modular fashion, such that mental functions are to some extent encapsulated in specific brain regions or brain pathways. Indeed, damage to the anterior part of the frontal lobes quite often leads to the kind of emotional instability and impulsivity observed in Phineas Gage. Such symptoms are common following severe head injuries due to automobile accidents, because the frontal lobes are frequently involved in such cases.

The Riddle of the Frontal Lobes

The search for the role of the frontal lobes in mental function has been a rather elusive endeavor. Most mysterious is the anterior portion of the frontal lobes—an area called the prefrontal cortex. During human evolution, this region grew disproportionately compared with any other brain region. It comprises about 25% of the cerebral cortex. It is also the last area to develop fully in humans. For some, the prefrontal cortex has been honored as the seat of human intellectual prowess, whereas for others, it has been relegated to no more than the front bumper for the rest of the brain. In 1964, the noted neuropsychologist, Hans-Lukas Teuber, described the study of the prefrontal cortex as a "riddle," because this brain area did not appear to affect sensory input or motor output. Yet, when this region is damaged, there are specific and identifiable derangements in mental ability.

Contemporary research has advanced and broadened our understanding of frontal lobe function. These advancements are part of the burgeoning field of cognitive neuroscience—the interdisciplinary approach that attempts to address the relationship between brain mechanisms and psychological function. Two important advances in cognitive neuroscience are (a) more sophisticated analyses of psychological deficits associated with brain injury and (b) improvements in human neuroimaging techniques that allow us to observe brain activity (e.g., positron emission tomography [PET] and functional magnetic resonance imaging [fMRI]). With these advances in human neuroscience research, along with those in animal research, we have reached a clearer understanding of brain-behavior relationships, including the relationship between the prefrontal cortex and cognitive function.

Based on current knowledge, the prefrontal cortex appears to be involved in controlling and monitoring our thoughts and actions. In anthropo-
morphic terms, the prefrontal cortex is the brain's chief executive—it monitors activity, filters irrelevant information, makes decisions, and initiates action. Without it, thoughts are disorganized, more susceptible to interfering information, and more confused, such that well-formed plans and decisions cannot be initiated. In truth, there appears to be several supervisors, each one overseeing a particular mental capacity, such as emotion, memory, perception, and action. Thus, the prefrontal cortex acts more like a governing board of supervisors whose job it is to monitor and control many aspects of mental activity. In the case of Phineas Gage, the supervisor in charge of emotional control was dysfunctional and, therefore, emotions and feelings were blunted out without regard to the situation or social context. In sum, Phineas was not able to monitor and control the expression of his emotions.

Metacognition: Controlling and Organizing Thoughts

In my laboratory, I have been interested in a region of the prefrontal cortex involved in the supervision of thoughts and memories. This region is called the dorsolateral prefrontal cortex. In psychological terminology, I am interested in metacognition, which refers to the ability to monitor, control, and organize mental activity (i.e., cognition). In many instances, our cognitions operate with minimal supervisory control or intervention. For example, you may be able to tell me what you ate for your last meal, without much effort. However, if I asked you to tell me what you ate for lunch 3 days ago, the task now involves mentally monitoring the activities during the past several days and attempting to organize the information. Perhaps, you retrieved the fact that you had lunch with a particular colleague that day, which then cues you into what you had for lunch. In such cases of memory retrieval, it is apparent that a great deal of mental monitoring, controlling, and organizing is involved. It is also likely that your prefrontal cortex was particularly active during your attempts to retrieve the information.

The ability to control and monitor thoughts and memories is severely disrupted in patients with lesions in the dorsolateral prefrontal cortex. The patients that I have studied had experienced a stroke that damaged this brain region in either the right or left cerebral hemisphere. These patients have severe impairment in supervisory control, but are not so impaired that they cannot function in daily living. In fact, these patients exhibit normal intellectual and social skills. Their deficit, however, is revealed on tests that require high metacognitive control. For example, in the task above in which you were asked to determine what you had for lunch 3 days ago, it was necessary to organize your thoughts around certain past events and episodes in your life. The construction of your autobiographical time line requires the organization of memories into a chronology with reference to places and time periods. The construction of such timeliness is severely impaired in patients with dorsolateral prefrontal lesions. As a result, they often have difficulty determining the temporal order of past events.

In addition to problems in placing thoughts within a temporal context, these patients also exhibit problems in placing thoughts within a semantic or knowledge-based context. For example, a particularly difficult task for these patients is to list examples from a particular category (e.g., name things you could buy at a supermarket or name as many occupations as you can).

Consider the metacognitive demands of this task. After retrieving some obvious examples, it is necessary to monitor the examples that you have already reported, control or inhibit those examples from being reported again, and organize your thoughts to derive other novel examples. On this test, patients performed as if they had a disruption in supervisory control—that is, they often retrieved a few of the most obvious examples, but then faltered and repeated the same examples over and over again. Thus, metacognitive control was needed to evaluate (monitor) thoughts and take control of the task demands.

Conclusions

In daily experiences of these patients, these problems exhibit themselves in absentmindedness (where did I put my keys?) and difficulty in word finding (what was the name of that person?). Best you think, as you read these symptoms, that you have a serious frontal lobe lesion, it is important to note that the same, although much more subtle, problems occur as a result of normal aging. It has been shown that, during normal aging, cerebral atrophy, which is caused by the gradual pruning of nerve branches, occurs most significantly in the frontal lobes compared with other brain regions. Thus, problems related to frontal lobe function, such as problems in retrieving words or the temporal order of recent events and absentmindedness are common features of normal aging, although such deficits are less severe and more variable among the elderly. Interestingly, these metacognitive problems of aging may be somewhat mitigated by intellectual activity.

In a recent study, my colleagues and I gave professors at the University of California at Berkeley a series of cognitive and memory tests. Although the findings indicated age-related decrements in some domains, such as response slowing, professors in their 60s performed as well as professors in their 30s on tests that required comprehension and remembering text material. Such a task involves organization and metacognitive control, because new knowledge must be categorized and integrated with existing knowledge. Thus, in terms of successful aging, there may be some validity to the adage: use it or lose it.