BRAIN AND INTELLIGENCE

Perhaps the first issue one should consider about the relationship between the brain and intelligence is that one is attempting to relate a physical entity, the brain, the activities of which must conform to the laws of physics and chemistry, with a nonphysical entity, "intelligence." This entry discusses the relationship between the brain and intelligence and reviews suggestions for future research.

Intelligence has no isomorphic physical correspondent; rather, it is a conceptual category used to characterize one type of functional activity of the brain. Another issue is that there has never been agreement on a definition of intelligence. However, one constant about intelligence is that it depends on an animal's ability to learn and remember, and what an animal can learn and remember is constrained by its learning capabilities. For example, a species that is incapable of concept learning can never be considered to show the intelligence of a species that is capable of concept learning.

Despite these formidable issues, for approximately 2,500 years scholars have sought to understand the relationship between brain and "mind" (another nonphysical entity). For present purposes mind is interchangeable with intelligence, and the abbreviation M/I will be used.

Historical Overview

During the 17th and 18th centuries, philosophers debated whether brain and M/I were identical (e.g., Thomas Hobbes' materialistic monism) or whether they were independent entities. René Descartes argued for independent entities that interacted, and G. W. Leibnitz argued for independent entities that functioned in perfect parallel. George Berkeley believed that the brain was only an idea in the mind (*idea*listic monism). The Greek philosopher Galen and earlier physician-scholars attempted to investigate brain functions, and Descartes added neuroanatomy and physiology to his brain-M/I interactionist view. Nevertheless, scientific investigation of the brain and M/I did not emerge strongly until the early 19th century.

Franz Joseph Gall correlated bumps and depressions on the cranium with psychological faculties that he believed constituted M/I. Gall assumed that bumps and depressions reflected the underlying development or lack thereof of brain tissue. Larger brain areas (located via cranial protrusions) reflected the superior development of a particular faculty while depressions reflected a deficiency in a faculty. Such a correlational approach is scientifically legitimate; however, Gall was careless about experimental control when seeking evidence for the manifestations of the faculties in his human

subjects. Nevertheless, the "science" or "pseudoscience" of "phrenology" was born, a term Gall disavowed in favor of "craniology" or "organology." Gall's enduring legacy is that he established the view that M/I-related functions are localized in the brain.

Phrenology was soon denounced by Pierre Flourens who experimentally ablated parts of the brains of frogs, rabbits, and pigeons and observed changes in their behavior. Flourens concluded that, although different parts of the brain might have their proper functions, many or most parts of the brain functioned together as a unit. Flourens' antilocalization view soon eclipsed Gall's localization view. However, localization remerged strongly in the second half of the 19th century with the discovery that a specific area of the cerebral cortex controlled human speech (Bouillaud, Aubertin, and Broca) and, using electrical stimulation in the brains of dogs, Fritsch and Hitzig determined that a specific area of the dog's cerebral cortex controlled motor movements.

Subsequent extensive cortical mapping of sensory and motor areas led to the discovery, especially for human and nonhuman primates, that large cortical areas were unassigned.   "Associationism," a largely British philosophy about how knowledge is acquired, was prevalent, and soon it was suggested that the unassigned cortical areas comprised "association" cortex. It was suggested that activities in sensory cortex and motor cortex were integrated in association cortex for higher-order brain activities such as learning, memory, and intelligence. Based on histological examination of the cerebral cortex, cortical mapping reached its zenith early in the 20th century with the general acceptance of Korbinian Brodmann's identification of 52 areas; Brodmann speculated that each cytoarchitecturely-distinct area had a distinct function.

The antilocalization view reemerged strongly in the first half of the 20th century with Shepherd Ivory Franz and Karl Lashley, who used cortical ablation and research tasks intended to measure learning, memory, and intelligence. Both accepted that there were well-defined sensory and motor processing areas, but both believed that learning, memory, and intelligence involved most of the cerebral cortex. Lashley was such a scholarly force that localization of higher-order functions was again eclipsed.

Within two or three decades following Lashley's death (1958) localization of function reasserted itself especially among brain imaging researchers. Localization of function was often taken to such extremes by these researchers that William Uttal, in 2003, felt compelled to refer to such research as the "new phrenology," a view shared by other contemporary, reputable critics.

Meanwhile views regarding association cortex were also changing. Summarizing decades of careful neuroanatomical and behavioral studies mostly by Irving T. Diamond and his colleagues, Diamond concluded that the neocortex consists only of sensory and motor cortex and that there is no association cortex per se. Further, Diamond (1979) identified the cortical areas only in sensory categories (vision, audition, etc.) and concluded that "… every area of the cortex could be viewed as a motor area, or layer V itself could be termed the "motor cortex."" (p. 35).

The neocortex has six cytoarchitecturely distinct layers from the surface (layer I) of the brain to the deepest (layer VI). Many contemporary scholars agree with Diamond that the entire central nervous system is a sensory-motor processing system, together with memory processing and formation, and that as the brain evolves it becomes increasingly capable of highly complex sensory-motor-memory processing.

Although *motor* is the term most used historically, the more general term *effector processing* is better. Motor usually implies skeletal muscle responding, but smooth muscle activation and glandular secretions have critical roles in emotions and behavior. For example, embarrassment manifested as blushing involves cutaneous vasodilatation. Fear and anger are usually associated with neurosecretions of the adrenal glands. Moreover, important results of sensory-effector activities are physical changes in the brain that enable memory. Memories can modify ongoing sensory-effector processing; thus, the brain is constantly changing as a result of sensory-memory-effector processing.

Brain Size and Intelligence

Somewhat independently of what was happening in the brain-behavior-M/I laboratories, investigation of the relationship between brain size and intelligence was occurring. This began in the late 19th century with the simple notion that bigger brains implied greater M/I. Little attention was given to measuring intelligence; rather this line of research proceeded on the assumption that the best brain-size index of intelligence will place humans at the top.

Data such as the elephant's brain size of 5,700 grams compared to the human's of about 1,350 grams quickly suggested that absolute brain size should be discarded in favor of a measure that took into account body weight. Using this approach, the human brain accounts for about 2.2% body weight compared to elephants' 0.08% of body weight. However, squirrel and cebus monkeys, have brain to body weight ratios of 4 to 5%; thus, simple brain-body weight ratios are not acceptable.

Harry Jerison's empirical approach may be the most accepted today. Using logarithmic coordinates, Jerison plotted brain weights on the Y axis and body weights on the X axis. He plotted data from a large number of vertebrates and saw, for example, that if he connected the outermost data points for "lower" vertebrates (fish, amphibians and reptiles) and, separately, the outermost points for "higher" vertebrates (birds and mammals) there was no overlap between the polygons that enclosed the data points for the two sets of vertebrates.

Furthermore, the best fit line for each group had a slope of 2/3, and the line for lower vertebrates crossed the Y axis (the intercept) below where the best fit line for higher vertebrates crossed. Similar best-fit lines were seen with other groups such as mammals or orders among mammals such as primates. Jerison expressed the general linear equation as follows:

$$E = kP^{2/3},$$

where E is brain weight, P is body weight, the slope of 2/3 was used as a constant, and k was the empirically-determined intercept on the Y axis. Related to the 2/3 constant, Jerison has reported a near-perfect correlation between two-dimensional brain area (cm) and three-dimensional brain volume (grams or cc).

One application of this equation might be as follows. Having determined that the best-fit line for mammals resulted in k = 0.12, one might use the equation to solve, for example, the "expected" brain weight (Ee) of humans compared to other mammals of human-body size. Using 58,275 grams for typical human body weight, the expected brain weight needed by a human to be a typical mammal of human body size is 180.36 grams. As the average human brain weight is about 1,350 grams, Jerison calculated an Encephalization Quotient using EQ = Ei/Ee, where Ei is the individual or representative brain weight for a species and Ee is the expected brain weight as calculated above.

Thus, the human EQ (1,350/180.36) is 7.5, or one might say, the human has 7.5 times more brain than needed to function as a typical mammal of its body size. The EQs of other mammals mentioned above are 1.25 (elephant), 2.80 (squirrel monkey), and 4.79 (cebus monkey). Clearly, one prospect is that EQs might be correlated with IQs to determine a relationship between brain and intelligence.

Guidance for Future Research Regarding Brain and Intelligence

First, there are ways to proceed now with better research. Jerison has provided a way to calculate EQ and Roger K. Thomas has provided a way to determine a numerical index for intelligence that can be used with any species. Further research may be needed to refine EQ measures, as they do not always agree with a priori expectations. For example, the EQ for squirrel monkeys (2.80) exceeds those of all the great apes (chimpanzee, 2.48; gorilla, 1.76; orangutan, 1.91), yet few contemporary primate researchers would accept that squirrel monkeys are more intelligent than chimpanzees.

In any case, that is an empirical question that might be decided best with further research. However, it seems likely that some brain-weight adjustment may be needed to optimize the EQ measure; for example, a squirrel monkey's brain weighs about 25 grams, whereas a chimpanzee's brain weighs about 385 grams.

Thomas proposed an eight-level hierarchy of learning that includes *all* types of learning. Complexity of tasks at Levels 7 and 8 can be increased systematically to challenge even the most intelligent humans. Rarely has a variety of species of animals had their intelligence assessed using a common testing approach.

When such has been done, results have been confounded by the failure to take into account variables, such as that animals are not equal in sensory and effector capabilities, in what motivates them, and in how the testing environment affects them (e.g., a room too bright results in fear in rats and a room too cold for reptiles may make

then torpid and appear less intelligent than they are). Tasks are needed that can be adapted to be administered optimally for each species; Thomas's approach provides that.

Finally, to accomplish the best possible research regarding the relationship between brain and intelligence, one must think clearly about that relationship. Figures 1 and 2 may be helpful. In both figures, the large open arrow entering the brain reflects sensory processing that is initiated outside the brain as a result of external observable antecedents. The solid arrow exiting the brain reflects effector processing associated with the initiation of external observable consequents such as behavioral (e.g., speech) or physiological (e.g., vasodilatation associated with blushing occurs only after one knows one has a reason to blush) responses. Note that sensory and effector processing may be assessed inside the brain with electrical recordings, chemical samplings, brain imaging, or invasive manipulations (e.g., chemical or electrical stimulation and targeted ablations).
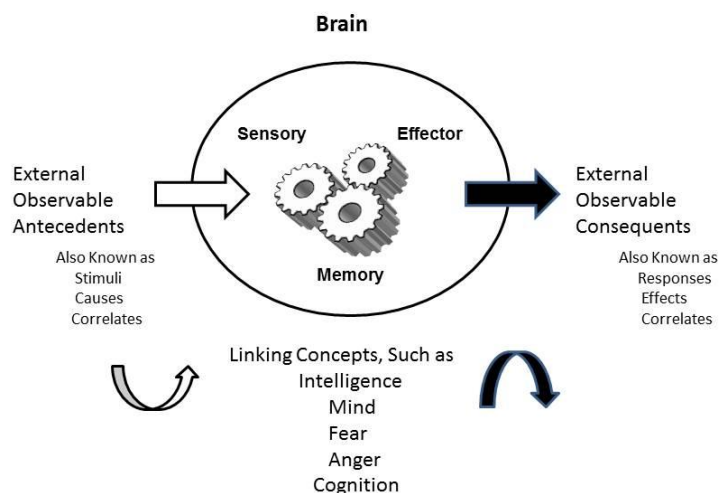

Figure 1. A static representation of the brain and how its physico-chemical based sensory, motor, and memory processing systems are affected by material-antecedent events and how these processing systems determine material-consequent events. The linking concepts used to describe such events are immaterial constructions derived from the material processes and events.

Note also that memory processing also involves physico-chemical activities resulting in physical changes within the brain. The gears in the figures symbolize that sensory, effector, and memory processing interact constantly and may modify one another's physico-chemical activities.

Nowhere in the brain does anything happen that can be said to be isomorphic with intelligence. Rather, "intelligence" is a linking concept used to represent certain sets of observable external and internal antecedents and consequents. Most concepts that

behavioral neuroscientists investigate are linking concepts that are equally fictitious in that they have no isomorphic physical manifestations. Behavioral scientists refer to them as intervening variables that function as short-cut terms to link a myriad of antecedent and consequent observations. Physicists, for example, refer to similar non-observed entities as hypothetical constructs.

Kenneth McCorquodale and Paul E. Meehl suggested that behavioral scientists might propose hypothetical constructs when they believe that isomorphic physical manifestations may be observed eventually. An example of a biological hypothetical construct is that the "gene" was hypothesized well before DNA and its biochemical composition were determined. Perhaps the only hypothetical construct in behavioral science is the "engram," Lashley's term for how memory is manifested in the brain, something which is still being investigated.

Figure 2 illustrates that the brain is always active, and, for example, some of the consequents of Time 1 may become part of the antecedents at Time 2. Comparable to Heraclitus's aphorism, "You cannot step twice into the same river," the brain is never the same from moment to moment. Meanwhile, tagging along in parallel with the brain's activities are linking concepts such as intelligence, mind, fear, anger, perception, cognition, etc., the meanings of which are always limited to observable external and internal antecedents and consequents.
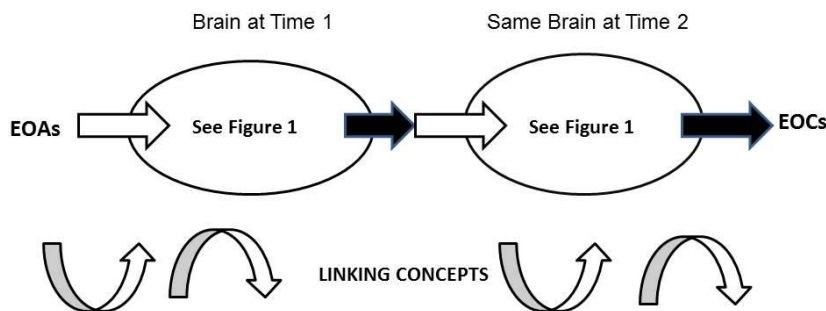

Figure 2. A dynamic representation of the processes and events associated with the brain in Figure 1 to show that processes and events are constantly changing as time passes and those consequent events at Time 1 may become part of the antecedent events at Time 2.

Roger K. Thomas

See also Cognitive Evolution; Evolutionary Psychology; Intelligence, Evolution of; Intelligence Testing; Measurement of Intelligence

Further Readings

Coltheart, M. (2006). Editorial: What has functional neuroimaging told us about the brain (so far)? *Cortex, 42*, 323-331.

Diamond, I. T. (1979). The subdivisions of neocortex: A proposal to revise the traditional view of sensory, motor, and association areas. In J, M, Sprague & A. Epstein (Eds.), *Progress in Psychobiology and Physiological Psychology* (Vol. *8*, pp. 1-43). New York, NY: Academic Press.

Jerison, H. (1973). *Evolution of the brain and intelligence*. New York: Academic Press.

Thomas, R. K. (1980). Evolution of intelligence: An approach to its assessment. *Brain, Behavior & Evolution, 17*, 452-474.

Thomas, R. K. (1996). Investigating cognitive abilities in animals: Unrealized potential. *Cognitive Brain Research, 3*, 157- 166.

Uttal, W. R. (2003). *The new phrenology: The limits of localizing cognitive processes in the brain*. Cambridge, MA: MIT Press.