Transactions of Illinois Academy of Sciences
(1982), Volume 75, 1 and 2, pp. 91-99

FUNCTIONAL TOLERANCES IN THE NERVOUS SYSTEM WITH PARTICULAR REFERENCE TO MAN

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INTRODUCTION

The adult mammal including man tends to develop more size in its organ systems than it needs for normal function. The amount of tissue that might be considered as "spare" represents an anatomic reserve. The reserve is called upon during the increased use of an organ and it helps to explain the functional tolerances that exist. An example may be drawn from the normal-sized but well-developed heart where a physically fit individual may increase his resting left ventricular cardiac output of about 5400 ml per minute at rest to perhaps seven times that amount in heavy exercise. Another striking example is the deviation that is claimed to occur from an expected 98.6°F oral temperature in a resting normal person to 41°F in a person with artificially controlled hypothermia (Scope Weekly, 1959) to 116.7°F in an individual with tremendously high fever (Southern Illinoisan, 1980), with survival in both instances.

The concept of a margin of safety is seen to hold true not only for tissue mass, but also for functional processes, all expressed as tolerances. No correlation seems to have been determined among the reserves of the various organs of the body.

The diverse bodily reserves bring into sharp focus the plasticity of the organism. This has a relevant bearing on the factors that favor organic evolution. A question may be raised as to whether the reserves or plasticity of cold-blooded vertebrates are as extensive as those of the homoiotherms. The evidence points toward an evolving plasticity. A frog has a more restrictive range of temperature than does a bird or mammal and this lesser adaptive capacity makes the frog a relative prisoner of its environment. Man is a more global organism.

The margins of safety appear to indicate not only the capacity for adaptation, but also the range of adaptation for any given process. Since an organism depreciates its reserve during an activity, adaptation is in sense imperfect and, if without warning signs, can end in disaster.

In the present account, only one class of organisms is under consideration, man being the focus of attention. Emphasis is placed on the fortunate occurrence of plasticity following impairment or loss in an organ system. The tolerances of the nervous system are an interesting area to consider. The present discussion considers only the central nervous system and the brain in particular. It must be emphasized that the cases presented herein represent extraordinary situations which serve only to illustrate the purposes of this presentation.

THE CENTRAL NERVOUS SYSTEM: BRAIN

The Cerebrum

Historically, perhaps the earliest clinical record of how much structural loss the brain can suffer without severe consequences was that of Phineas Gage. Harlow (1868) described the case history. As a result of an explosion, a crowbar passed through both of Gage's frontal lobes, destroying them. The patient showed no marked signs of illness and recovered with only persistent personality changes.

This case is not without parallel in recent times. Sachs (1959) discussed the progress of a 15-year-old boy who fell on the spiked end of a ski pole. The pole was thrust through the right antrum and across the midline, injuring both right and left frontal lobes. The patient recovered and by the 17th postoperative day he had only a slight diplopia. Intellectually and emotionally he appeared normal thereafter to all observers.

A medical paper from Nigeria (Ohaegbulam and Ojukwu, 1980) described an unexpected lack of severe craniocerebral symptoms following the practice of "nailing." A 48-year-old female was punished for stealing by driving a 10 cm nail into her head. Examination revealed the head of the nail in the midline of the parietal area. The patient claimed that the nailing was relatively painless and that she never lost consciousness. Physicians described her as alert and well-oriented. A week after extraction of the nail she became disoriented, but she responded to seven days of psychiatric treatment and was discharged.

A 20-year-old male was caught stealing and had a nail driven into his parietal skull. He experienced no loss of consciousness and claimed that the assault was not painful. The patient was discharged one week after removing the nail and was symptom-free when observed three months later.

Experimentally, the cerbral cortex in part or totally has often been removed in animals. Goltz in 1881 (quoted by Houssay, 1955, pp. 1035-1036) found that dogs can survive up to 18 months after removal of the entire cerebral cortex. There are profound changes. The dogs lack normal phasic and postural reflexes. They do not walk. Sham rage occurs. There are no marked changes in visceral functions. Persons or objects are not recognized, memory being lost, and there is no capacity to learn.

Considerably more capability has been reported for cats whose cerebral cortex had been removed, but whose thalami and basal ganglia were left intact (Guyton, 1976, p. 708). The cats were said to be capable of almost any type of motion, and could avoid obstacles. They lost purposefulness of locomotion and sat very quietly for hours.

Houssay (1955, p. 1036) cited human cases of dysgenesis in which much of the

cerebral cortex was missing at birth. In general, a primate does not survive long with a total failure of cortical development. Houssay noted that decorticate children have been kept alive. Hayashi and his coworkers (1979) discussed human children with failure of development of the entire forebrain (holoprosencephaly). They stated that radiologic examination is essential to determine the extent of the dysgenesis. One of their patients, an eight-month-old girl, had no cerebral hemispheres. She had been admitted to the hospital at three months of age because of continual fever and she lived until age eight. The symptomatology of three patients listed in Hayashi's paper is only vaguely described.

Hemispherectomy

The term hemispherectomy usually means the removal of one entire cerebral hemisphere, but it has been used variably to describe partial hemidecortication. There may be defects of different severity in the embryological development of a hemisphere. Cole and Zollinger (1970, p. 613) discussed such dysgenesis in cases where the capillaries were defective, producing an ischemia which resulted typically in epilepsy. They removed the affected tissues, thereby controlling the seizure, without any worsening of the existing weakness and often with improved behavior of the patient.

McKenzie in 1938 (cited by Wilson, 1970) was the first to perform a right hemidecortication in a young woman with spastic hemiplegia. The hemiplegia was unchanged, but her mental alertness and general health improved. Krynaw in 1945 in Johannesburg (Wilson, 1970) pioneered hemispherectomy for infantile hemiplegia, stating that there was relief of epilepsy and improved behavior. Wilson (1970) reviewed 50 cases in which the pallium of the affected hemisphere was removed, sparing the caudate nucleus, hippocampus and thalamus. Epilepsy was abolished or relieved in 82% of the cases. Frank behavioral disorder was abolished or improved in 93%. The I.Q. was not changed. Followup, however, showed a high general morbidity in 38% of the cases.

Smith and Sugar (1975) removed in a 5½-year-old boy the entire left cerebral cortex and white matter, except for the basal ganglia. The patient's originally distorted speech returned to normal. At age 21, 15-½ years later, he displayed normal language and verbal and non-verbal reasoning capacity. At age 26, he was a college senior and a part-time industrial executive. His I.Q. was 126. The development of superior language and intellectual abilities in this patient after left hemisphere ablation at 5 years of age reveals the plasticity of the remaining (right) hemisphere. It had the potentiality to provide normal and apparently complete cerebral function.

Basser (1962) stated that there is no lateralization in very young children. Before age 10, one entire hemisphere can be removed without subsequent aphasia. The hemispheres appear to be equipotential, but after 10 years children upon surgical operation usually suffer permanent defects.

Fleischhacker (1954) claimed that hemispherectomy lessens or "cures" epilepsy, exerting a beneficial effect on behavior and mental development. Of five patients, four became well-oriented in place and time. None showed ataxia or dyscoordination although hemianopsia was present.

Commissurotomy (Split Brain)

Commissurotomy refers to a surgical operation in which the two hemispheres of the brain are separated, in part or totally. The literature is extensive.

Gazzaniga and Sperry (1967) reported on the condition of patients following transection of the corpus callosum plus the anterior and hippocampal commissures and separation of the massa intermedia. Postsurgical studies indicated a striking independence of the gnostic activities of the two hemispheres. Each hemisphere retains activities which are cognitive, perceptual, mnemonic, learned and volitional. These proceed independently and outside the realm of awareness of the other hemisphere. The subjective experience of each hemisphere is known to the other only indirectly through lower level and peripheral effects.

The disruption of bilateral integration produces remarkably little disturbance in ordinary daily behavior, temperament or intellect. Functional deficits get compensated by development of bilateral motor control from each hemisphere and by bilaterality of the sensory projection pathways. There appears to be a large common denominator of similar and closely related background activity in right and left hemispheres. The effects of sectioning are most obvious in activities involving language. Linguistic expression appears to be organized almost exclusively in the left hemisphere. The left hemisphere also processes all visual functions for the right half of the visual field and the stereognostic functions for the right hand.

Comprehension of both spoken and written language is represented in the minor as well as in the major hemisphere, although less proficiently. Writing is organized only in the major hemisphere. Ordinarily, the right hemisphere is linguistic, logical and propositional.

Sperry (1961) stated that complete section of the corpus callosum in man produces no clear-cut functional impairments. Complete division of forebrain commissures to alleviate intractable epilepsy was shown by Gordon (1980) to be followed by no major deficits. Overall, each hemisphere can function in many ways on its own and the results of surgery tell us that the brain under duress can be greatly reorganized.

Individual Regions of the Cerebrum

The losses described vary considerably in bilateral as contrasted with unilateral excisions.

Frontal Region

Moniz in 1935 performed the first prefrontal lobotomy, for anxiety and melancholia. Such "psychosurgery," to relieve certain behavioral disorders, expanded rapidly in usage, then sharply declined after 1950 because of the more controllable electric shock therapy and subsequently the use of such drugs as lithium, phenothiazides and others.

Following lobotomy, intelligence and memory do not appear to be much affected, but the patient becomes apathetic. His "personality" is changed. There is very little disturbance of neurologic function.

Parietal Region

Wright (1946, p. 78) summarized failures resulting from removal of the parietal lobe as the inability to note differences in the relative intensity of stimuli, the loss

of recognition of spatial relationships, and the loss of ability to note differences and similarities of external objects in contact with the body.

Temporal Lobe

Resection of the temporal lobe includes in some patients the major portion of the hippocampus, the dorsolateral part of the amygdala, the parahippocampal gyrus, the uncus, and the superficial temporal gyri. The temporal lobe has extensive connections with other regions of the brain.

Cole and Zollinger (1970, p. 633) discussed the advantage of resection of the temporal lobe to relieve local epileptogenic foci when the seizures are incapacitating and refractory to drugs. Walker (1973) discussed the surgical management of psychomotor epilepsy and stated that in his experience there was encouraging relief and little overt neurologic impairment of the patient. Similar conclusions were reached following unilateral temporal lobectomy in 25 patients by Cogen et al. (1979) for temporal lobe epilepsy; seizures were controlled and there was improvement in sexual libido and reproductive capacity.

Angular Gyrus

The angular gyrus is at the posterior tip of the lateral fissure where the occipital, parietal and temporal lobes meet. There is evidence that it is a master area which collects sensory impulses from individual association areas. In this sense, it appears to be the most important single region for the synthesis of thought (cerebration). Following severe angular gyrus damage a person hears normally and recognizes words distinctly, but he cannot arrange the words into coherent thoughts (Guyton, 1976, p. 746-747). This syndrome is termed a syntactical, or Wernicke's aphasia. An adult compensates to some extent by developing similar capacities in the contralateral temporal lobe and angular gyrus. If the gyrus is spontaneously destroyed unilaterally in a child under six years of age, the opposite side is claimed to develop functionally to full extent, all neurologic capabilities eventually returning to normal. This is a remarkable margin of safety for an area so complex in its integrative activities.

Cingular Gyrus (Gyrus cinguli)

This area is dorsal to the corpus callosum. It is part of the limbic system which is a ring of cortex that surrounds a group of deep structures that function in behavior. The limbic cortex may be an association area for the control of behavior.

Bilateral ablations were first done in monkeys by Ward (1948). Fear and aggression no longer occurred postoperatively.

Livingston (1951) performed bilateral cingulectomies in human patients, claiming benefit for those with anxiety states. His series of patients were severely psychotic and refractory to nonsurgical therapy. The surgical approach was made by suction ablation. Tow and Armstrong (1954) reported on 17 patients in whom bilateral cingulectomy was followed by temporary overall improvement; somatic complications were nonpersistent epilepsy and urinary incontinence.

Occipital Region

Ferrier in 1886 claimed that monkeys with extensive occipital lobectomies suffered no appreciable impairment of vision. Weiskrantz (1972) reviewed the literature and confirmed Ferrier's statements about primates. One explanation is

that other cerebral areas compensate; the probability also exists that some visual cortical nuclei were not excised during the lobectomies.

Petty (1973) described the clinical progress of a 24-year-old male who had an occipital knife wound by penetration through the foramen magnum. The patient remained conscious, oriented and had no abnormal neurologic signs. He was free of any signs or symptoms one month later.

Walther (1952) discussed the case history of a 33-year-old male in whom 15 years previously the left occipital lobe and a part of the parietal lobe had been surgically removed because of an oligodendroglioma. The patient showed a well-integrated personality and only some quantitative reduction in mental performance. The slight impairment was in memory and comprehension. The writer was surprised not by the slight impairments, but rather by the absence of greater disturbances. The results confirm the views that the right half of the brain can adequately compensate for the left half.

Amygdala

The amygdala is a complex of nuclei found just below the medial surface of the cerebral cortex in the pole of each temporal lobe.

Stereotactic surgery on human patients involving bilateral amygdalotomy for bilateral temporal lobe seizures was stated to eliminate the seizures without any incapacitating permanent complications (Andy et al., 1975).

Corpus Callosum and Anterior Commissure

These white structures connect the two cerebral hemispheres and thus are the anatomic links between hemispheric correlated activities. Guyton (1976, pp. 756, 757) cited the instance of a person born without these structures. The patient could perform most functions that are thought to be interassociated by the commissures. Apparently, other structures can be called upon to correlate the processes that occur between the right and left brain.

Chiarello (1980) emphasized the view of many workers that agenesis only of the corpus callosum produces no clearly defined neuropsychologic syndrome. The anterior commissure substitutes as one of the compensatory agencies. Also, each hemisphere can become self-sufficient by independent specialization or it may develop greater than normal reliance on noncallosal connections. Chiarello noted that the congenital absence of the corpus callosum results in fewer disconnection symptoms than surgical transection does.

Basal Ganglia

The basal ganglia include several major nuclei (centers of neurologic control) embedded within the forebrain and the midbrain. They are especially involved in muscle tone, bodily movements and posture. Lesions deliberately created, especially by precise stereotaxic placement of electrodes in a previously affected basal ganglion region, may restore a balance in effector motor circuits, e.g., in Parkinson's disease and other syndromes of unbalanced neural circuitry. Patients whose primary signs are hypertonia or tremor without secondary muscle and joint changes may expect alleviation of the tremor and rigidity. Surgery can be performed bilaterally, in operations staged several months apart (Cole and Zollinger, 1970, p. 634).

Cerebellum

The cerebellum forms the superoanterior part of the hindbrain and is a reflex center between afferent proprioceptive impulses and the responsive control of all qualities involved in adaptive muscle responses.

Much of the available data on the cerebellum indicate that up to one-half of the cerebellar cortex can be removed before marked clinical effects occur. The patient can perform practically normal movements if he does them very slowly. Associated centers of the brain play a part in this enormous power of compensation.

Tolerance for Sleep Deprivation

The lethal limits particularly for oxygen lack and secondarily for controlled water deprivation are well defined, but those for sleep lack are vague and many reports are anecdotal. As examples, Rosenstein (1957, pp. 72, 229) in a popular book cited the case of a patient who survived 4-½ years of supposed sleep deprivation. Rosenstein described another case, stating that it was known by Pavlov, where an artifically-fed patient "slept" for 20 years without gross physical degeneration.

Although scattered data in the literature suggest that wakefulness may extend only up to about 50 hours, a news item in Scope Weekly (1959) asserted that a New York disc jockey set a record of staying awake 201 hours and 13 minutes.

The observations on sleep deprivation indicate that progressive deterioration is usually expected, including delusions, hallucinations and confusion as to place, time and self.

Coma

Whereas sleep is a normal form of "unconsciousness," coma is a persisting, pathologic form, variable in its duration. The Chicago Daily News (158) reported the case of a male in Chicago with Wilson's disease who spent the last 13 years of his 34-year life in a coma. The same newspaper (1960) reported another case, in Moscow, where a 29-year-old male, following an explosion, was said to have gone into a coma and was revived at age 47. The Guinness Book of Records lists the longest record of unconsciousness ever recorded as being that of a female who lapsed into a coma after an appendectomy at age 6 and who died still in coma at age 43 (quoted from the Daily Egyptian, Southern Illinois University, Nov. 29, 1978).

Brain Death and Survival Time

Parisi et al. (1982) discussed the clinical course of a 49-year-old male, terminally ill and kept alive by external support. His heart kept beating, despite accepted criteria for brain death, for 74 days. At this point a court order permitted termination of his life support system.

Epilogue

The tolerances, or margins of safety, of the human organism are truly remarkable. The discussion herein for the brain can be extended to every bodily organ and system. Every known recorded limit of function or survival seems always to be stretched just a bit further as one reads the expanding literature.

The ultimate (if that is possible) in optimum functioning with a minimum of brain tissue present is described by J. Lorber (cited in a paper by Lewin, 1980, in SCIENCE under the title "Is Your Brain Really Necessary?)." The patient was a student at Sheffield University in England. He had an I.Q. of 126, achieved high honors in mathematics, and he was said to be socially normal. Brain scans showed that he had virtually no brain! He was referred for clinical study only because of an unusually large head. The scans showed that instead of an expected 4.5 cm thickness of brain substance between the cortical surface and the ventricles, there was only a one mm layer of mantle. The cranium was filled mainly with cerebrospinal fluid.

This case does not necessarily startle all neurologists. The innovative aspect is the information obtainable from newer instrumentation. Lorber has simply brought to light by improved visualization the great amount of structural reserve present in the brain. The case history minimizes, although in a limited sense, the classical views of the importance particularly of the cerebral cortex.

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