1994

Factors Related to Functional Recovery After CNS Injury

Traceylin B. Sales

University of North Dakota

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FACTORS RELATED TO FUNCTIONAL RECOVERY AFTER CNS INJURY

by

Traceylin B. Sales
Bachelor or Science in Physical Therapy
University of North Dakota, 1993

An Independent Study
Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Master of Physical Therapy

Grand Forks, North Dakota
May
1994
APPROVAL

This Independent Study, submitted by Traceylin B. Sales in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

(Faculty Preceptor)

(Graduate School Advisor)

(Chairperson, Physical Therapy)
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Title       Factors Relating to Functional Recovery After CNS Injury
Department  Physical Therapy
Degree      Masters of Physical Therapy

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ACKNOWLEDGMENTS

I would like to take this opportunity to express my deepest gratitude to those special individuals who were involved in my education as well as those who helped me to pursue the one profession I have come to enjoy so much. That is, the discovery of serving the needs of others in the field of physical therapy. Thank you to all my professors, instructors and mentors who have generously shared their time, invaluable wealth of knowledge and experience. Thank you to my parents, family members, relatives and friends who have always encouraged me to complete what I have so desired to accomplish since my high school days as a volunteer at a local hospital. Lastly, I thank the good Lord for His abundance, His provision, the talents He has given me, and most of all, the opportunity to serve in this capacity, doing for others what He has already done for me.
ABSTRACT

Factors that act either directly or indirectly, such as the age of the person, the time of injury, the site and size of location, mechanisms of neural repair, therapeutic intervention, and general medical and family support have been suggested to contribute to the overall motor and functional recovery of an individual. This paper is a literature review of these influential factors, with emphasis on restoration of functional skills. Overall, findings have been consistent to some degree. Generally, the more severe and dense the injury, the resulting increase in behavioral and motor deficits. Neural mechanisms of repair have been found to occur throughout one's lifetime, with full recovery being evident in both young and older individuals. Younger individuals have been found to fare better in terms of recovery. However, some deficits are not manifested until the appropriate maturational stages, some take time to appear, others take time to disappear. A comprehensive rehabilitation program and its timely implementation following injury were found to enhance the extent and quality of functional recovery. Motivation, family support, and functional activities have also been significant. An understanding of what is actually involved in an individual's total functional outcome and how, insofar as possible, these factors can be manipulated is imperative both in the sense of promoting recovery and in improving upon an already existing comprehensive treatment approach for individuals with CNS involvement.
CHAPTER 1
INTRODUCTION

Neurologic injuries, particularly head injuries and stroke, account for a large percentage of impairments and disability across all age groups and are said to be responsible for nearly 50% of functional incapacity in the elderly population. The results are an array of deficits ranging from sensorimotor, cognitive, visual-perceptual, communication, and behavioral problems. Full or adequate restoration of function may be possible, but how it occurs appears to be an area of intense study, though it still remains a mystery. What processes take place within the brain itself in response to injury and how the temporal, physical, and environmental factors surrounding the injury of the individual affect the overall outcome has neither been consistently delineated across studies nor completely understood.

There are several variables that affect the overall degree and quality of functional motor recovery, some of which can be controlled to some extent though post-injury intervention such as therapy and environmental factors. Recovery becomes limited by those variables which cannot be controlled such as age, location and extent of damage, and the inherent plastic capabilities of the nervous system to repair itself. Physical therapists are committed to utilizing effective treatment strategies while working within the natural constraints surrounding the individual. Studies report that there is a "window" or "critical period" during which intervention must occur in order for functional recovery to occur. The purpose of this paper is to review current literature regarding these influential factors relating to recovery of function, more specifically motor function, following injury to the brain. Several commonly used treatment
approaches in the field of physical therapy, the models upon which these approaches were devised, and recommendations for therapists in enhancing the recovery process and outcome will be presented. The limitations of this paper are as follows:

1. Emphasis will be directed at functional motor recovery. The return of cognitive, memory, or speech abilities, though related to recovery, will not be specifically addressed.

2. Central nervous system (CNS) injury in this paper refers specifically to injury of the brain as commonly seen in stroke or brain injured victims.

3. The various factors relevant to functional recovery are investigated but are not presented in any order of significance.

4. This paper will not attempt to predict recovery based on the factors presented as the nature and involvement of injuries are variable and unique to each individual.

5. This paper will not detail the physiologic and anatomical sequelae of stroke or brain injury.

6. Pharmaceutical or surgical approaches to promoting functional recovery will not be covered.

7. Recovery of function is defined as the ability to perform functional activities (i.e., bed/floor mobility, sitting, standing, transfers, ambulation) with or as close to a level of independence and use of assistive devices as appropriate.
CHAPTER 2

CELLULAR MECHANISMS

Following injury to the central nervous system, reactive changes take place, consisting of a variety of repair mechanisms responsible for the restoration of function. The view of the adult mammalian brain being a "static" organ no longer holds true. The brain's inherent "plastic" properties are said to allow for adaptive and functional motor recovery in addition to restoring learning and memory abilities. Not much is known concerning the extent of plasticity, the ability of the brain to restructure itself in mediating recovery. After several days to several months during which time the initial edema resolves itself and circulation return, neural changes have been found to occur and accompany functional recovery. These processes may be enhanced over a period of many years. Results from animal studies have also documented accompanying anatomical and neural changes as well as measurable behavioral recovery. Whatever recovery does occur after brain damage would seem to reflect only those natural processes or changes in the nervous system, some of which are spontaneous or are influenced either by direct or indirect means. Some of the proposed theories and mechanisms which account for recovery following injury to the CNS are discussed in the following paragraphs.

According to Von Monakow's Diaschisis theory, there is a "shock of distinct neural connections and cease of operations" following injury to the CNS. Also termed "spinal shock," diaschisis refers to the cutting off of facilitating impulses resulting from the destruction of a region remote from the lesion site, leading to ceased function. Though this theory may account for the early period of recovery, it is said to lack an
explanation for a recovery mechanism beyond the depressed state. Almli and Finger described redundancy theory as one that assumes an excess or "spare set" of neurons in the CNS which mediate similar functions following significant injury. In keeping with the idea of localization of function, where different parts of the brain are function-specific, it was also proposed that numerous back-up systems would then be required to restore functions in the exact fashion as lost or damaged tissue. Similarly, the concept of equipotentiality refers to all parts in a given area of the brain mediating a particular function, thus the remaining tissue would continue to carry on a lost function. This implies that functional recovery would depend on amounts of "spare" tissue rather than the location of the damage. According to Wall, redundancy also can have three implications: 1) more cells are produced than are normally needed, 2) extra systems are produced, or 3) that one system overlaps and silences another.

Much debate has come about due to the opposing notion of localization of function. Lashley cited comprehensive data and experimental tests that do not support the notion of substitution of functions. Experiments in monkeys revealed that recovery depended upon the premotor areas and that combined destruction of the precentral and premotor regions responsible for motor functions resulted in permanent paralysis. Therefore, in this example, restitution of motor function was accounted for by regions normally concerned in the control of movement itself.

Rather than a localized area of the brain taking over for the lost function, any part of the brain might assume functions controlled by other parts. Vicarious function, first proposed by Fritsh and Hitzig in 1860, refers to the idea that any part of the brain might take over the functions of other parts and so the nervous structure sets almost no limit to recovery. Vicarious function was also said to be an active process where the organism does not just make external adjustments to such loss, but adapts to the loss of tissue,
demonstrating true functional and behavioral recovery similarly seen prior to injury. The nervous system may have also had a latent capacity to control the functions which were lost, with motor recovery being manifested only after injury.

Denervation supersensitivity refers to an increase in the cell's responsiveness to the transmitter substance and is said to contribute to the enhanced motor activity of spasticity. The functional consequences then being that less transmitter substance produces the same synaptic action as a normal synapse, with an increase in the area of transmitter sites to act upon.

Another proposed mechanism is neural or axonal sprouting, which is said to have two forms. The first, known as axonal regeneration, refers to newly generated axons innervating denervated areas. Kiernan stated that cells replace their amputated axons with no involvement in mitotic activity or formation of new neurons. He also concluded that axon regeneration does not normally occur in the mammalian brain but is more commonly found in the peripheral nervous system. Maladaptive connections could also result in which an axon may connect with an alternative target.

The second form, known as collateral sprouting or reactive synaptogenesis, refers to new growth in undamaged neurons adjacent to destroyed neural tissue. This was not limited to the spinal cord but had also been found in certain regions of the brain following experimentally produced lesions. Raisman and Field documented that axon collaterals from viable neighboring neurons sprouting toward vacant synapse sites in the brain's septal neurons in the red nucleus of rats. In addition, only axons sharing a common target were once originally thought to send collateral sprouts to vacant synapses, however, afferent inputs may also arise from very different brain regions. Yet, still other brain regions have been found to lack sprouting capability in response to deafferentation. Rasiman stated that sprouting would further lead to an increase in
synaptic effectiveness, allowing the new system to substitute for the destroyed synapses. Sprouting was considered to be an underlying physiological mechanism for relearning or a method of compensation, since changes were observed to begin several weeks from onset of injury and occur for an indefinite amount of years.\(^2\) Laurence and Stein\(^3\) suggested the possibility of a number of cells dying in a normal brain, thus leaving a number of vacated sites which can be filled by intact cells. Repetitive functional demand or training in specific activities have been said to stimulate sprouting as well as branching of dendrites.\(^3\) Axonal or dendritic sprouting may said to be responsible for the slower aspects of recovery.\(^6\)

Unmasking is another mechanism, occurring from within weeks to several months post-injury, whereby pathways previously inhibited or suppressed by cortical region are activated in response to nerve degeneration.\(^3\) This may be the reason for the diffuse neural connection laid down in the very early stages of a developing mammalian embryo,\(^2\) where maturation of the CNS involves the destruction of some connections and suppression of others.\(^3\) A mature brain could therefore be differentiated from an immature brain by the increased number and complexity of its interneural connections and elaboration. However, Wall\(^3\) stated that unmasking may prove to be maladaptive since substituted connections may bring in nonsense information which the recovering nervous system cannot handle. Some maladaptive changes seen include spasticity, memory dysfunction, and seizures.

Dombovy\(^2\) stated that both cortical reorganization via synaptogenesis and unmasking may account for a considerable portion of immediate recovery seen post-stroke. For example, in recent studies of primates,\(^3\) redundant connections of somatosensory inputs to the motor cortex may be possible in part for recovery of motor function. It was said that impulses may be rerouted due to a rapidly acting feedback
mechanism.

Carr and Shepherd\textsuperscript{6} mentioned a behavioral strategy change or "substitution" mechanism that may account for possible functional recovery, where the individual may use a different strategy to achieve the same goal or motor pattern. For example, one used a different sensory cue for guiding movement. Essentially the same movement was produced but in a different functional manner. However, in all cases following cerebral injury, the ability of the organism to regain problem solving processes does not always indicate an underlying change via cellular mechanisms in the nervous system.\textsuperscript{39} In the same manner, the presence of neural mechanisms, such as sprouting or synapses, does not imply functional or behavioral changes.\textsuperscript{6}

Therefore, as can be seen from the literature reviewed, the brain uses a variety of mechanisms for self-repair and reorganization after injury. Other enhancing mechanisms said to occur include changes in the neurotransmitters and cerebral metabolism following injury to the brain.\textsuperscript{2} However, several difficulties arise from these studies. Since the majority of the research findings originated from animal studies, it is almost impossible to generalize findings for clinical application to human subjects. Because of the lack of agreement and understanding about the functions of different parts of the brain and how the various components work together, it proves much more difficult to discuss or explain recovery of function after injury and the actual processes that accompany it. Another difficulty that arises in research is the debate of exactly what is responsible for recovery. In addition, some of the proposed mechanisms are in opposition to one another. Whether the recovery is due to anatomical and physiological changes, to compensatory mechanisms such as substitution, or to both, remains uncertain. Lastly, the presence of cellular changes do not necessarily accompany functional or behavioral changes, nor can we say the opposite is true. Aside from this, other factors must also be considered in the overall recovery process and outcome.
CHAPTER 3

AGE AND TIME CONSIDERATIONS

The age of the individual, the maturation level of the CNS at the time of injury, time factors surrounding the injury, duration as well as frequency of therapy, and the nature of the brain lesion, all contribute to the outcome of recovery. A survey of literature concerning the degree of functional recovery shows a wide range of views concerning their impact on recovery. Studies on age groups do not draw a consistent, definite picture favoring one age group over another. Younger individuals were said to be more resilient, recovering quicker and experiencing less symptoms while early rehabilitation appears to enhance recovery. In addition, physiological, behavioral processes, and plasticity (the ability of the CNS to modify its own structural organization and function), are also discussed.

General findings support the notion that the younger patients fare better in terms of recovery. Jennet et al showed that the younger patients could withstand a longer coma and yet still retain the capacity to recover in spite of the fact that poorer prognosis is associated with a longer coma duration. Lucas stated that children are more likely to be conscious after a severe head injury than adults, and that they rarely experience the interval between initial onset of unconsciousness and rapid deterioration that is commonly seen in adults. Overall, Lucas concluded that approximately 90% of children with a severe head injury recover.

The "plasticity" or malleability of the young, developing nervous system was said to be more responsive to accommodate for changes and to adapt in response to injury. The younger the organism, the greater the chance that the older systems of the CNS are
still dominant and less differentiated, therefore able to adapt to functional reorganization. These older circuits may be utilized and strengthened as the newer, higher centers have not yet had the opportunity to inhibit their control over the lower centers (see Chapter 4, Part I. Hierarchical System). Early studies suggested that the immature brain had a somewhat flexible organizational scheme and that if one area was damaged, another area could pick up the lost region's function. Brain lesions specific to age do affect the degree of functional improvement. Some examples cited by Moore include the switching of hand dominance following brain injury at a fairly young age, the right hemisphere taking over motor speech functions, or a contralateral Wernicke's area taking over receptive speech functions after a left hemisphere lesion. In the fetus, the CNS undergoes continuous remodeling. These changes were said to be the result of rapid cell proliferation, of which more cells were generated than do survive.

As a result, damage to a given area of the brain at different times in life resulted in significantly varied outcomes, particularly due to the degree of maturation of the CNS and the ability of the brain to compensate for injury, of which was said to occur only during specific times during life.

As the age of an individual correlated with normal development and maturation of the CNS, the relationship of age to brain injury was not straightforward. In one study of rats with bilateral injury to motor, prefrontal, parietal, visual, and temporal cortex areas, some behavioral loss was noted after the first few days of life than with a similar injury at seven to ten days of life. The same cortical injury at 20 days of life was associated with more severe behavioral losses, being more or less equivalent to that observed in adulthood.

Kolb stressed that the organization of the brain at the time of injury was the most important factor predicting behavioral outcomes. Jennet et al similarly stated that the time at which behavior was assessed was equally important in documenting recovery
of function. Kolb\textsuperscript{39} illustrated that compensatory mechanisms were effective during childhood but not during aging. He described patients who had contracted polio during childhood with no clinical signs and symptoms of neurological impairment until their fifth decade of life. Teuber\textsuperscript{44} concluded that the younger the injured brain, the greater was its resiliency.

In contrast, some motor and behavioral deficits were found to occur later in life. A study\textsuperscript{45} of rats with prefrontal lesions was performed, with impairment in some behavioral tasks discovered earlier in life at ten days of age. However, by adolescence these deficits disappeared. Such a phenomena was referred to as "growing out of disability." The results of another study\textsuperscript{44} showed a linear relationship between age and the number of symptoms of motor deficits; as age increased, the number of symptoms of motor deficits increased. Goldman\textsuperscript{46} demonstrated no behavioral loss in monkeys relative to age-matched normal control animals if subjects were tested at young ages, whereas the same animals tested later in life did show significant behavioral impairment. The responses at specifically different time periods in life may provide the key to tapping the neural mechanisms within the CNS and its relevance in enhancing optimal functional recovery. Teuber\textsuperscript{43} also concluded that the presence and degree of resiliency could be determined by neurological and behavioral tests, which measured the effects, site, size of lesion, and time frame in which deficits would be manifested or reduced.

However children, once thought of as wonderfully resilient beings who could adapt to even severe trauma, were shown to be just as vulnerable as adults. Sometimes it took much longer for the effects of trauma to be manifested.\textsuperscript{46} Skills that were undergoing rapid development at the time of injury were usually more impaired. Therefore, any damage occurring before the critical maturation of sensory and motor systems between age six and seven and a half years was bound to have a significant impact on motor skills development. Although plasticity may diminish with age, it does
not disappear. Lab studies have documented that recovery of function continues to occur more than 5 years after a stationary lesion. One stroke case described by Aguilar showed plasticity of the nervous system still present during the rehabilitation outcome at 65 to 70 years of age. Plasticity was said to occur throughout life, even up to the point of senescence and recovery occurring even in advanced age. Harlow found evidence of continuing recovery as late as the sixth year following brain injury in monkeys and long-term recovery being documented in humans as well.

Kolb mentioned that the time after injury was also important in securing functional abilities during the recovery process. Although the causes of behavioral improvements seen after CNS injury had been the attention of much debate, it was evident by review of literature that behavioral changes do correlate with a series of cellular and molecular events in the brain that follow a time sequence. At least some behavioral changes correlated with post-lesion changes in the brain. On the other hand, failure to see any measurable recovery beyond a certain time period was said to be due to the occurrence of certain cellular mechanisms or to completion of other physiological changes. Kolb further suggested that the lesion-induced physiological changes may interfere with recovery due to the fact that the nervous system may not regrow injured regions in the same manner as that seen during development.

The time at which therapy was initiated also impacted the outcome of recovery. Functional reorganization in the CNS was said to occur even when therapy had been delayed for a long time, but overall improvement was usually greater when therapy was initiated early. Black et al studied the effects of active motor retraining following a standard lesion in the motor cortex of rhesus monkeys. When training in the weak limb was delayed 4 months post-operatively, spontaneous recovery was about 50% after one week of training, as compared to only 9% after one week in groups trained immediately.
one week after surgery. However, the group trained immediately following surgery continued to improve over a six-month period to approximately 82% of their performance prior to operation. The delayed group showed a limitation in further improvement, reaching a plateau of 67% recovery after 6 months following training.

Nieto-Sampedro and Cotman contended that establishing neural regeneration was dependent upon a strict order of events observed during development, consisting of physiological changes. They suggested that interventions likely to prove successful in promoting behavioral recovery were those that permitted the nervous system to repeat the original developmental sequence of events. Several different neurological interventions would thus be required to ensure that each stage occurred at an appropriate time.

Therapeutical intervention, its impact on CNS function, and outcome of recovery will be discussed in the following chapter.

Therefore, loss of age-specific functions correlated with the maturity of the nervous system at time of injury, also consistent with age. Some may take time to appear, others to disappear, according to the stage of CNS development. Behavioral recovery may also be specific to the organism, as seen in the different functional outcomes between human and animal studies. The age of the individual, the time at which therapy or intervention is begun, the duration and frequency of therapeutic intervention, and the age at which the individual is assessed, all influence the final outcome of the individual's functional recovery one way or another following a brain injury or lesion. It is difficult to assess which of these are solely responsible for the outcome since it is almost impossible to isolate and manipulate each variable. The concluding point is that several factors, of which those mentioned are certainly not exclusive, play some part in contributing to the person's ultimate functional outcome.
CHAPTER 4

REHABILITATION/ THERAPEUTIC INTERVENTION

Therapeutic intervention has a significant role in the recovery process of an individual with central nervous system injury resulting from stroke or trauma to the brain. Assuming that the brain has the ability to restructure and adapt itself following injury, much of what happens to the patient thereafter, in addition to spontaneous recovery, is just as important. Principles of rehabilitative treatment approaches are built upon our understanding and knowledge of the central nervous system structure, organization, and functioning in normal and pathological states. They incorporate techniques founded upon models focusing on the developmental sequence of the nervous system, spatiotemporal adaptation, or the subcortical sensorimotor integrative action of the nervous system. Much of the literature reviewed documented observable behavioral changes over time, which in part, were said to be attributed to aggressive therapeutic intervention strategies or approaches. This chapter will be divided into two parts: a) the structural and functional development of the motor nervous system, and b) the common treatment approaches in rehabilitation of functional motor skills.

PART I: MODELS OF CNS FUNCTIONING

The integrative nature and functioning of the CNS can best be understood by its structure and development. Two models for motor control have been proposed, each of which attempts to describe motor development, the regulation of movement, and flow of information within the central nervous system.
Hierarchical System

The hierarchical system represents a "top-down" model in which a higher center was said to be responsible for the motor planning while the lower centers were recruited to execute the movement. Moore specified that the first systems to develop are the archi (oldest), followed by the paleo (intermediate) and lastly the neo (recent) systems. The neo systems were said to be the only ones that do not obtain full functional capabilities until years after birth. Full maturation of the nervous systems was said to begin at age one and end at approximately 21 years. In terms of function, Moore explained that the archi (oldest) system was the "central core of man's CNS", involving the autonomic, reticular and cerebello-vestibular systems; the paleomammalian system was said to be involved with protective mechanisms; and the mammalian system was concerned with exploratory or learning behaviors. These systems, more specifically the neo-system, were said to contribute to preservation of the bilaterality of the nervous system, in which the two cerebral hemispheres are interdependent for normal functioning. Moore added that the subcortical, older systems were structurally and functionally the foundations upon which the neo-system functioned.

In the same manner, Hughlings Jackson proposed that the nervous system represented movements, and certain parts of the brain represented those movements in different combinations. These combinations were represented from higher to lower centers, with the highest center consisting of the sensory cortex, the frontal motor areas, and those responsible for consciousness; the motor cortex being the middle; and the spinal cord making up the lowest center. According to Newton, the higher center contained all the information and delegated commands to the lower centers without any feedback from these lower centers. This enabled the higher centers to effectively carry out higher cortical functions without utilizing excess energy. The higher centers served
to inhibit or suppress the more primitive and reflexive movement patterns of the lower centers. CNS maturation was seen as a function of inhibition or suppression of the primitive, non-purposeful, motor movements displayed in the presence of CNS injury. Damage to the higher centers, commonly seen in stroke or traumatic brain individuals, would then result in the lower, more stable systems regulating function, producing these reflexive movements that were not influenced by external feedback and the environment. In CNS trauma, the neo-mammalian components were said to be more severely involved because of its: a) increased metabolic demands in comparison with the other systems, b) less vascularization, and c) an increased susceptibility by virtue of their superficial or peripheral location.42

Motor Systems

As the hierarchical model served as a basis for the theory of motor control from middle of the nineteenth century to early twentieth century, there still was a lack of understanding regarding the role of feedback and error in the ultimate movement produced. According to the Systems model,53,56 the CNS functioned as a heterarchy, having no linear relationship between the different levels of the brain. The CNS was described as a network of independent systems that interacts to produce a desired movement.56 The assumptions55 of the systems model were that: 1) information flowed between two or more neural structures; 2) a single center may have had more than one function, while several centers also shared the same function; 3) the centers worked in a collaborative fashion to produce movement; and 4) function was commanded by a consensus of several centers working together.

Today, many researchers and clinicians view motor control via the systems mode and no longer as the "step-by-step" hierarchical model.53,56 However, though the
hierarchical relationship may exist in certain systems, therapists are advised to use both models to further understand motor control and function. But, what needs to be understood is that the overall structure and function of the individual is affected after trauma. Moore added that the individual loses his/her ability to relate to three-dimensional self and environment, and the severity of the damage reflects the degree of lost function on the opposite side due to the crossing of motor pathways. However, this loss has also been seen to some degree on the ipsilateral side because of the interruption of interneurons, association, and projection fibers that enable the body to function as a bilaterally integrated whole.

As one can see, a proper understanding of the structure and functioning of the nervous system that are based on sound, scientific knowledge will greatly aid in the work of physical therapists in establishing principles for rehabilitation. Theoretical models serve as a foundation upon which clinical treatment approaches and strategies are established. The hierarchical model refers to the CNS as a strictly ordinal type of system, where the higher centers hold the lower centers in check and suppress the more primitive, reflexive movements. However, this would imply a localization and storage of concrete behaviors and an inefficiency and inflexibility that is not characteristic of the human nervous system. On the other hand, the Systems model depicts the CNS as a circular network of interacting yet autonomous subsystems. As we come to understand the nature of the nervous system and its function in relation to recovery, the better we can improve our treatment approaches and strategies in restoring individuals to more independent and functional lives. The next section briefly describes some of the more commonly used treatment approaches for the rehabilitation of individuals with CNS injury.
PART II: TREATMENT APPROACHES

Review of literature indicates that almost all spontaneous recovery of function occurs during the first six months post-injury and that any substantial gains achieved after this time can be attributed to learning from rehabilitation training. Many studies which have been cited earlier sought to delineate the functional motor recovery after lesions to the CNS, of which many were animal studies. Other studies also documented effectiveness of rehabilitation or therapeutic intervention in stroke or traumatic brain injured individuals by assessing the functional performances. The general consensus appeared that rehabilitation training does significantly improve the quality and extent of function following participation in a rehabilitation program.

The time frame in which most gains were observed generally occurred during the first six months and up to one year. Dombovy mentioned that motor recovery reached a plateau after 3 months. However, some continued to show improvement for subsequent years and reached a functional level that was higher than predicted. Recovery can occur even in the presence of extensive CNS damage and advanced aging. Lehmann et al determined the influence of rehabilitation training by assessing the ultimate functioning in the living environment of the individual after discharge. Significant gains in functional activities (i.e. in ambulation, transfers, bed/floor mobility, self-care activities) were obtained and the number of these patients who became independent also increased. In addition, functional recovery was noted through training even with an unchanged reflex status. It was interesting to discover that those who underwent intense stroke rehabilitation also demonstrated an improved disposition at discharge and follow-up one year later.

Damage to the CNS results in the loss of inhibitory mechanisms, permitting the more primitive, reflexive movements to dominate. Coordination is disturbed, movements in skilled activities become less refined, and more gross movements are
observed. From an understanding of the CNS structure and function, therapeutic techniques and approaches have been established and practiced for many years in attempts to restore neuromuscular control, functional motor movements, and coordinated activity.

Proprioceptive Neuromuscular Facilitation (PNF)\(^9\) is one approach that seeks to promote or hasten the neuromuscular response through stimulating proprioceptors. PNF involves procedures and techniques superimposed upon movement and posture. Basic principles\(^5^8\) are as follows:

1) all human beings have potentials not fully developed which can be harnessed and directed toward reducing the inabilities; 2) normal motor development proceeds in a cervicocaudal and proximodistal manner; 3) early motor behavior is ruled by reflex activity, seen as spontaneous movement and postural reflexes; 4) motor development progresses in an orderly sequence of total patterns of movement and posture, but lacks a step-by-step quality; 5) motor development has cyclic trends (i.e. shifts between flexor and extensor dominance; 6) locomotion results from reciprocal contraction of flexors and extensors, with continual postural adjustments for balance; 7) improving motor ability depends upon motor learning which is acquired as a result of practice or experience; 8) frequency of stimulation and repetitive activity are useful for learning retention, building strength and endurance; and 9) goal-directed activities are coupled with facilitative techniques to promote learning of total patterns.

The Rood approach\(^8\) to treatment of neuromuscular dysfunction is based upon the premise that motor patterns are developed from fundamental reflex patterns present at birth and controlled at subcortical levels (lower centers). These reflex patterns were said to form the basis of movement. Sensory stimulation was used to modify these reflexes, which then became movements whose control was transferred to the higher centers.
Basic assumptions include: 1) motor functions are said to be inseparable from sensory mechanisms; 2) sensorimotor control is developmentally based; 3) motor movements are activated in an automatic manner; 4) movement is purposeful; and 5) coordinated movements are the result of interactions between mobility and stability. The basic principles are: 1) sensory factors and their relationship to motor functions are vital in the analysis of dysfunction and in application of treatment; 2) motor responses will be sought out in order of developmental sequences; and 3) there must be interaction among autonomic, somatic and psychic functions.

The Brunnstrom approach utilizes common reflex patterns and attempts to work with the patient at his/her present level of functioning. Reflex training provides the wedge which will allow for the progression of motor control from subcortical to cortical region. The stages of recovery can be thought of as developmental patterns, leading ultimately to skilled movements and active, volitional control of these movements. However, developmental patterns of motion, as they relate to postures and movement of an infant, are not used in this approach but rather, posture and positioning are used to facilitate or inhibit reflex activity and response.

Neurodevelopmental Treatment (NDT) is another approach and is based upon the Jacksonian view of hierarchical levels of integrated motor functions. Keshner stated that a normal postural reflex mechanism was necessary for normal movement and CNS damage permits the abnormal mechanism to be released from the control of the higher levels, with reflex movement patterns now dominant and preventing normal sensorimotor experiences to occur. Thus, input into a damaged system would be shunted to the lower centers, resulting in the production of primitive movement patterns. With this comes abnormal tone, and it is the intent of the NDT approach to change these abnormal postural movement patterns for normal ones by changing the relationship of
body parts to each other. The sensorimotor learning used in this approach allows an individual to learn how to control abnormal movements. Every movement was said to have a postural set from which it can be initiated and carried through in a most efficient and controlled manner (i.e. adjusting head, arms, trunk and legs in preparation for getting up from a chair).

Sensory Integration is based on the underlying premise that higher cortical functions are dependent on adequate neural organization at the subcortical brain level. It addresses problems primarily concerned with sensory processing rather than motor processing as seen in NDT. Principles include 1) the provision of planned and controlled sensory input to stimulate an adaptive response and in turn, to enhance the organization of the neural mechanisms; and 2) the principle that lower parts of the brain develop before higher structures and that cortical functions are in some ways still dependent upon the lower, brainstem functions.

Considerations must be taken during the planning and implementation of such therapeutic techniques in order to be effective to meet the individual needs of the patient. Several aspects critical to the delivery of the rehabilitation programs are motivation, meaningful therapy, repetition, and family support.

Any loss of self-motivation can be traumatic to an individual, upsetting the emotional tone throughout recovery. One of the major goals of rehabilitation was to motivate the patient over a long enough period of time until self-motivation is restored. To continually recognize and reinforce a patient's healthy drives while, at the same time, inhibiting negative, unrealistic behavior patterns were very important. Motivation can be provided by success, reward, and positive reinforcements (i.e. praise, feedback). Active participation in therapy was necessary for any learning to occur and this also resulted from being motivated.
Therapy must also be meaningful to the individual, taking into account his/her interests, goals, and desires in the treatment process and at discharge. Moore stated that the activities in itself must also have some meaning or degree of importance to the individual doing the learning. If one was unable to perceive or make some type of meaning out of the stimulus in a purposeful way, it became ignored and not stored in memory. It was said that learned best if the event or learning situation was tied in more closely to survival or to functional activities within the home, school or work setting. Thus, the patient came to see the importance of activities engaged in during therapy and driven to perform.

In addition, therapy must be meaningful to the patient's nervous system. Several of the treatment approaches mentioned earlier are designed in such a way that allows for meaningful stimulus and interaction at the neural level of functioning. Activities need to be based upon normal physiologic reflexes/responses or sequential sensorimotor movement patterns. Moore stated that the neurological maturation of the cervical levels of the body were responsible for producing coordinated, purposeful and stable movements. He emphasized the importance of the order of embryonic development in relation to the stages of rehabilitation, stating that early closure of the neural groove in the cervical area preceded the caudal area. This was seen as being very crucial to further growth, development, coordination, and function in the nervous system. He implied the necessity of securing stability at the cervical levels and head before obtaining stability at the shoulder, hip girdles, and lastly at the appendages. Instability in distal areas would result if these specific regions of the body were not targeted in proper order. Likewise, instability occurring in distal areas would affect proximal and midline stability.

Moore also claimed that individuals learn and function in relation to total bilateral and reciprocal patterns of movement, as well as, in response to some meaningful
stimulus. Goals must also be realistic to the patient, family or caregivers and suited to the needs of the current functioning level of the CNS. Goals were to be identified and easily attainable, yet challenging in order for improvements to occur. The patient must be able to see the importance or relevance of what he is practicing so that carryover of these skills would be seen in functional, daily activities.

Other factors said to enhance therapeutic approaches were practice and repetition. One study discovered that the degree of improvement correlated strongly with the amount and intensity of therapy. Carr and Shepherd stated that practice was a necessary prerequisite for learning and acquiring skilled motor performances. Learning a motor task involved identifying what was to be learned and organizing the information in the correct sequence to carry out the task. Active versus passive participation in therapy was also strongly encouraged.

Emotional support from family and/or friends was said to be critical during this time as disease or illness usually create stress and requires adapting to lifestyle changes. Lucas suggested that people who can provide encouragement, strength, and hope are a positive influence on the individual. Family members or caregivers were needed in the rehabilitation process, to understand and accept the patient, helping the patient to become positively motivated and in planning realistic long-term goals.

Approaches and strategies to treatment play a large role in facilitating functional recovery. Treatment approaches usually arise from models which describe the structure and function of CNS in normal and pathological states. Many of these treatment approaches sought to mirror or simulate the development of sensorimotor skills. In the case of young infants and children, normal developmental patterns were utilized to teach the individual how to respond and progress through the normal stages of development. The approaches either followed one of the two models presented for motor development.
and control. PNF, Rood, Brunnstrom, NDT, Sensory Integration all are based on the premise of the hierarchical system. The treatment approaches mentioned are not exhaustive, either in theory or practice, and most therapists use a combination of two or more approaches. Though it is difficult once again to document the effectiveness of these treatment approaches in the restoration of function because of the presence of other factors mentioned throughout this paper, evidence from literature does validate the effectiveness of therapy in promoting and enhancing functional recovery. By the same token, there has not been data indicating the ineffectiveness of these approaches.
CHAPTER 5

IMPLICATIONS FOR PHYSICAL THERAPISTS

Several factors have been covered in this paper in regard to contributing to the functional outcome from CNS lesions. Damage to the CNS undoubtedly results in cognitive, sensorimotor, visual-spatial, and balance problems leading to impairments and functional disability (i.e. difficulty with bed/floor mobility, gait, transfers into/out of bed, chair, toilet, car). Physical therapists play an active role in working with such individuals to restore motor skills necessary for such activities of daily living. Some implications can be gathered from the literature reviewed.

First of all, concerning the brain's anatomical and physiological processes following injury, the fact that changes do occur cannot be discounted as research provides evidence for its occurrence. With more emphasis on the inherent plastic capabilities of the brain, there is to be continued efforts aimed at obtaining maximum recovery via the reorganizational processes of the brain. Also, in keeping with the assumption that functional motor recovery reflects only what is taking place in the brain, we can be hopeful that any attempts to influence the nervous system through therapeutic means would further promote recovery. It is unknown which one(s) of these mechanisms is (are) responsible for the final outcome, however, we can utilize those treatment approaches which appear to enhance these cellular mechanisms. For example, repetition, demand for, and training of meaningful activities have been said to stimulate the growth of dendrites and axonal sprouting. Therefore, we need to concern ourselves with teaching functional tasks to which the individual can relate, emphasizing practice, repetition and reinforcement of learned tasks.
Age and time considerations were also vital in terms of intervention. Young children were generally found to have a more favorable prognosis from brain lesions. In goal planning, it may be evident at times where children may progress beyond the level as that projected in adults and perhaps at a more rapid rate. Because of the uncommitted, yet developing nervous system, functional recovery of lost functions could be mediated by the remaining tissue. However, as the CNS ceases development around age 21, any progress of individuals of equal or older age may be seen to have a less adaptive nervous system and full functional restoration may not be as easily achieved. However, we must not limit our expectations for the patient's function since we also see recovery of function in older individuals, even up to senescence. Therefore, we should plan our treatment approaches with the anticipation that even older adults can recover.

The time of intervention was also an important factor. As noted, those who had begun intervention or rehabilitation early were found to improve in functional gains not only quantitatively but qualitatively as well. This implies that early intervention add to enhance the final outcome of recovery. Also, as the majority of gains were observed to occur in the first six months from onset of injury, an aggressive treatment approach that attempts to influence the CNS during this time should be implemented. In addition, it was documented in several cases that recovery continued over the course of several years. Threfore, the attitude that we hold as clinicians can truly influence the degree of recovery; if we regard recovery as an ongoing process, we may further promote and enhance the total outcome. Patient and family education are also vital in this regard if functional gains and improvements are to be maintained.

Though recovery has been noted even without the presence of therapeutic intervention, treatment should never be aimed at anticipating recovery without therapy, since its beneficial effects have never been discounted in literature. Substantial evidence
has been given to support the effectiveness of treatment of stroke or brain-injured individuals. Though it has been difficult to assess and measure the quantitative or qualitative gains, there has been no evidence that therapy does not make an impact on functional recovery. Also, there has been evidence of spontaneous recovery in the presence of unchanged reflex status, thus giving some indication as to the dynamic state of functioning of the CNS even in the presence of injury. An individual can still make functional motor gains although reflex status may still be impaired to some degree.

The treatment approaches presented appear to imitate or mirror the "early stages of CNS functioning and development as that seen in an infant. The primitive, stereotyped reflexes gradually become replaced by the more higher level, refined righting and equilibrium reactions as the CNS matures. As an individual receives further sensorimotor experiences, the CNS responds in a way that favors the development of highly skilled motor patterns, allowing for more efficient and quality movements.

Things to keep in mind while implementing treatment for persons with CNS involvement include repetition or meaningful tasks, motivation builders, family or caregiver support, an atmosphere that is conducive to learning, and setting realistic, yet attainable goals. Most importantly, therapeutic approaches must simulate ADL's and activities similar to that seen prior to injury and that are also in harmony with conditions surrounding discharge. Rehabilitation treatment should also be approached on the basis of retraining the individual in tasks that approximate daily life activities as closely as possible with some of his/her unique needs or interests being incorporated. Above all things considered, the patient must be medically stable to prevent any further complications and be mentally as well as physically prepared for learning.
SUMMARY

Several variables interact together to bring about functional recovery in individuals sustaining stroke or brain injuries. The central nervous system has a tremendous capability of healing itself via direct means, such as cellular mechanisms or by indirect means, such as therapeutic intervention. Other factors which are not as easily manipulated in enhancing recovery include the age of the person, the extent of damage and residual mass of nervous tissue. Nevertheless, the nervous system is capable of interacting with the environmental factors as well as its own internal mechanisms to contribute to the final outcome.

Cellular mechanisms have been suggested to take place following CNS injury. It has been documented that neurons within the CNS, specifically the brain and spinal cord, do not regenerate. However, active growth has been documented from animal studies, those of which include axonal or neural sprouting and synaptogenesis. Other mechanisms include unmasking, functional reorganization, vicarious functioning, and denervation supersensitivity. These mechanisms are said to occur within several weeks and continue for months, and even years, depending on the internal functioning of the nervous system as well as environmental influences. These cellular changes are said to account for motor and functional recovery beyond that time of initial circulatory return and resolution of edema.

Age and time factors surrounding the onset of injury, the implementation of therapeutic techniques, and approaches to enhance motor return also play important roles. Children, by virtue of their young, developing nervous systems, are able to adapt to neural changes and accommodate for loss of function. Thus they are usually
said to have a more favorable prognosis when involved in a brain injury. However, even older adults in the 60's or 70's have been said to exhibit plasticity and recover from CNS damage as well. Motor and functional return have been seen in this age group with continued improvement reported for up to five years post-stroke. Cellular mechanisms have been proposed to occur throughout lifetime, and even up to the point of senescence in some individuals.

The time at which rehabilitative measures are implemented, if at all, are also imperative in enhancing functional recovery. Studies have indicated that the earlier therapy is initiated, the better the resulting outcome. Significant amount of return is usually seen within the first six months and continues up to one year, and occasionally for several years thereafter after the onset of CNS insult. Changes in function and behavior may parallel with the anatomical and physiological changes occurring within the nervous tissue itself.

The Hierarchical model and Motor Systems model are two models representing the structure and function of the CNS. It is these models upon which treatment approaches are established. PNF, Rood, Brunnstrom, NDT, and Sensory Integration are just some of the commonly used, though not exclusive, approaches to the treatment of CNS injuries. Almost all of these approaches mentioned are based on the hierarchical model and these approaches emphasize the learning of the developmental motor stages to restore function once again. In young infants, children, and adults, these gross motor skills are strongly emphasized since they make up the foundation of all our movement and are important for independent mobility. Treatment is then geared to advance the individual through these stages, simulating activities of daily living in the process. A comprehensive and focused rehabilitation program also includes certain aspects of treatment which augment functional recovery. As mentioned earlier, although the extent of recovery may be contingent upon the location, severity of the lesion, and age of the
individual, other factors can be manipulated to favor restoration of function.

Though it has been suggested that functional motor return was dependent upon intact premotor areas of the cerebral hemisphere, it has been difficult to correlate affected areas of the brain with restitution of certain functions. It has been reported that recovery can occur even in the presence of extensive damage, with as little as 2% to 3% of remaining tissue mediating a high degree of function, while other studies reported at least 5% to 10% was necessary. Other factors surrounding the individual can be manipulated to favor optimal restoration of independent function. Functional, meaningful and purposeful therapy for the individual as well as aspects surrounding therapy itself must also be incorporated. Instilling motivation into the patient and thus promoting active participation in his/her rehabilitaion experience are other factors which promote learning and maintenance of functional motor return. An illness or disease such as stroke or traumatic brain injury can and usually will create new stresses in life in the form of lifestyle changes. Adaptations to physical, emotional, social, and/or vocational areas of one's life must also be made. Emotional support from family members or caregivers have also proven to be a source of strength, encouragement, motivation, and hope to the recovering individual.

In many instances it is difficult, if not impossible, to determine which of these factors are influential or active in promoting functional recovery. However, as we discover more about the capabilities of the nervous system in responding to situations of injury and healing, we can determine how best to facilitate recovery. It is our role as physical therapists to be aware of and apply current knowledge in the process of goal planning and treatment strategies. In addition, careful and accurate documentation in our treatment approaches is necessary and vital to bringing about this outcome. This approach will both serve to solidify our treatment approaches in theory and practice, and in turn, benefit the many individuals affected by CNS lesions or injury each year.
REFERENCES


53. Goldman PS. The role of experience in recovery of function following orbital prefrontal lesion in infant monkeys. Neuropsychol. 1976;14:401-12.


