Effect of Experience on Recovery Following CNS Lesions

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Recovery of function following central nervous system lesions can be attributed to several changes in the nervous system that occur with time following the initial injury. This article reviews research demonstrating that if the subjects were required to perform specific tasks on a daily basis, recovery was facilitated. Pyramidal tract, cerebellar, and central visual lesions are discussed. Although most of the studies cited deal with research on monkeys, examples are given in the visual system of applying the established monkey paradigm to human subjects, which resulted in an increase in the functional recovery.

Key Words: Central nervous system, Functional recovery, Task performance.

The appearance of voluntary movement and of reflexes following CNS lesions has been ascribed to several different anatomical and physiological changes in the nervous system. Factors such as the resolution of neuronal compression secondary to local edema and hemorrhage, the recovery of neurons from central chromatolysis, and the reestablishment of boutons following withdrawal from a neuron may contribute to recovery. The development of denervation supersensitivity and of collateral sprouting also have been shown to be involved with reflex recovery. Additionally, functional recovery following CNS lesions can be attributed to the recovery from diaschisis, the loss of function of an area discrete from the injured portion of the CNS. Recovery may also occur through the substitution of a behavior similar to, but not the same as, the lost behavior or through the expression of a latent function by an intact portion of the nervous system. These latter two mechanisms, especially, may be subject to manipulation by the amount of training or conditioning the animal or person receives following the CNS lesion.

One of the assumptions made by therapists involved in the rehabilitation of a patient with a CNS lesion is that having the patient practice a task will facilitate the recovery of that task. Certainly, task experience is a component of many of the different approaches to treating patients with CNS lesions, although controlled studies of patients with CNS lesions in which task experience was the significant factor in the recovery of function are rare. However, studies that address this question have been done on animals with CNS lesions.

The purpose of this article is to review those studies of adult humans and monkeys in which the significant factor in the behavioral recovery was the training or conditioning that occurred after the CNS lesion. Research concerning lesions in the motor portions and the visual portions of the CNS will be reviewed in the context of two questions: 1) Is time alone sufficient for recovery? That is, with sufficient time, will a particular function recover no matter what is done or not done? 2) Is the recovery that occurs "transferable"? If there is recovery of the task practiced, will there be concurrent recovery of other related tasks or, perhaps, will the recovery period of the other tasks be shortened?

RECOVERY OF MOTOR CONTROL IN MONKEYS

Pyramidal Tract Lesions

Several studies of adult rhesus monkeys (Macaca mulatta) will now be reviewed that support the hypothesis that specific task experience after a CNS lesion will facilitate recovery beyond that which occurs with time alone. In a series of experiments on monkeys that had undergone unilateral and bilateral pyramidotomies, Lawrence and Kuypers reported that within 24 hours after recovery from anesthesia, the monkeys were able to walk and climb around their cages. The affected upper extremity, however, tended to hang flaccidly next to the trunk, and the monkeys would not use that extremity. When the monkeys were...
forced to use their affected limbs, their fingers were often malpositioned and were tucked into the palm as the animals tried to grab an object. For the first four to six weeks, reaching toward an object "consisted of circumduction at the shoulder with the elbow slightly flexed and the fingers extended and abducted... closure of the hand tended to be part of the total movement of the arm."8 Although the monkeys had recovered some of the lost function, there was a persistent loss of fine-skilled movement of the fingers. Gross grasp was present, but the monkeys were unable to oppose thumb to the index finger to pick up objects, and they had difficulty manipulating small objects.

The monkeys that had undergone unilateral pyramidalotomies preferred to use their unaffected limbs. Significantly, Lawrence and Kuypers observed that if the monkeys were not continually forced to use the involved limbs, the motor recovery reversed. The Bobath approach also discourages the use of the uninvolved arm as a substitute for the involved upper extremity because if the involved extremity is not used there will be no recovery in that extremity. The forced use of the involved body part does not guarantee recovery, but it is a technique that has been used by many researchers to facilitate motor recovery in adult monkeys.9-14

Chambers and Kozart,11 Liu et al,12 and Schwartzman13 repeated the Lawrence and Kuypers study of monkeys that had undergone unilateral pyramidalotomies and then extended the observations by looking at the effect of specific daily training on the recovery of function. For the untrained monkeys with unilateral pyramidal tract lesions the results were essentially the same as in the Lawrence and Kuypers study. However, the monkeys given daily experience in such tasks as picking food out of small wells with index and thumb opposition showed a marked improvement in their abilities. In these studies the monkeys were trained using operant conditioning on a daily basis.11-13 Schwartzman best describes the time course of the recovery.13 For 30 days, for instance, there was no independent finger movement; by six weeks a pincer grasp was noticed, but it was slow and easily fatigued. It was only after one year that the movement was performed easily.

Although the results of these studies are encouraging, there are several discouraging aspects. First of all, the recovery was not complete. Like Lawrence and Kuypers' monkeys, the monkeys in these two studies had a persistent fine tremor in the affected hand, and they preferred to use the unaffected upper extremity.12,13 The recovered motor functions were also much more easily fatigued than the motor function in the unaffected extremity. The monkeys in the study by Liu et al (Chambers, WW, PhD, 1981, personal communication) also retained an inability to open the hand when the extremity was flexed.12 Schwartzman found that only after three years were the monkeys in his study able to release a grasped object easily.13

Another discouraging observation of Chambers (personal communication) was that the monkeys used the recovered function only in the testing situation. When the monkey picked up a raisin from the floor, for instance, he would not use the reacquired individual thumb and finger movement but rather a gross grasping movement in which all fingers flexed together. An additional problem was that the recovered abilities were not transferable to new situations. Each task had to be practiced before recovery occurred.

Thus, with unilateral and bilateral pyramidal tract lesions in adult rhesus monkeys a certain amount of recovery can be expected with the passage of time alone. Further motor recovery has been demonstrated after unilateral pyramidal tract lesions if the monkey is forced to use his involved extremity on a daily basis to perform certain tasks. However, the recovery is limited to the tasks that are practiced.

Cerebellar Lesions

Motor recovery that specifically resulted from task experience following cerebellar lesions in adult rhesus monkeys has also been reported.9,14 In a study by Growden and associates, monkeys with unilateral and bilateral lesions of the dentate and interpositus nuclei were divided into two groups: one group was trained daily in a conditioned situation, and the other group served as a control and received no training.9 Training consisted of performing several tasks, each designed to reveal any underlying dysmetria. Successful performance of the task required that the monkeys could control or correct their upper extremity movements. For example, the monkeys were required to open a drawer by pulling a small handle (5 mm in diameter) to get a piece of food, or they had to tactually discriminate between two shapes and choose the correct shape to receive a food reward.

All monkeys were observed in the "free cage" situation. Neither the trained nor the untrained monkeys would use their affected limbs in the free cage situation, although the trained monkeys with the unilateral lesion would take food using their involved limbs more readily than the untrained monkeys. (Bilaterally lesioned monkeys in both groups were much more severely affected than the unilaterally lesioned animals, although the trained monkeys still did somewhat better than the untrained monkeys.) When the animals with unilateral lesions were supported in a chair and tested, the movements of the trained monkeys had smaller oscillations than those of the un-
trained monkeys and the trained monkeys were able to perform more highly skilled tasks successfully (eg, partially pulling open a small drawer to remove food).

RECOVERY OF VISION FOLLOWING CORTICAL LESIONS

Another example of experience-related recovery following lesions in the CNS is found in work done on the visual system. The primary visual pathway is from the retina to the dorsal lateral geniculate nucleus of the thalamus to the striate cortex (area 17 or VI) of the occipital lobe. The striate cortex projects to a number of other visual cortical areas and because this portion of the visual system seems to be arranged serially, it was believed to act as a "bottleneck" for visual processing. In monkeys, lesions of area 17 cause deficits, including an elevation in the threshold for luminous flux discrimination (difference in figure/ground intensity), a decrease in acuity, and a disturbance in pattern discrimination learning.

Weiskrantz and Cowey studied the scotoma, or blindspot, which is produced by discrete lesions in area 17. They used adult rhesus monkeys trained to look through a peephole at a grid of lights. Two types of trial situations were presented to the monkeys: an auditory stimulus alone or an auditory stimulus coupled with a brief flash of a small light placed randomly in the visual field. The monkeys pushed one lever in response to the auditory stimulus alone and a different lever when both stimuli were presented.

Weiskrantz and Cowey found that during the several months of testing, the size of the scotoma decreased and the threshold intensity of the light that the monkeys could detect approached normal. In addition, they found that if testing was not started for several years after the initial surgery, the animal would still have a scotoma and would require the same training period for the scotoma to "fill in." This clearly was not a matter of relearning the task, because the monkeys were able to perform the task correctly when the stimulus was presented in the intact portion of the visual field.

Weiskrantz and Cowey hypothesized that the recovery was due to a change in the function of either the remaining striate cortex or a visual pathway other than the retino-geniculo-striate system. We now know that the visual system contains a second, parallel pathway from the retina to the visual cortex and that the striate cortex does not act as a bottleneck for visual processing. The second visual pathway goes from the retina to the superior colliculus to the pulvinar of the thalamus and from there to visual cortical areas V2 and V3 and to other cortical areas.

This second visual system is clearly implicated in the recovery phenomenon following unilateral striate cortex lesions. Recently, Mohler and Wurtz repeated the Weiskrantz and Cowey study as part of a study on saccadic eye movements. When they tested the monkeys, however, they divided the scotoma into two parts and gave the monkeys experience in only one half of the scotoma. They found that recovery of the visual detection task occurred only in the half of the scotoma that had received the experience. In addition, when they ablated the ipsilateral superior colliculus, the recovered function was abolished. The training period lasted about one month, but the daily training sessions lasted several hours each. Each point in the visual field that was tested required a minimum of 30 trials before recovery was observed.

In humans, lesions of the striate cortex have been thought to result in absolute and permanent blindness. This has been demonstrated clinically with static perimetry tests and through subjective reports and the observation of overt behavior of patients with cortical blindness. Recent studies challenge this concept, however. If a patient with cortical blindness is asked to guess whether a shape projected into the scotoma is a circle or a square, or a horizontal line or a vertical line, the patient will be correct far more often than he would by chance occurrence even though he is saying that he cannot see the shape. Apparently there is visual information available to the patient that he is unable to use. This ability to "see" the discrete shapes is not a function of experience-related recovery, because no training was involved.

Zihl applied the Weiskrantz and Cowey paradigm to patients with known retrochiasmal lesions, that is, blindness due to lesions of the optic tracts, the optic radiation, or the visual cortex. All patients had stabilized after the initial lesion, and no further recovery had been anticipated. All patients had intact vision in some portion of their visual fields. The patients were first tested using both static and dynamic perimetry. Then they were taught to fixate on a small red light in the center of a screen; their heads were stabilized using a chin rest, and eye position was controlled by having the patients look through a telescope. The patients responded by pushing a button when they saw the target stimulus. Daily training consisted of giving the patients experience in detecting a small light displayed against a background of constant luminance. The signal/ground contrast was varied, and the ability of each patient to detect the smallest difference was recorded. The small light stimulus was always presented at the border of the scotoma and the intact portion of the visual field.

Experience-related recovery did occur in these patients and apparently was related to the experience during the training period rather than any visual experience between testing periods. (Patients were tested before and after the training period, and the recovery always occurred in relation to the training.)
Cowey, the size of the patients' scotoma decreased. In patients in whom there was a gradual change from the scotoma to the intact visual field, the recovery varied and the scotoma decreased in size by 7 to 27 degrees. In patients in whom there was an abrupt change from scotoma to intact visual field, however, the recovery was insignificant (1°).

There are many questions that need to be answered, such as what caused the difference between the two groups and whether the type of experience and duration of it was optimal. One finding was particularly encouraging, however. Zihl and Von Cramon found that although daily training was restricted to one particular task, other visual functions also improved, such as form and color perception.

CONCLUSIONS

The experiments reviewed in this article demonstrated that after certain CNS lesions in adult primates, task experience can facilitate recovery beyond that which would occur with time alone. In all the examples presented, however, the recovery was incomplete, and in the monkey studies, there was no evidence of the transfer of the recovery from task to task. Only in the human visual studies did it appear that experience in one task facilitated the recovery of an entirely different function. This observation about human visual studies may be due to differences in the systems studied (motor vs visual) or to differences between monkeys and humans.

One cannot infer from these experiments that task experience will always further recovery. Recovery may depend on many other factors, such as the site of the lesion and the age of the subject. The type and duration of experience also may be important factors. In all cases the experience that facilitated the recovery involved the active interaction of the subject with the environment. For instance, after the pyridotomy the monkeys were not passively taken through thumb and index finger opposition on a daily basis but instead were required to attempt to use that motion to attain a goal. Even the visual studies, in which the reception of a sensory stimulus could be considered to be passive, had an active component, because subjects used a motor response (pushed a lever, spoke a word) to indicate whether the stimulus was perceived.

The premise that recovery of function after CNS lesions can be facilitated by task experience is an integral part of both physical therapy and occupational therapy. The series of experiments reviewed in this article provides support for this premise for the adult, although the recovery in these studies was not complete. Recovery observed in monkeys may not occur under similar conditions in humans because monkeys and humans are different species and, in the monkey research, the determination of the location and size of the lesions is severely limited and they are unlike lesions seen in humans. However, one purpose of performing research on nonhuman primates is to develop a model for work with humans. The monkey research should therefore be a guide for human research that can be used to determine whether specific task experience will facilitate recovery following CNS lesions.

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