The purpose of this study was to determine if patients with hemispheric brain lesions and subsequent paresis demonstrated a correlation between the perception of joint position sense and the ability to combine component parts of the limb synergies. Twenty-one adult patients with 6-week to 87-month histories of unilateral, hemispheric, paralytic brain lesions were evaluated by each of two tests. The first test evaluated the subject’s ability to perceive joint position sense. The second evaluated the subject’s ability to combine components of the limb synergies. A pilot investigation was performed which established the reliability of the testing instruments. The correlation between the perception of joint position sense and synergy test results, .83, was significant at p <.01. Implications for therapeutic management of the patient with hemiplegia are discussed.

Key Words: Hemiplegia, Proprioception, Kinesthesia.

Movement disorders resulting from brain lesions in humans have been the subject of considerable investigation. Of importance in the physical management of these disorders are the limb synergies as described by Brunnstrom,¹ ² Bobath,³ and Michels.⁴ Brunnstrom² and Michels⁴ have proposed treatment approaches that use these limb synergies to help regain functional movement. Those authors suggested that by practicing these movement patterns more normal movement may be learned. Michels also suggested that patients suffering a concurrent loss of sensation along with hemiplegia may experience extreme difficulty when attempting to learn normal movement from those patterns.⁴ This concept is supported by the clinical experience of the first author of this paper. This clinical experience also has indicated that the most important element of sensation that is needed when attempting to combine the limb synergies into normal movement patterns is the perception of joint position sense. This apparent relationship between the sensory and motor systems was generally accepted until Knapp and associates reported findings from deafferented monkeys.⁵ These investigators produced well-controlled movements in monkeys deprived of sensory feedback. With this information, much doubt has been cast upon the previously well-accepted relationship between movement and sensation. The present study was undertaken to determine if patients with hemispheric brain lesions and subsequent paresis demonstrated a correlation between the perception of joint position sense and the ability to combine component parts of the limb synergies. If a relationship such as this can be established, support will be rendered for the original hypothesis of a sensory-motor link.

REVIEW OF LITERATURE

Many investigators have used a variety of methods to evaluate the relationship between the sensory and motor systems. Among the earliest investigators were Mott and Sherrington who, in 1895, reported severe lasting motor impairment following dorsal rhizotomies in monkeys.⁶ More recent work by Lassik⁷ and Twitchell⁸ has substantiated these findings. In 1971 Adams used these and other investigative reports to formulate a closed-loop theory of motor learning that is based heavily on proprioceptive feedback.⁹ According to his theory, a person suffering loss of joint position sense would have more difficulty relearning movements than would someone with normal feedback.

Using quantitative and semiquantitative methods, Stern and associates evaluated 62 patients with cere-
brovascular accidents in an attempt to delineate factors that influenced rehabilitative outcome. Hemi-
sensory loss, defined by poor scores on two-point discrimination tests and abnormal results on vibration sense tests, proved to be an important factor in that patients with hemiplegia and hemisensory loss had poorer functional outcomes than their counterparts without sensory loss.

In a related study, Michels assessed motor behavior through observation of 174 hemiplegic patients. The result of his observations showed the presence of four upper extremity limb synergies in patients with hemiplegia. Michels described these limb synergies as isolated parts of continuous patterns of movement called neuronal scores. These neuronal scores not only appeared to be the motor repertoire with which man and other lower vertebrates have been endowed for posturo-locomotor purposes, but they also appeared to incorporate the previously fragmented reflex phenomena as described by Magnus and Simons and reported by Brunnstrom. Michels stated that movement control may be relearned by initially facilitating motion through the use of the limb synergies. In the upper limb, functional movement can ultimately be achieved only through the combination of the individual synergistic elements.

Michels proposed a treatment approach, based upon the use of the limb synergies, to help restore lost movement control. He suggested, as did Brunnstrom, that movement control may be relearned by initially facilitating motion through the use of the limb synergies. In the upper limb, functional movement can ultimately be achieved only through the combination of the individual synergistic elements.

Kent studied the relationship between joint position sense and motor ability in 50 adult hemiplegic patients 2 to 23 weeks after cerebral insults. Her test for joint position sense consisted of contralateral limb duplication of the passively produced movements of shoulder flexion, abduction, and internal and external rotation; elbow flexion and extension; and finger extension. For the motor tests, angular degrees of available movement were recorded for the gravity eliminated motions of shoulder horizontal abduction and horizontal adduction and elbow and wrist flexion and extension. Opposition of the thumb to each of the four fingers was tested against gravity. The results indicated a very low coefficient of correlation between position sense and motor ability. Kent concluded, on the basis of these coefficients, that no relationship between the perception of joint position sense and motor performance was apparent.

### METHOD

Twenty-one adult subjects with histories of unilateral, hemispheric, paralytic brain lesions were selected from clinics and inpatient facilities. All subjects were able to follow the testing commands and had sufficient range of motion to allow passive placement of the test extremity into 1) at least four of the six test positions used to determine the perception of joint position sense and 2) three of the four test positions used to determine the ability to combine elements from the limb synergies. The subjects also demonstrated adequate joint position sense in the uninvolved upper extremity as tested by the finger-to-nose test described by Steegman. Nine patients demonstrated left hemispheric involvement and 12 had right hemispheric involvement. The subjects (mean age 51 years) were tested no sooner than 6 weeks after the onset of the brain lesion. The time range between onset of the lesion and testing was from 6 weeks to 87 months.
Two tests were developed to achieve the purpose of this investigation. The first evaluated each subject's ability to perceive joint position sense. To initiate the test the examiner held the subject's involved upper extremity using a tip-to-tip prehensile grip with fingers placed medially and laterally over the bony prominences of the elbow and over the anterior and posterior aspects of the wrist. The subject's upper extremity was then moved into one of six different positions (Tab. 1) at a velocity of about 10 to 15 degrees a second. When a test position was reached, the examiner asked the blindfolded subject to place the index finger of the uninvolved upper extremity upon a small piece of tape affixed to the radial styloid of the involved upper extremity. The manner in which the subject moved toward the piece of tape (target) was scored according to the criteria listed in Table 2. The procedure was then repeated until each of the six randomly ordered positions was scored. Only one trial per position was allowed. 

The second test measured the amount of synergistic influence on the subject's motor responses. After instructing the unblindfolded subject on the procedure, the examiner demonstrated to the subject, in random order, one of the four test positions in Table 3. After each demonstration, the examiner asked the subject to assume, using the affected upper extremity, the position just demonstrated. If the subject was unable to duplicate the test position, the experimenter passively placed the subject's extremity into the test position and asked the subject to maintain this position. If the subject was able to assume or maintain the test position, the experimenter then asked him to hold the shoulder component of the position while attempting to reciprocate the most distal component of that position. For example, in test position one, the subject was asked to maintain the shoulder abducted to 80 to 90 degrees in the coronal plane while alternately flexing and extending his elbow through a range of about 90 degrees. The same procedure was repeated for the other test positions and scored according to criteria in Table 4. For each of the two tests, the average value of the scores was used in the data analysis.

A pilot investigation was performed to measure interexaminer reliability of the two tests. The sample included two normal subjects and four subjects with paralytic brain lesions. Average ages were 36 years and 52 years, respectively. Both examiners, examining independently, consecutively, and in random order, used the testing instrument described previously. The intraclass correlation coefficient for the scores given by each of the examiners was .54 for the sensory test and .90 for the motor test. The Spearman rank correlation coefficient was used in the data analysis.

| TABLE 3 |
| Positions for Testing the Ability to Combine Elements from the Limb Synergies |

<table>
<thead>
<tr>
<th>Position No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shoulder abducted to approximately 80°–90° in the coronal plane, elbow extended fully, forearm in free position</td>
</tr>
<tr>
<td>2</td>
<td>Approximately 40° of shoulder extension, 80°–90° internal rotation with elbow flexed to 70°–80°, arm not in contact with back, forearm in free position</td>
</tr>
<tr>
<td>3</td>
<td>Shoulder flexed to approximately 60°, elbow fully extended, forearm supinated to 80°–90°</td>
</tr>
<tr>
<td>4</td>
<td>Shoulder flexed without rotation to approximately 80°, elbow flexed to 80°–90°, forearm in free position</td>
</tr>
</tbody>
</table>

RESULTS

Table 5 shows the mean scores and the rank order for each of the tests. The correlation between Test 1 and Test 2 was .83 (p < .01). These results indicate a relationship between the perception of joint position sense and the degree of synergistic dominance in the upper extremity of individuals who are well into their recovery phase after hemispheric brain damage.

DISCUSSION

Clinical observation of patients with hemiplegia caused by hemispheric brain lesions leaves an impression of a relationship between the perception of joint position sense and the ability to combine elements of the limb synergies. This study has demonstrated this relationship.

One possible explanation for such a relationship can be given in terms of motor learning. Michels, after studying 48 normal subjects, suggested that clini-
development in the ability to combine elements of the limb synergies may constitute motor learning. If these results can be generalized to include the recovery phase following hemispheric produced paralysis, then the quality and quantity of movement-produced feedback becomes critical.

According to Adams’ theory of motor learning, feedback is necessary in error correction and in aiding the formation of the perceptual trace. This perceptual trace is a combination of immediate feedback on the momentary position of the limb, information about the error in the last movement, and references of past movements of that same limb. The beginning of a movement brings an anticipatory arousal of the perceptual trace with which the feedback from that movement is compared. According to Adams, the strength of the perceptual trace is a positive function of experiencing feedback of which proprioception is an important element. Thus, learning becomes a process of strengthening the perceptual trace and then matching a motor response to this trace. Without correct or inadequate feedback, the process of developing and strengthening a perceptual trace is made more difficult and perhaps could act as a limiting factor in the recovery of motor ability following hemiplegia.

A striking dissimilarity exists between the results of our investigation and the Kent study. The discrepancies between these two investigations is in all probability a result of the methods used. In the conclusion of her paper, Kent stated that her results showed little correlation between motor and sensory loss. However, she also stated that with refinements of the testing instruments, better correlation between partial sensory and motor losses could be expected. Kent suggested that future sensory and motor tests should not be scored solely on the end result of a response, but should also be scored according to the manner in which this response was performed. In Test 1 of our investigation, the way the subject reached out into space to locate a target was considered in the scoring rather than solely scoring the distance by which the target was missed. This modification of the sensory test could have made it more sensitive, and thus affect the correlation.

If indeed the relationship between motor recovery and perception of joint position is mediated by the process of learning, then sensory perception following a brain lesion may be an important prognostic indicator for motor recovery. This possibility, however, would need further investigation through a longitudinal experimental design to follow both sensory perception and motor recovery over the entire recovery period.

As a number of investigators have determined, deafferented monkeys have been trained to perform tasks that involve a high degree of motor control. These results apparently contradict the results of our study until one considers which systems were lesioned in each of the studies. In the studies with deafferented monkeys, sensory input was interrupted before entering the CNS and without interrupting any of the motor tracks directly. In our investigation, lesions were within the CNS and involved both the motor and sensory systems to varying degrees. In both cases, the lesions were sufficient to produce hemiplegia.

The hemiplegia that resulted from the pure sensory lesions in the monkeys was considered for many years to be permanent. Not until the 1950s were researchers, with the aid of conditioning, able to encourage these monkeys to move their deafferented extremities in a purposeful manner. From this information, it would appear that total sensory lesions are capable of producing severe and lasting paralysis unless the process is interrupted by aggressive treatment. If a lesion directly affecting the motor system is then added to the already existing sensory lesion, recovery may be more difficult. If this phenomenon does exist, it would explain the discrepancy between the deafferented monkey studies and the present investigation. Perhaps, in order for a positive relationship between sensory perception and motor control to exist, a lesion in the motor system must be present. If indeed this is the case, a person who suffers a primary motor system lesion with concurrent sensory deficit will demonstrate a higher relationship between motor control and the perception of joint position sense than will a person with a similar sensory loss but with a less severe motor system lesion. This concept would also
have to be tested in a longitudinal design with the degree of primary dysfunction of each of the sensory and motor systems being known.

Care must be taken when interpreting the results of this study. Currently, no prognostic use of the results can be made inasmuch as no measurement was made of how the relationship between perception of joint position sense and limb synergies changes over time. The results only show a relationship between the perception of joint position sense and motor ability in subjects who are well into their recovery phase. Caution must also be used when applying this relationship to hemiplegic patients with more or less pure sensory lesions because this relationship may not hold true for these patients.

Many physical therapy approaches are based on the assumption that the motor and sensory systems are interrelated. The results of this investigation support this assumption and may eventually lead to more realistic goal setting for hemiplegic patients with hemispheric brain lesions.

From a clinical standpoint, the results of this investigation would indicate that a thorough evaluation of both the sensory and motor systems should be completed on all patients with hemispheric brain lesions. These two systems are apparently related in the sense that the level of function of one system may be dependent upon the level of function of the other. A poor score on the sensory examination may indicate insufficient sensory processing to allow normal motor activity to develop. In order to improve an individual's motor function, treatment should be directed toward both the sensory and motor systems.

This study, although limited in scope and purpose, has provided a basis for more comprehensive research as applied to problems of patients with CNS deficits. The testing instruments developed provide a valid and reliable method of assessing both perception of joint position sense and the degree of synergistic dominance within a limb. These tests, which use only common equipment and require minimal time, should provide an instrument to further evaluate the efficacy of treatment techniques.

CONCLUSION

This study demonstrated a high correlation between the perception of joint position sense and the ability to combine component parts of the limb synergies in hemiplegic patients who are well into the recovery phase.

REFERENCES