Tracking Ability of Hemiparetic and Healthy Subjects

The purpose of this descriptive study was to investigate differences in tracking ability between the involved and uninvolved hands of hemiparetic (n = 10) and healthy (n = 10) subjects. The subjects tracked a sine-wave target pattern by flexing and extending their index finger metacarpophalangeal joints. The amplitudes of the target patterns were proportional to each subject's active range of motion. The root-mean-square (RMS) of the vertical distance between the target and response lines was expressed as a percentage of the RMS of the target pattern and subtracted from 100 to give an index of each subject's accuracy. The authors used t tests to compare the uninvolved and involved hands of the hemiparetic subjects (p > .05), the dominant and nondominant hands of the healthy subjects (p > .05), and the uninvolved hands of the hemiparetic subjects with the dominant hands of the healthy subjects (p < .005). This study indicates that within the available active ROM, finger tracking ability is impaired bilaterally in hemiparetic subjects. The implication for physical therapists is that treatment strategies for improving motor control should be directed bilaterally. [Halaney ME, Carey JR: Tracking ability of hemiparetic and healthy subjects. Phys Ther 69:342–348, 1989]

Key Words: Hand; Hemiplegia, evaluation; Motor skills; Psychomotor performance; Tests and measurements, functional.

An important component of stroke rehabilitation is objective evaluation of sensorimotor function. Physical therapists are able to quantify range of motion and muscle strength fairly reliably1-5; however, the objective measurement of integrated sensorimotor control is more elusive.

Computerized tracking provides a means of quantifying one aspect of integrated perceptual motor function. Tracking involves the attempt by a person to follow or trace a target pathway with an object by appropriately manipulating a device with some body part. Tracking, therefore, requires attentive visuosensory monitoring in combination with appropriate adjustment of joint position, a process involving closed-loop control. This kind of sensorimotor feedback processing is used throughout an individual's daily activities.

Tracking has been used fairly extensively in the behavioral sciences and in the military for measuring eye-hand coordination or control.6-9 Its application to medicine, however, has been limited.7,10,11 DeSouza et al found a high correlation between tracking ability of the involved elbows of stroke patients and clinical assessment of their arm and hand function.12 Jones and Donaldson demonstrated neurological recovery in stroke patients using steering-wheel tracking.13 Heilman et al demonstrated impaired motor learning in apraxic hemiplegic patients using rotary pursuit tracking.14

Upper limb dysfunction following cerebrovascular accident (CVA) often involves primarily the wrist and fingers.15 None of the previous tracking studies, however, have documented the effects of CVA on finger

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tracking ability. Tracking is an important test of perceptual motor function that can provide valuable information regarding changes in fine motor control following CVA.

The purposes of this descriptive study were 1) to compare finger tracking performance of hemiparetic subjects with that of healthy subjects, 2) to compare tracking performance of the involved hands with that of the uninvolved hands of hemiparetic subjects, and 3) to compare tracking performance of the dominant hands with that of the nondominant hands of healthy subjects. We expected to observe impaired tracking performance only in the involved hands of the hemiparetic subjects.

**Method**

**Subjects**

Ten subjects with hemiparesis and spasticity (4 female, 6 male) and 10 subjects with normal hand function (6 female, 4 male) participated in this study. Five of the hemiparetic subjects had left-side involvement, and five had right-side involvement. The hemiparetic subjects each met all of the following criteria.

They all had a history of at least one CVA. The mean time since the most recent CVA for these subjects was 41.4 ± 22.8 months.

They each had minimal to moderate flexor muscle spasticity of the index finger. This spasticity was defined as minimal to moderate resistance to a slow, gentle stretch imposed passively on the index finger flexor muscle by the tester, with the wrist in a neutral position.

They were each able to actively extend the index finger metacarpophalangeal (MP) joint through at least 20 degrees of motion, measured goniometrically. Some subjects were able to isolate this motion, whereas for others it was part of a synergistic pattern.

They all demonstrated the ability to see the cursor on the computer monitor by carrying out the following task correctly. A horizontal line was presented on the monitor, and they were asked to position the cursor on the line by correctly positioning an electrogoniometer affixed to the index finger MP joint. Finally, they all demonstrated understanding of how to perform the task through verbal responses or demonstration.

The healthy subjects all denied having problems with their index fingers, and none demonstrated resistance to passive finger extension. All were faculty or staff members at the University of Minnesota.

The mean age of the hemiparetic subjects was 62.9 ± 12.7 years, and that of the healthy subjects was 50.9 ± 12.5 years. All of the hemiparetic subjects and all but one of the healthy subjects were right-handed. An informed consent form was read and signed by each subject.

**Instrumentation**

The pursuit tracking device used in this study is composed of an electrogoniometer, an analog-to-digital converter,* and an Apple IIe personal computer† (Fig. 1). The electrogoniometers used in this study were calibrated to be accurate to within 1 degree over a range of 0 to 90 degrees.

The computer program produces a sine wave target pattern on the computer monitor. The peak-to-peak amplitude of the sine wave is set at 70% of each subject's total available active index finger MP joint flexion-extension ROM, as shown in Figure 2. The vertical midpoint of the sine wave's amplitude represents the mid-
Fig. 2. Target pattern for tracking task. The peak-to-peak amplitude of the sine wave is 70% of the subject's available range of motion. The target pattern starts at the left side of the screen at the midpoint of the subject's available ROM, then alternately rises to the maximal extension angle and falls to the maximal flexion angle.

Fig. 3. Example of tracking response pattern for a hemiparetic subject. This subject had 56 degrees of flexion-extension range of motion at the index finger of the involved hand. Thus the peak-to-peak amplitude of the target pattern is 70% of 56 degrees, or 39.2 degrees. The cursor crosses the screen in 10 seconds.

Error Measurement

The total error (E) between the target and response lines is obtained by calculating the root-mean-square (RMS) value of the vertical distance between the target and response lines at each of 256 points across the screen. The RMS is calculated as follows. The vertical distance (in degrees) between the target and response lines at each point is squared. The mean of the 256 squared values is determined, and the square root of this mean is the RMS value. The total error, expressed as a percentage of the RMS value of the target pattern (P) and subtracted from 100%, gives a relative index of the subject's level of accuracy (AI = 100 - 100[E/P]). Thus the possible range of AI scores is from 0% to 100%.

For the extension phase, or that part of the sine wave that represents the extended part of the available ROM, the value of the target pattern equals the RMS value between the target and the horizontal line representing full extension. Thus the value of the target pattern is equal for both phases.

By using the normalized AI score, as opposed to the raw error score, the effect of differences in ROM among subjects is cancelled because the target line's amplitude is based on the subject's available ROM at the start of each test. Thus performance on the tracking task represents sensorimotor control within the available ROM.

Procedure

The order of testing for the two hands was randomly assigned such that half the hemiparetic subjects started with the spastic, or involved, hand and half the healthy subjects started with the dominant hand. We determined hand dominance in the healthy subjects simply by asking them which hand was dominant, and in no instance was there any indication by the subjects of mixed hand dominance.

Each subject was then seated comfortably in a chair or wheelchair with the test forearm resting on the subject's lap. If necessary for comfort, a pillow was placed on the subject's lap (Fig. 1).

In pilot studies on hemiparetic subjects, stabilization of the thumb and forearm was attempted using a splint to maximize standardization of the testing situation. Such stabilization significantly interfered with active movement of the index finger and created an excessively artificial testing situation. Some of the hemiparetic subjects had so much spasticity in the thumb that it interfered with index finger motion. The thumb of these subjects was held in abduction by the tester (MEH) or by the subject, whichever allowed the subject to actively extend and flex the index finger through the greatest ROM. The tester observed the subject's hand carefully throughout the test to ensure that no other assistance was provided by the subject's opposite hand.
The electrogoniometer then was securely strapped to the test hand, one strap around the wrist and one around the proximal phalanx of the index finger. The axis of the electrogoniometer was aligned over the sagittal axis of the index finger MP joint and did not slide during active extension and flexion of the joint. The subject was then asked to flex the index finger MP joint as far as possible. This flexion was followed by maximal active extension. The computer thus recorded each subject's active ROM.

The subject was then instructed in performance of the tracking task and was allowed at least three practice trials. Some of the hemiparetic subjects needed more than three practice trials to fully understand the task. For all the hemiparetic subjects, the number of practice trials allowed ranged from three to six.

The tester did not speak to the subjects during the task, but answered questions between trials. Each subject was allowed to rest 30 seconds between trials while the computer calculated the AI scores. After the practice trials, each subject performed two test trials.

**Data Analysis**

Two-tailed paired \( t \) tests were used to analyze the differences in performance between the involved and the uninvolved hands of the hemiparetic subjects and between the dominant and nondominant hands of the healthy subjects. The hemiparetic subjects were compared with the healthy subjects using a two-tailed Welch's approximation to the \( t \) test because the variances of the two groups were significantly different \((p < .001)\). The dominant hands of the healthy subjects were compared with the uninvolved hands of the hemiparetic subjects because these are the preferred hands for each group. Likewise, neither the nondominant nor the involved hands are preferred for functional use, so their tracking performance was compared.

**Method**

Reliability was evaluated by comparing AI scores for the first and second test trials of each hand. Intraclass correlation coefficients (ICC(3,1)) are given in Table 1. The ICCs for the hemiparetic subjects were high, but the correlations for the healthy subjects were low, in part because of the much lower variability in this group. The mean differences between trial 2 and trial 1 for the groups were all less than 3%. Paired \( t \) tests were used to compare the scores for trial 1 with those for trial 2, and the differences were not significant with the exception of the healthy subjects' dominant hands \((p < .005)\). This difference was significant because 8 of the 10 subjects improved from trial 1 to trial 2, whereas the other subgroups for handedness did not show a learning tendency.

We found no significant difference in tracking performance between the involved and the uninvolved hands of the hemiparetic subjects or between the dominant and nondominant hands of the healthy subjects (Tab. 2). The AI of the hemiparetic subjects was significantly lower than that of the healthy subjects. This difference was found by comparing the healthy subjects’ dominant hands with the hemiparetic subjects’ uninvolved hands \((p < .005)\) and by comparing the healthy subjects’ nondominant hands with the hemiparetic subjects’ involved hands \((p < .002)\).

Qualitatively, the healthy subjects’ responses were very similar, but the hemiparetic subjects’ response patterns varied considerably. Figure 4 gives one example of a response by a healthy subject and two examples of responses by hemiparetic subjects.

**Discussion**

The purposes of this study were to investigate differences in tracking ability between 1) the involved and uninvolved hands of hemiparetic subjects, 2) the dominant and nondominant hands of healthy subjects, and 3) hemiparetic and healthy subjects. We expected to find impairment only in the involved hands of the hemiparetic subjects. To the contrary, we observed bilateral impairment in the hemiparetic subjects.

This finding was surprising because simple observation of hand function revealed obvious hemiparesis in all subjects in this group. Previous studies have also revealed impaired function of the apparently uninvolved hands of hemiparetic subjects. Jebsen et al tested the hand function of 12 right-handed stroke patients, all of whom demonstrated unilateral brain involvement through detailed neurologic examination and electroencephalograms and none of whom were receiving psychotropic medications.17 The subjects’ performance of seven discrete functional tasks (eg, writing, eating) was timed. The uninvolved (premorbidly dominant) hands of the left-hemiparetic subjects performed slower than the dominant hands of healthy subjects on three of the seven tests, and the uninvolved (premorbidly nondominant) hands of the right-hemiparetic subjects performed

Table 1. Test-Retest Gains and Intraclass Correlation Coefficients (ICC) for Accuracy Index Scores of Hemiparetic and Healthy Subjects

<table>
<thead>
<tr>
<th>Group</th>
<th>Hand</th>
<th>Gain (%)</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemiparetic (n = 10)</td>
<td>Involved</td>
<td>0.04</td>
<td>.82</td>
</tr>
<tr>
<td></td>
<td>Uninvolved</td>
<td>1.64</td>
<td>.97</td>
</tr>
<tr>
<td>Healthy (n = 10)</td>
<td>Nondominant</td>
<td>0.58</td>
<td>.62</td>
</tr>
<tr>
<td></td>
<td>Dominant</td>
<td>2.83*</td>
<td>.59</td>
</tr>
</tbody>
</table>

*\(p < .05\).*
A review of the literature identified weaknesses as compared with comparable healthy subjects. They were not able to state whether this weakness was due to disuse or to an ipsilateral effect of their brain lesions.

A review of the literature identified few studies that investigated tracking ability of hemiparetic subjects. None were found that eliminated the effect of available ROM. Wyke studied patients with unilateral brain lesions. Unlike the hemiparetic subjects in our study, her subjects had not sustained CVAs and did not have motor impairment. She found that subjects with right brain lesions who did not have visual field defects demonstrated only contralateral tracking impairment, whereas those with left brain lesions demonstrated bilateral impairment of tracking ability. She also found that all subjects with visual field defects demonstrated bilateral impairment of tracking ability. Visual field was not evaluated in our study.

Kimura studied 45 patients with unilateral CVAs and found more error by the uninvolved hands of right-hemiplegic subjects than by the uninvolved hands of left-hemiplegic subjects. The task she used involved moving the arm and hand through a particular sequence of motions including pressing a button with the index finger, pulling a vertical bar with all four fingers, and pressing a horizontal bar with the thumb. The subjects performed the tracking task with their uninvolved hands only, and neither group was compared with healthy subjects.

In this study, we found bilateral impairment in both left- and right-hemiparetic subjects. The tracking task used for this study is quite different from those described above. Wyke measured the number of times each subject failed to make contact with a series of discrete targets. Kimura measured the amount of time each subject required to complete the sequence of hand motions. In contrast, the tracking system used in this study measures the amount of error between each subject's response and the target and is thus a more sensitive measure of tracking performance. In addition, this was the first study to investigate isolated finger tracking ability, which may differ from the ability to track using more gross movements of the entire upper limb.

Although this study revealed bilateral impairment, it did not identify which components of perceptual motor control were dysfunctional. It also did not distinguish between effects of perception and effects of motor function. These are areas that should be investigated further.

The responses of the hemiparetic subjects were much more varied than those of the healthy subjects, as indicated by the significantly different standard deviations of the two groups. No pattern emerged regarding the type of error made with the involved and uninvolved hands of the hemiparetic subjects. For example, in some instances the error was primarily due to overshooting or undershooting the target, whereas in others the error was primarily due to a phase shift in which the subject consistently responded either too early or too late with respect to the target pattern. Overall error RMS, as measured in this study, is a combination of amplitude and timing error. These are two different components of control, which were not measured separately in this study. The sine wave target pattern used for this study does not allow for a distinction between amplitude and timing error. These variables could be distinguished using a step mode pattern.

The sine wave was selected because it is more representative of the functional movements that typically occur at the MP joint. A fundamental difference between the tracking task and functional activities, however, is that functional activities are usually self-paced. Tracking tasks can be devel-

### Table 2. Accuracy Index Scores (in Percentages) of Hemiparetic and Healthy Subjects

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Hemiparetic Subjects (n = 10)</th>
<th>Healthy Subjects (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Involved Hand</td>
<td>Uninvolved Hand</td>
</tr>
<tr>
<td>1</td>
<td>83.92</td>
<td>81.76</td>
</tr>
<tr>
<td>2</td>
<td>61.81</td>
<td>43.44</td>
</tr>
<tr>
<td>3</td>
<td>45.04</td>
<td>48.06</td>
</tr>
<tr>
<td>4</td>
<td>65.14</td>
<td>67.29</td>
</tr>
<tr>
<td>5</td>
<td>60.81</td>
<td>62.21</td>
</tr>
<tr>
<td>6</td>
<td>79.92</td>
<td>72.15</td>
</tr>
<tr>
<td>7</td>
<td>54.28</td>
<td>42.34</td>
</tr>
<tr>
<td>8</td>
<td>80.63</td>
<td>72.86</td>
</tr>
<tr>
<td>9</td>
<td>72.18</td>
<td>89.88</td>
</tr>
<tr>
<td>10</td>
<td>84.13</td>
<td>87.76</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
\bar{X} & = 68.78 & 66.77 & 87.45 & 87.76 \\
s & = 13.49 & 17.56 & 2.61 & 2.83 \\
p & \approx 0.542 & \approx 0.005 & \approx 0.672 & \\
p & \approx 0.002 & \\
\end{align*}
\]

*Significance level set a priori at .05 alpha level.
Fig. 4. Examples of tracking responses by a healthy subject's nondominant hand (top) and by two hemiparetic subjects' involved hands (center and bottom).

cluded that allow for self-pacing by the subject, and these tasks might be advantageous for patient training. With this kind of task, the cursor speed would be determined by the speed at which the subject moved the MP joint. This kind of task would not be useful for research because it is likely that if the subject could move the cursor as slowly as desired, there would be little or no error. That is, to assess error, speed must be controlled.

Another limitation of the tracking system used in this study is the very short duration of the task. A tracking task that lasts only 10 seconds may not be adequate for demonstrating response pattern trends. For example, it might not reveal tendencies for progressive lags in the response line, or decreasing extension ROM with successive repetitions, something frequently observed in clinical work with hemiparetic patients.

To allow for a long duration of the tracking task, a moving target pattern is required. Such systems have been described by several authors. Bowen et al used a pulley system to move a light behind a glass screen in a random pattern. An oscilloscope with a pseudorandom pulse generator was used by Potvin et al. Jones and Donaldson described a system composed of a computer with a dynamic graphics display unit. The computerized system is most advantageous in that it allows rapid calculation of error values; however, it is also the more expensive system.

Conclusions

Finger tracking ability was impaired bilaterally in hemiparetic subjects following CVA. The results of this study have major implications for the rehabilitation of patients who have sustained CVAs. Specifically, rehabilitation should be directed toward improving sensorimotor control bilaterally.

References

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