The Effect of Upper Extremity Trauma on Handedness

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Key Words: activities of daily living • hand injuries • laterality • motor skills

The effect of severe trauma on handedness was studied through patient responses from 146 questionnaires that were correlated with individual chart review. Subjects were asked to designate their hand use preference, before and after injury, when performing 16 activities. The incidence of change in hand use was determined within four diagnostic types and five designated anatomical levels of injury. Results indicated a significant difference in the way subjects in different diagnostic types and anatomical levels of injury performed. Simple, short activities that did not require sustained fine motor coordination were reported as being performed more easily with a different hand after injury than complex, continuous activities that required sustained fine motor coordination. Significant differences in job duties and place of employment were found for the anatomical level of an injury but not for diagnostic type. Findings suggest that the diagnostic type, the anatomical level of an injury, and the complexity of a task should be considered before changes in hand use are recommended.

Minimal information is available to assist therapists in knowing when certain types of upper extremity injuries will be likely to necessitate a change in hand use. Surveying patients after injury allows one to assess the actual effect an injury has had on hand use. It is hoped that this information will aid the therapist in guiding the patient's selection of hand use for daily activities.

Literature Review

A critical area of occupational therapy intervention lies within the restoration, promotion, or reallocation of gross and fine motor skills in the upper extremity. However, a scarcity of information exists that defines the exact indications for developing specific functional skills with a nondominant extremity after injury to the dominant extremity. There is no definitive information that identifies either the appropriate methods to achieve these skills or the preferred timing for such training.

Literature exists regarding the nature of motor learning (Anderson, 1990; Kleinman, 1983), the development of prehension (Rosenbloom & Horton, 1971), handedness (Annett, 1968; Subriana, 1969), and the effects of practice on skill development (Denckla, 1973). Most of the literature describing how new motor skills are learned has come from the areas of psychology and physical education. These disciplines have advanced theories to explain the process and have studied various aspects of motor learning, such as timing of practice sessions and the ability to transfer motor skills (Anderson, 1990; Elliott & Connolly, 1974; Fitts, 1964).

According to Guthrie (1952) and Smith and Smith (1966), motor skill acquisition is learned by the constant association between a stimulus and a response, with continuous adjustments made by the body until a standard response becomes associated with a standard stimulus. These motor responses may constitute what we define typically as skills. Elliott and Connolly (1974) described skill as "the organization of actions into a purposeful plan which is executed with economy" (p. 135). The entire skill may be composed of many subroutines, as seen with writing in the formation of each letter or stroke. Anderson (1990) and Fitts (1964) reported that the process of learning new motor skills occurs in three phases. Anderson (1990) described these phases as being: "(1) a cognitive stage, in which a description of the procedure is learned; (2) an associative stage, in which a method for performing the skill is worked out; and (3) an autonomous stage, in which the skill becomes more rapid and automatic" (p. 258).

Rosenbloom and Horton (1971) described a general development of prehension skills in which the hand is first used in a nonspecific manner and later is used in specialized patterns. Although animal species with paired structures develop laterality, the concise relationship be-
tween lateral dominance and cerebral specialization is not clearly understood. It can be seen, however, that the preferential use of one of a paired set of structures can, over time, allow greater proficiency at a given task (Subriana, 1969). Several authors (Annett, 1968; Satz, Nelson, & Green, 1989; Subriana, 1969) have suggested that handedness is most accurately represented by a continuum ranging from the one extreme of pure right-handedness to the other extreme of pure left-handedness. Even though the selection of a preferred hand is thought to be genetically predisposed (Touwen, 1972), persons with congenital absence of the upper limb have shown that handedness can be developed in either upper extremity, thus demonstrating the human capacity for adaptation.

For the adult, unlike the child, learning of feeding skills or writing with a nondominant extremity is not a new task; it is the acquisition of an ability to use a new body part for a previously mastered task. Learning transfer involves the effects of a previously acquired skill on the acquisition of a succeeding skill. The effects can be either positive or negative. The amount of learning transfer is found to be a function of stimulus similarity (Deese, 1958). According to Fairclough (1952) and others (Koh & Roenker, 1980; Michels, 1970), most motor skills are specific. There is little support for the idea that a general coordination could be developed that would transfer from task to task.

Although authors (Book, 1973; Kleinman, 1983; Kottke, Halpren, Easton, Ozal, & Burtill, 1978) have investigated the area of practice in the development of motor skills, none have specifically examined the effect of practice on changing hand use. Olsen (1980), Newman (1982), Pendleton (1972), and Gardner (1966) have written manuals or described techniques to be used when training specific skills such as writing, but research on the efficacy of these techniques has not been reported.

Several authors (Apfel, 1990; Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969) have examined methods of evaluating functional hand use after injury and others (Apfel, 1990; Fess & Moran, 1981; Jebsen et al., 1969; Smith, 1973) have developed tests involving bilateral performance of motor skills that compare the injured extremity to the uninjured extremity in a variety of prehension patterns. But none of these publications provides specific implications for task performance by the nondominant extremity after injury to the dominant extremity or addresses clinical relevance to change in hand use.

Meyer (1991) cited the importance of identifying the type and number of structures involved, and Hollis (1978) indicated that severe injuries require functional adaptations to recover from both motor and sensory loss. Determining which types of injury result in a change in handedness should identify patients who need assistance with these adaptations.

The anatomical level of an injury has long been recognized as a predominant factor in the determination of functional recovery from a severe injury (Meyer, 1991). Studies reporting results of upper extremity nerve lacerations indicate the significance of the level of the injury (Omer, 1974; Stanley, 1990). The more proximal the level of nerve injury, the greater the number of structures affected. Replantations at more proximal anatomical levels such as the forearm had less recovery of sensation, range of motion, and strength than replantations at more distal levels such as the wrist (Meyer, 1985; Zhong-Wei, Meyer, Kleinert, & Beasley, 1981). Historically, for trauma involving flexor tendons, the anatomical level of injury significantly determined both the management and the functional outcome of these repairs (McKay, 1980). None of the studies cited above, however, addressed change in handedness.

Study Purpose

The purpose of this study was to investigate the effect that traumatic injury had on handedness. Specific research questions were

1. What is the frequency that specific activities are reported as being performed with a different hand after an injury to the dominant extremity than before the injury?
2. What is the frequency within four diagnostic groups that hand use changed after traumatic injury?
3. Does the occurrence of a injury at a certain anatomical level have an effect on handedness?
4. What effect does upper extremity trauma have on employment status?

Method

Subjects

One hundred forty-six patients between the ages of 18 and 65 years, from two regional hand centers, served as subjects. All subjects injured their dominant upper extremity within the 6 years immediately preceding initiation of data collection.

Study selection criteria required subjects to be at least 1 year post severe injury, 1 year from their last surgery when applicable, and 1 year from hand therapy discharge. These intervals were chosen to allow sufficient time for tissue response to injury and subsequent changes in hand use to stabilize. Patients with bilateral injuries or preexisting medical conditions known to affect upper extremity functioning (i.e., diabetes, collagen disorders, cerebrovascular accident) were excluded from the study.

Subjects were assigned to one of four diagnostic groups depending on the type of injury. Selection of the four diagnostic groups was based on the researchers' judgment that certain types of injuries were among those...
most likely to result in a change of hand use. Subjects who could not be clearly assigned to only one of the groups were excluded from the study. Operational definitions for the four selected groups were as follows:

- **Peripheral nerve injury**: an injury to the median, ulnar, or radial nerve (or a combination of these), no more than one artery or wrist tendon, and only superficial soft tissue injuries.
- **Revascularization or replantation**: an injury to at least one of each of the following structures: nerve, artery, tendon, and bone.
- **Multiple digit flexor tendon injury**: an injury to the flexor tendon or tendons of two or more digits.
- **Crush injury**: an injury to the bone and soft tissue without tendon or nerve severance.

Once categorized by diagnostic type of injury, subjects were then assigned or grouped by anatomical level of injury. Five levels of injury were selected by use of anatomical landmarks and universal classification of tendon repair zones. If injuries occurred at multiple anatomical levels, the subject was assigned to a group according to the most proximal level of the injury. Operational definitions for the five levels of injury were as follows:

- **Forearm**: includes injuries to the forearm, elbow, and arm, not including the gleno-humeral joint.
- **Wrist**: includes injuries to the carpus and the distal radial-ulnar joint.
- **Metacarpal**: includes injuries to the metacarpal and the metacarpal-phalangeal (MP) joint.
- **Proximal phalanx**: includes injuries from the proximal phalanx up to but not including the distal interphalangeal (DIP) joint.
- **DIP**: includes injuries from the DIP joint to the fingertip (see Table 1).

### Instruments

A questionnaire and a chart audit were used to collect the data. A cover letter and the patient questionnaire were critiqued by a medical records specialist to determine whether reading level and content were appropriate for the selected subjects. In addition, the letter and questionnaire were screened by current patients who qualified in the same diagnostic groups but were not eligible for participation in the study because of the date of their injuries or surgeries.

Specific information requested in the questionnaire included identification of the extremity injured, injury date, surgical date or dates, and effect of injury on the person's job duties, employment, and occupation. Also, subjects were asked to identify which hand they previously used before injury and which hand they currently used for a list of 16 activities. The list included 10 functional activities used in the Edinburgh Handedness Inventory (Oldfield, 1971). Six other functional activities were selected from other handedness inventories and activities of daily living (ADL) indexes (Annett, 1968; Belding & Walsh, 1985; Harris, 1972; Price, 1954; Suchenwirth, 1969; White & Ashton, 1976) because of their reported value as hand preference indicators (i.e., using a hammer, turning a key, and handing out coins).

In addition to reporting their hand use for these specific activities, subjects were asked to state what their hand preference was before and after the injury and the length of time for which it was affected.

The chart audit form was developed to establish the level of injury, identify which specific anatomical structures were injured, confirm reported dates, and verify subject eligibility for the study. This information was used to place subjects in one of the four diagnostic groups cross-referenced by level of injury.

### Procedure

Data were collected after project approval by the Human Subjects Research Committee at Duke University Medical Center. Potential subjects with injury to their dominant extremity were identified through computer and manual search of registration records and then selected for the study on the basis of the investigators' ability to classify them into one of the four diagnostic groups. The 487 patients selected were sent an initial mailing. Those who did not return the mailing within 3 weeks were sent a follow-up letter.

### Table 1

**Number of Subjects in Each Diagnostic Type Subdivided by Anatomical Level**

<table>
<thead>
<tr>
<th>Anatomical Level</th>
<th>Forearm</th>
<th>Wrist</th>
<th>Metacarpal</th>
<th>Proximal</th>
<th>DIP</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nerve</td>
<td>14</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>28</td>
</tr>
<tr>
<td>Replant and revascularize</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>25</td>
<td>3</td>
<td>45</td>
</tr>
<tr>
<td>Flexor tendon</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>Crush</td>
<td>7</td>
<td>13</td>
<td>12</td>
<td>21</td>
<td>9</td>
<td>62</td>
</tr>
<tr>
<td>Total</td>
<td>29 (20%)</td>
<td>26 (18%)</td>
<td>25 (17%)</td>
<td>54 (37%)</td>
<td>12 (8%)</td>
<td>146 (100%)</td>
</tr>
</tbody>
</table>

Note: DIP includes injuries from distal interphalangeal joint to the fingertip.

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Tables 2, 3, and 4). When the cell size was not large enough to compute \( \chi^2 \) analyses, the two-tailed Fisher's Exact Test was used.

Thirty-two analyses were conducted, 16 for type of injury and 16 for level of injury. All analyses resulted in significant differences of at least \( p \leq .05 \), except for three tasks within the analyses for level of injury.

Removing a box lid, hammering, and using scissors were not significantly different across the five levels of injury. Except for those three tasks, it can be stated that a significant difference exists in the way subjects in the different anatomical levels and diagnostic types performed in comparison with subjects in other levels and types. For example, significantly more subjects with forearm injuries used the noninjured hand to open a door after injury than did subjects with DIP level injuries. Significantly more subjects with a peripheral nerve injury used the noninjured hand to hold a toothbrush than did subjects with a crush injury.

To make the determination that significant differences existed within the diagnostic types and anatomical levels of injury, a change score was created to reflect the difference between performance on the 16 tasks before and after injury. The total number of activities performed before the injury with the dominant hand minus the total number of activities performed with the nondominant hand was called the before-injury score. The same procedure was used for the after injury performance to create an after-injury score. An overall change score was then derived by subtracting the before-injury score from the after-injury score. Results were tabulated with a positive number to ease comprehension.

Due to the lack of normality in the data, nonparame-
Table 4
Frequency of Hand Use Change After Injury for the 16 Activities According to Anatomical Level

<table>
<thead>
<tr>
<th>Activity</th>
<th>Fore/arm</th>
<th>Wrist</th>
<th>Metacarpal</th>
<th>Proximal</th>
<th>DIP</th>
<th>P = *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coins</td>
<td>143</td>
<td>8/29</td>
<td>28</td>
<td>1/24</td>
<td>4</td>
<td>0.005*</td>
</tr>
<tr>
<td>Screws</td>
<td>134</td>
<td>11/27</td>
<td>41</td>
<td>5/22</td>
<td>23</td>
<td>0.010**</td>
</tr>
<tr>
<td>Box</td>
<td>135</td>
<td>14/27</td>
<td>52</td>
<td>6/23</td>
<td>26</td>
<td>NS</td>
</tr>
<tr>
<td>Door</td>
<td>136</td>
<td>14/27</td>
<td>48</td>
<td>7/21</td>
<td>33</td>
<td>0.016**</td>
</tr>
<tr>
<td>Key</td>
<td>141</td>
<td>14/27</td>
<td>48</td>
<td>8/24</td>
<td>33</td>
<td>0.017</td>
</tr>
<tr>
<td>Light</td>
<td>137</td>
<td>12/28</td>
<td>43</td>
<td>2/22</td>
<td>9</td>
<td>0.000</td>
</tr>
<tr>
<td>Broom</td>
<td>121</td>
<td>10/22</td>
<td>45</td>
<td>5/20</td>
<td>25</td>
<td>NS</td>
</tr>
<tr>
<td>Hammer</td>
<td>137</td>
<td>8/27</td>
<td>30</td>
<td>5/25</td>
<td>20</td>
<td>0.006</td>
</tr>
<tr>
<td>Knife</td>
<td>135</td>
<td>10/27</td>
<td>37</td>
<td>5/22</td>
<td>23</td>
<td>0.032</td>
</tr>
<tr>
<td>March</td>
<td>137</td>
<td>11/28</td>
<td>39</td>
<td>4/24</td>
<td>17</td>
<td>0.019</td>
</tr>
<tr>
<td>Thyrone</td>
<td>137</td>
<td>13/28</td>
<td>46</td>
<td>5/23</td>
<td>22</td>
<td>0.000</td>
</tr>
<tr>
<td>Spoon</td>
<td>140</td>
<td>10/28</td>
<td>36</td>
<td>3/24</td>
<td>13</td>
<td>0.005</td>
</tr>
<tr>
<td>Toothbrush</td>
<td>141</td>
<td>10/27</td>
<td>57</td>
<td>4/24</td>
<td>17</td>
<td>0.005</td>
</tr>
<tr>
<td>Scissors</td>
<td>138</td>
<td>9/27</td>
<td>35</td>
<td>4/23</td>
<td>17</td>
<td>NS</td>
</tr>
<tr>
<td>Wtite</td>
<td>143</td>
<td>8/29</td>
<td>28</td>
<td>1/24</td>
<td>4</td>
<td>0.000</td>
</tr>
<tr>
<td>Draw</td>
<td>139</td>
<td>9/28</td>
<td>32</td>
<td>1/24</td>
<td>4</td>
<td>0.000</td>
</tr>
<tr>
<td>M</td>
<td>137</td>
<td>38.9</td>
<td>18.1</td>
<td>17.9</td>
<td>10.4</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Note: *n' is a subset of n
* Fisher's Exact Test was used in determining the level of significance unless otherwise noted.
** x² was used in determining the level of significance.
NS = Not Significant. DIP includes injuries from distal interphalangeal joint to the fingertip.

Discussion
Handedness of the general population is best represented on a continuum from pure right-handedness to pure left-handedness, with a significantly larger percentage being purely right-handed. Within each person, handedness is also best represented on a continuum from right hand preference to left hand preference with a significantly larger percentage of activities being performed by the preferred hand.

In response to the first research question regarding change in hand use, results ranged from 13% to 35% for the 16 activities displayed in Table 2. Patient responses indicate that simple, short activities that did not require sustained fine motor coordination were more easily performed with a different hand after injury than complex, continuous activities that required sustained fine motor coordination. For example, the short, simple, gross motor tasks of opening a door, turning a screwdriver, and opening a box lid were activities more frequently completed by subjects with a different hand after injury than...
Figure 1. Differences in hand use scores before injury and after injury according to diagnostic type. Pairs of means with common superscript characters do not differ significantly at $p \leq .05$; pairs of means with different superscript characters differ significantly at $p \leq .008$.

were the more complex, sustained, fine motor tasks of writing, drawing, and cutting with scissors.

Therapists can determine the complexity of an activity through task analysis (Goodgold-Edwards & Cermak, 1990). Task analysis can identify the motor planning and performance skills that a patient will need to change hand use successfully. Furthermore, analysis may help determine the inherent characteristics or performance requirements of complex activities that could assist the patient after injury in selecting which extremity would be the most appropriate for a particular activity.

Ackerman (1989) stated that the process of skill acquisition increases in difficulty as the complexity of the task increases. In other words, the more complex the task, the more difficult it is to learn. An appreciation of this factor can assist therapists in helping patients with impairments to choose the most efficient and effective methods for completing daily activities.

In response to the second research question, findings indicated that a patient's propensity to change hand use after injury to perform specific functional tasks was related to the diagnostic type of injury. Subjects with peripheral nerve injuries (45.3%), revascularization and replantations (22.3%), flexor tendon injuries (13.1%), and crush injuries (7.8%) changed hand use the most frequently after injury. These results indicate that subjects in certain diagnostic groups were more likely to change hand use after injury, especially if there was peripheral nerve involvement. Although the motor and sensory deficits from peripheral nerve trauma were not examined specifically in this study, our findings implicate denervation as possibly having played an important role in this change. Presumably, the impairment in hand function from denervation after injury necessitated use of a different hand than was normally used before the injury. Stanley (1990) stated that the loss of sensibility may prove more disabling than motor loss.

In response to the third research question, findings
Figure 2. Differences in hand use scores before and after injury according to anatomical level. Pairs of means with common superscript characters do not differ significantly at \( p \leq 0.05 \); pairs of means with different superscript characters differ significantly at \( p \leq 0.005 \).

indicated that a patient's propensity to change hand use after injury was related to the anatomical level of the injury. The rank ordering that occurred within the results demonstrated that the more proximal an injury, the more likely it was to result in a change in hand use. Subjects with injuries at the fore/arm level (38.9%), wrist level (18.1%), metacarpal level (17.5%), proximal phalanx level (10.4%), and DIP level (3.9%) changed hand use the most frequently after injury. Therefore, for the four specific diagnostic groups studied, it can be stated that the more proximal an injury occurred the more likely it resulted in a change of handedness. This is consistent with other studies indicating greater loss of functional skills with more proximal injuries (Meyer, 1985; Meyer, 1991; Zhong-Wei et al., 1981).

The fourth research question, regarding employment status after injury, was answered with subjects reporting changes of significant differences in job duties and place of employment based on the anatomical level of injury only. Specifically, subjects injured at the fore/arm level reported significantly more changes in job duties than did DIP, metacarpal, or wrist level subjects. As for changes in place of employment, subjects with fore/arm level injuries reported significantly more changes than did subjects with wrist or metacarpal level injuries. These changes in job duties and place of employment could be based on the assumptions that the more proximal injuries take longer to recover, require a more extended rehabilitation program, and often result in a greater amount of permanent impairment of hand function, particularly if there is peripheral nerve involvement.

A limitation of this study was the reliance on human recall. An additional limitation was the 38% return rate. After chart reviews, not all of the responses received could be used, which precluded an ample and balanced number of subjects in each of the injury categories (see Table 1). Furthermore, the imbalance within the categories disallowed a more detailed analysis of diagnostic

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groups by injury levels and limited our ability to generalize the findings.

Future research on handedness is needed to identify the types of sensory and motor pathology that result in a change in hand use after injury. Identification of the inherent characteristics or performance requirements of specific activities that determine which extremity will be used for task accomplishment after injury is also necessary.

Additional studies with larger and more balanced sample sizes are needed to allow for comparison of separate results for injuries to different peripheral nerves. Such studies would also allow for a more discrete segregation of anatomical levels within the more proximal injuries and for a comparison of injuries to the flexor tendons of differing digits. Lastly, future studies looking at the development of specific retraining programs will be needed to determine the most appropriate methods for facilitating a change in handedness.

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