Upper-Limb Kinematics of the Presumed-to-Be-Unaffected Side After Brain Injury

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OBJECTIVE. The purpose of this pilot study was to investigate the kinematics of the presumed-to-be-unaffected upper limbs of people with brain injury (BI) compared with people without brain injury (WBI) during reaching.

METHOD. Seventeen people with BI with no apparent motor deficit and 17 people WBI were measured and compared. A six-camera motion analysis system was used to determine movement duration, average speed, and smoothness during reaching.

RESULTS. The group of people with BI was found to be significantly longer in movement duration (p < .0001), were slower in average speed (p < .0001), and had decreased smoothness (p < .0001) during reaching than the group of people WBI.

CONCLUSION. The results suggest that people with BI may have undetected motor deficit in their presumed-to-be-unaffected upper extremities. Further research is needed to explore the upper-limb motor performance and the impact on function and safety.


Acquired brain injury (BI) from stroke or head trauma can result in hemiplegia of the contralateral upper extremity. The ipsilateral, or presumed-to-be-unaffected, upper extremity is often assumed to be unremarkable, without motor impairment. Increasing evidence, however, supports the presence of motor alterations such as weakness (Jung, Yoon, & Park, 2002); bilateral slowness (Malouin, Richards, Desrosiers, & Doyon, 2004; McCrea, Eng, & Hodgson, 2003); unsmooth-segmented movements characterized by multiple starts and stops (Sugarman, Avni, Nathan, Weisel-Eichler, & Tiran, 2002); and alterations in muscle contraction patterns, such as diminished scapular protraction, humeral external rotation, and diminished shoulder elevation (Meskers, Koppe, Konijnensbelt, Veeger, & Janssen, 2005).

Some researchers postulate that people with left- but not right-brain damage who have minimal motor impairment show more evident motor deficits in the ipsilateral upper-extremity and hand (Baskett, Marshall, Broad, Owen, & Green, 1996; Pohl, Luchies, Stoker-Yates, & Duncan, 2000). Trunk compensatory movements also have been noted and related to proximal upper-extremity and distal upper-extremity movements because trunk movements assist both in upper-extremity transportation and hand orientation for grasping when distal deficits are present (Esparaza, Archambault, Weinstein, & Levin, 2003).

Preservation of motor function in the ipsilateral upper limb is critical to independence of daily living. There is a need to further investigate kinematic alterations of the presumed-to-be-unaffected upper extremities after BI.
The aim of this exploratory pilot was to compare the kinematics of the ipsilateral, or presumed-to-be-unaﬀected, upper extremity of people with BI and without brain injury (WBI). The purpose of the study was to answer the following research question: How are the upper-limb kinematics of a person’s presumed-to-be-unaﬀected limb impaired after BI compared with those of people WBI?

Methods

Participants

Seventeen people with BI and 17 people with WBI participated in this study, which took place at a community-based center located in the southern portion of the United States. Nine participants had traumatic brain injury, and 8 participants had stroke. Eight participants were in an acute stage of recovery (<1 year onset), and 9 participants were at a chronic stage (>1 year after BI). The BI group was between 20 and 83 years old (mean age = 40.7), and the WBI group was between 21 and 70 years old (mean age = 41.5). The BI group included 15 right-handed people and 2 left-handed people. Twelve right-handed participants presented with a left hemiplegia or hemiparesis with a presumed-to-be-unaﬀected dominant right side, 3 right-handed participants showed both upper limbs presumed to be unaﬀected, and 2 left-handed participants showed a right hemiplegia with a presumed unaﬀected dominant left side. The control group was measured bilaterally, and only the matching upper-extremity scores were compared with the BI group. All participants in the control group were right handed.

Unaffected Arms

The Fugl-Meyer scale (Fugl-Meyer, Jäärkä, Leyman, Olsson, & Stéglind, 1975) was used as a screening tool to determine baseline diﬀerences between upper-limb motor performances to identify the presumed-to-be-unaﬀected side of people with BI. The Fugl-Meyer scale often is used to measure motor impairment for people with spasticity and hemiplegia, and the upper-limb motor component was used for this study. Several studies have demonstrated the construct validity and excellent interrater and intrarater reliability properties of the Fugl-Meyer scale (Bohannon & Smith, 1987; Sanford, Moreland, Swanson, Stratford, & Gowland, 1993). The Fugl-Meyer upper-extremity scale is a 3-point ordinal scale (2 points for the detail being performed completely, 1 point for the detail performed partially, and 0 for the detail not being performed). The upper extremity scale has a maximum score of 66 points when clients have no apparent motor deﬁcits (Fugl-Meyer et al., 1975). All participants in this study scored the maximum (66) on the Fugl-Meyer scale.

To be included in the study, participants had to have a diagnosis of head trauma or stroke, be older than 18, have the cognitive capacity to follow multistep requests, and have had no history of apraxia. The control group had no history of brain or musculoskeletal injury to their upper extremities. Before the study, the researchers obtained informed consent from all participants and Institutional Review Board approval from the clinical and educational institutions.

Procedures

Sequential reaching and touching tasks to a lighted touching board were tested. The board (15 cm × 30 cm) was instrumented with a built-in switch and red light-emitting diode (LED). Participants were seated in a straight-backed chair. A reﬂective sphere marker was attached on the back of the hand (on the third metacarpal head) with double-stick tape. Three marker positions were recorded on the trunk: One marker was attached between the sternoclavicular joint, one marker at C7 (base of the posterior neck), and two markers at each acromion. The markers deﬁned the local coordinates of the trunk. An additional set of markers was placed on the seat frame to deﬁne the global reference. The touching-board platform was placed anterior to the shoulder center of the testing side with a horizontal distance of upper-limb length +10 cm.

Participants were asked to rest their hand at the starting platform, which was placed just lateral to their proximal thigh, allowing slight abduction of the upper arm for initial arm positioning. They were then asked to touch the board when a red LED was lit and a short beep sound was given. The light and sound were turned off when the participant touched the board. Touching was repeated six times. Time sequence of the audiovisual cueing was controlled automatically by computer software developed at the occupational therapy laboratory. Participants were required to place their hands at the platform and wait for the next signal on completion of each touching task. The target was adjusted so that a line connecting the center of the shelf and the shoulder made a 90° angle with vertical axis (90° of shoulder ﬂexion). A motion analysis system with six cameras (Motion Analysis Corporation, Mountain View, CA) recorded the three-dimensional position of the hand-attached marker during entire reaching sequences at 60 frames per second (60 Hz sampling rate). Data from the cameras were processed by the tracking program, which created three-dimensional coordinate ﬁles for the markers.

Kinematics Measures

The four kinematics measures included the following: (1) Movement duration, defned as the time to complete the task, was calculated between onset and end of the reaching
motion. The onset of hand motion was defined as the time when the hand exceeded a threshold velocity of 5 cm/s. Similarly, the end of the reaching movement was defined as the time at which hand velocity was reduced to 5 cm/s. (2) Average speed was calculated as the hand-travel distance divided by the movement duration. (3) The smoothness of the movement, or an indicator of jerk, was described as the ratio of speed and direction changes during the reach (Kitazawa, Goto, & Urushihara, 1993; Yan, Hinrichs, Payne, & Thomas, 2000). The larger the jerk was, the less smooth the motion was. The smoothness measure used in this study was normalized by the duration of the movement. This normalized jerk, which was introduced by Kitazawa and colleagues in 1993, provides a real-world description of smoothness and offers advantages including analytical tractability, computational manageability, and simplicity. (4) Trunk movement was defined as the travel distance of the sternoclavicular marker during the reach.

Motor Impairment Measures

Data Analysis

Kinematics data were collected and analyzed to distinguish differences between the presumed-to-be-unaffected side and people without BI. Statistical analyses were performed on the data using PC–SAS 9.1.3 (SAS Institute, Cary, NC). An analysis of variance using the Proc GLM (General Linear Model) in PC–SAS was used to test for differences in average speed, duration, and smoothness. Unless explicitly stated otherwise, in this report, a p ≤ .01 was considered to be statistically significant.

Findings

Movement Duration and Movement Speed. The differences between people with BI and WBI are shown in Table 1. The movement duration was longer for those in the BI group (F = 463.39, p < .0001) than in the WBI group. As expected from the duration results, the average speed was slower in people with BI (F = 97.67, p < .0001) than WBI (Figure 1). The findings on movement duration and average speed during reaching indicate that they might make useful measures for upper-limb function during reaching.

Movement Smoothness. The participants with BI showed significantly decreased smoothness (F = 63.5, p < .0001) than those WBI (Table 1). In addition, the participants with BI showed a larger amount of trunk movement (Table 2) than those in the WBI group, and the differences were statistically significant (p < .001). Their trunk compensated 28.2% of the total distance needed to complete the reaching task (direct distance), whereas the trunk movement of the participants WBI contributed a much smaller proportion (19.9%).

Study participants with BI were divided into two groups: (1) admitted <1 year after BI or (2) admitted for treatment >1 year after BI. Participants admitted for treatment >1 year after BI showed significantly faster and smoother movement (p < .0001) than participants admitted <1 year after BI (Table 3). In addition, participants with more chronic onset were not significantly faster or smoother than people WBI (p < .11).

Discussion

Upper-limb kinematic measures appear to provide more fidelity in describing motion than the Fugl-Meyer scale (a commonly used measure of motor impairments for people

Table 1. Comparison of Upper-Limb Kinematics, Brain Injury (BI) Group and Without Brain Injury (WBI) Group

<table>
<thead>
<tr>
<th>Upper-Limb Kinematics</th>
<th>WBI Group</th>
<th>BI Group, Fugl-Meyer = 66</th>
<th>Type III Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement duration (s)</td>
<td>0.56</td>
<td>0.80</td>
<td>1</td>
<td>8.71</td>
<td>8.71</td>
<td>220.02</td>
</tr>
<tr>
<td>Average speed (cm/s)</td>
<td>125.54</td>
<td>98.58</td>
<td>1</td>
<td>115,700.06</td>
<td>11,570.06</td>
<td>107.06</td>
</tr>
<tr>
<td>Smoothness</td>
<td>0.049</td>
<td>0.038</td>
<td>1</td>
<td>0.02</td>
<td>0.02</td>
<td>63.50</td>
</tr>
</tbody>
</table>

Note. M = mean, SD = standard deviation, df = degrees of freedom.
with BI). The Fugl-Meyer scale appears to be susceptible to a ceiling effect because of the categorical nature of the measures. The movement duration of participants with BI was found to be significantly longer than that of participants WBI. In addition, participants with BI were significantly slower in average speed and had decreased smoothness during reaching than the group of participants WBI. This finding supports previous studies that describe the presence of motor alterations, such as bilateral slowness (Malouin et al., 2004; McCrea et al., 2003) and unsmooth-segmented movements characterized by multiple starts and stops (Sugarman et al., 2002). Our results suggest that people with BI may have undetected motor deficit in their presumed-to-be-unaffected upper limbs. Upper kinematics measures can be used to detect subtle motor alterations in the presumed-to-be-unaffected side. The motor alterations in our findings were small; their detection may have been affected by the simplicity of the motor task used. In addition, the nature of the BI may have affected the degree of motor alterations. Direct kinematics measures can improve understanding of the nature of these subtle motor alterations, especially with clients who have unawareness of motor impairment and disability.

The decreased smoothness of the presumed-to-be-unaffected upper limb raises the following question: Is the decreased smoothness in the presumed-to-be-unaffected upper limb a result of bilateral impairment after BI? The decreased smoothness can be a consequence of impaired neural, muscular, and or skeletal systems.

The findings also showed that participants with BI had excessive use of the trunk during the upper-limb reaching task performed with the presumed-to-be-unaffected side, even when the target was placed within the limits of the stretched arm. This is a recurrent finding in people with hemiplegia (Levin, Michaelsen, Cristea, & Roby-Brami, 2002). It appears that the trunk movements compensate for the subtle loss of neuromuscular synergism of the scapula, shoulder, and elbow. The causal implications of the trunk involvement and the segmental contribution of scapula, shoulder, and elbow will require further investigation.

Other occupational therapy researchers have used kinematics and force measures to quantify upper-limb movement deficits after BI (Fasoli, Trombly, Tickle-Degnen, & Verfaellie, 2002, Rohrer et al., 2002; Trombly, 1993). Our results expand on their work by showing decreases in smoothness, movement duration, and average speed in the presumed-to-be-unaffected upper limb in both acute and chronic BI. These kinematics measures may provide objective quantification of motor performance. The BI onset can determine the level of spontaneous recovery and improvements in motor function of upper-limb function. The findings showed that participants’ upper-limb movement duration, speed, and smoothness were more evident when the BI onset was less than 1 year. This finding is in agreement with the general perception that the recovery after BI displays a nonlinear pattern, particularly the knowledge that recovery profiles may extend far beyond the first year after BI. The challenge will be to explore the longitudinal relationship between kinematic adaptations and gains in motor performance. In this way, it becomes possible to investigate the manner in which changes in motor control are generated by training or compensation.

Table 3. Comparison Between Without Brain Injury (WBI) and Brain Injury (BI) Acute Group Onset (≤1 Year), and BI Chronic Group Onset (≥ 1 Year)

<table>
<thead>
<tr>
<th>Upper-Limb Kinematics</th>
<th>BI, Acute</th>
<th>BI, Chronic</th>
<th>WBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement duration (s)</td>
<td>0.93 0.34</td>
<td>0.67 0.14</td>
<td>0.56 0.15</td>
</tr>
<tr>
<td>Average speed (cm/s)</td>
<td>87.12 36.23</td>
<td>109.73 24.35</td>
<td>125.54 32.93</td>
</tr>
<tr>
<td>Smoothness</td>
<td>0.03 0.02</td>
<td>0.05 0.01</td>
<td>0.049 0.016</td>
</tr>
</tbody>
</table>

Note. M = mean, SD = standard deviation, df = degrees of freedom.

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Quantification of rehabilitation progress is necessary for accurate assessment and interventions. Although kinematic measurement systems can accurately quantify upper-limb motion, further work is required to investigate the ability of the results to be repeated. Differences in hand dominance and lesion site were assumed to be negligible because the task was designed to be a slow, simple touching task. We also need to expand on the study limitations with increased sampling and stratification of the participants. Motion analysis techniques have not been used routinely, in part because of a lack of standardized protocols stemming from the complex nature of upper-limb motion. This report may aid in the use of kinematics analysis for the affected and presumed-to-be-unaffected upper limb after BI.

Conclusion
This brief report has provided a preliminary exploration of motor performance in the presumed-to-be-unaffected upper limb after BI. The results provide a useful insight into upper-limb kinematics. The findings suggest that movement duration, average speed, and smoothness might be able to assist in the quantification necessary for accurate assessment and intervention of upper-limb function after BI. Kinematic deficits have been reported in people with BI, as stated in the introduction to this article. Occupational therapy practitioners and researchers need to further explore the kinematics of the presumed-to-be-unaffected extremities as well as the impact of those extremities’ motor performance on function and safety. ▲

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References