Effects of Object Affordances on Reaching Performance in Persons With and Without Cerebrovascular Accident

Ching-yi Wu, Catherine A. Trombly, Keh-chung Lin, Linda Tickle-Degnen

Key Words: cerebrovascular disorders • environment • movement

Objective. This study investigated whether affording objects with different levels of functional support would have an impact on reaching performance in patients after cerebrovascular accident (CVA) and in adults who were neurologically intact. Reaching performance was quantitatively analyzed, using several kinematic variables.

Method. Two groups, 14 participants after CVA and 24 age-matched adults who were neurologically intact, performed a food chopping task under two conditions: enriched affordances and impoverished affordances. Enriched affordances involved reaching forward to a chopper and pushing down on the handle to chop a fresh mushroom. Impoverished affordances involved reaching forward to a simulated chopper (i.e., a chopper covered with cardboard) without anything in it and then pushing the handle down. Reaching movement was measured by a three-dimensional motion analysis system.

Results. For the CVA group, the enriched condition of reaching to chop the mushroom resulted in more efficient, direct, smooth, and preplanned movement than the impoverished condition of reaching to push on the chopper handle. The neurologically intact group responded similarly except that the participants' movement was equally smooth, as measured by movement unit, between the two testing conditions. Force generation, as characterized by peak velocity, was similar for both conditions for both groups.

Conclusion. The finding that enriched affordances had a positive effect on movement kinematics in both CVA and neurologically intact groups suggests that providing natural objects for completing a task and providing functional information on the objects may enhance the functional performance of persons who have had a CVA. These findings should be replicated and extended to confirm the validity of these effects and allow for generalization.

Occupational therapists often engage a person in meaningful occupation through the purposeful or functional use of objects. Providing persons who have brain lesions with objects for a reaching or reach-to-grasp task may be one effective method of re-establishing function (Carr & Shepherd, 1987a, 1987b; Ryerson & Levit, 1997). This view has been echoed in Nelson's (1988) model of occupation wherein he defined occupation as the relationship between occupational form (i.e., context) and occupational performance (i.e., doing). Materials-based occupation is one type of occupational form that involves the use of everyday objects to elicit or shape movement and that occurs as a by-product of pursuing task-specific goals (Nelson, 1988). Materials-based occupation, or affording objects for a motor task,
may be a more effective means to promote motor performance than object-absent conditions (e.g., objectless exercise) (see Lin, Wu, Tickle-Degnen, & Coster, 1997, for meta-analytic evidence). However, forms of occupation are not limited to the ones that have been contrasted (i.e., materials-based occupation vs. objectless exercise). To understand occupation better, we must expand the typology of occupational form. One possibility for research in this direction is to differentiate levels of materials support (or object affordances) to investigate the effects of enriched object affordances on occupational performance. This study was designed to investigate how enriched and impoverished object affordances affect reaching performance in persons with and without cerebrovascular accident (CVA).

Literature Review
Affordances describe the functional utility of particular objects within the performance context in reference to the performer's action capabilities (Konczak, Meeuwsen, & Cress, 1992; Mark, 1987; Warren, 1984). A person can actively differentiate the perceptual information provided by an object (i.e., object attributes) during object-oriented action (Gibson, 1966, 1977, 1982; Jeannerod, 1994; Leeuwen, Smitsman, & Leeuwen, 1994; Rosblad, 1992). Such object affordances may specify response dynamics during a given action (Bajcsy, 1994; Newell, 1986; van Emmerik & Newell, 1990; Vogels, Sary, & Orban, 1995). Response dynamics are based on a person's constraints coupled with perceived information on the objects. If object affordances actually specify response dynamics and if they are varied, a person's movement performance should also vary.

Object affordances may be specified by the number (e.g., Mathiowetz & Wade, 1995) or the informational attributes (e.g., Wu, 1995) of objects. The number of objects afforded for task performance refers to the number of the objects used to support the completeness of a whole task (e.g., Mathiowetz & Wade, 1995). The informational attributes of objects refers to the symbolic information about content or function of the objects (e.g., Wu, 1995). Providing a sufficient number of objects for completing a task (e.g., providing a knife and bread for performing the task of slicing bread) or a higher level of information of object attributes (e.g., offering a real can of cola for drinking) creates conditions that are more natural compared with providing fewer objects (e.g., providing a knife to demonstrate how to slice bread) or a lower level of object information (e.g., offering an unlabeled can for drinking) and can be considered enriched object affordances (Mailloux, 1996). In contrast, impoverished affordances involve fewer objects or a lower level of object information.

Empirical Work on the Effects of Object Affordances
Numerous studies, documented here, have been devoted to testing the effects of object affordances. Their findings, on average, show that enriched object affordances facilitate better movement performance than impoverished object affordances.

Effects of the number of object. One line of research in this area suggests that offering a sufficient number of objects with added purpose or functional relevance for a motor task would produce better motor performance than providing an insufficient number of objects or materials with single purpose or deprived functional meanings in persons without disabilities (Bakshi, Bhambhani, & Madill, 1991; Ferguson & Trombly, 1997; King, 1993; Mathiowetz & Wade, 1995; Miller & Nelson, 1987; Morton, Barnett, & Hale, 1992; Poizner et al., 1995; Steinbeck, 1986; van der Weel, van der Meer, & Lee, 1991; Yoder, Nelson, & Smith, 1989) and in clinical populations (Mathiowetz & Wade, 1995; Nelson et al., 1996; Poizner et al., 1995; Schmidt & Nelson, 1996; van der Weel et al., 1991; Yuen, 1993). Most of these studies have centered on outcome-oriented measures such as the number of movement repetitions (Bakshi et al., 1991) to measure motor performance. These outcome-oriented measures involve crude observations of performance (e.g., observing visible changes in movement performance). The studies by Mathiowetz and Wade (1995) and Poizner et al. (1995) examined the spatiotemporal characteristics of movements during task performance by means of three-dimensional motion analysis, that is, kinematic analysis. Kinematic analysis is process oriented and provides more detailed measures of movement performance than outcome-oriented measures (Goodale, Milner, Jakobson, & Carey, 1990).

Using kinematic measures, Poizner et al. (1995) asked persons with and without CVA to perform the task of slicing bread under different conditions. In the enriched condition, the participants were provided with a knife and bread. Under the impoverished condition, the participants performed the miming task with either knife or bread afforded. The findings indicated that the enriched condition elicited better movement kinematics (e.g., shorter movement time, higher peak velocity) than the impoverished condition.

Effects of informational attributes of objects. Another line of research studied how informational attributes of objects (e.g., the symbolic information about content of beverage) influence movement kinematics. Wu (1995) compared kinematic profiles of reaching in healthy young adults under the conditions of drinking a bottle or can of beverage with or without a commercial label on the surface. The results showed that enriched affordances (the
beverage with the label) elicited shorter total displacement and higher peak velocity than impoverished affordances (the beverage without the label). It appeared that it was helpful for participants to draw on the knowledge of the symbolic meanings and functions of the can or bottle to assist in organizing an appropriate action and setting the parameters for the movement.

The Research Problem

The present study attempted to integrate these two lines of inquiry by examining how the reaching kinematics of persons with and without CVA can be modified through enriched and impoverished object affordances during a chopping task. Enriched affordances involved providing sufficient task objects (i.e., a food chopper and a fresh mushroom) for performing a functional task (i.e., chopping the mushroom). Impoverished affordances involved a motor task (i.e., pushing movements) with only one task object (i.e., a chopper) for a single and nonfunctional purpose. The surface of the task object (i.e., the chopper) was covered with cardboard so that the functional meaning or the external properties of the object were not fully revealed. However, the participants were not prohibited from imagining that they pretended to chop food when they performed pushing movements under impoverished affordances. Performing imagery-based tasks has been found to produce worse performance of movements than performing natural tasks involving object use (Lin et al., 1997), suggesting that the affordances that provide the possibilities for imagination are still impoverished.

The chopping task was used in this study (i.e., the use of a manual food chopper for chopping a mushroom) because it is often involved in meal preparation. Previous studies (Miller & Nelson, 1987; Poizner et al., 1995; Yoder et al., 1989) that used meal preparation tasks involved fine motor skills for task performance (e.g., grasping). However, because all persons with CVA may not regain fine motor skills, gross motor functional activities must be used in studies with this population. Therefore, the chopping task, which involved simple reaching movements, was a functional task appropriate for this purpose.

Knowledge of kinematic modifiability of performance of persons with and without CVA under various affordances may help formulate hypotheses about underlying control processes and treatment strategies in physical rehabilitation. To date, only one study (Poizner et al., 1995) has used persons with and without CVA to investigate movement kinematics under different affordances. This investigation attempts to further study the effects of object affordances in this population.

Reaching Kinematics

Kinematic variables of reaching include movement time, total displacement, peak velocity, percentage of reach where peak velocity occurs, and movement units. Movement time refers to the time for the execution of the reaching movement. The path of the hand in three-dimensional space is described by total displacement in x, y, and z coordinates. Once the reaching movement starts, the arm generally accelerates toward the target and then decelerates at each point of direction change or correction of trajectory (see Georgopoulos, 1986). One acceleration and one deceleration phase comprise a movement unit. The peak velocity is maximal instantaneous velocity and corresponds to the changeover from the acceleration to the deceleration phase (Thelen, Skala, & Kelso, 1987; Wing, Lough, Turton, Fraser, & Jenner, 1990).

These movement kinematics are produced as a result of motor programming (Schmidt, 1988; Sidaway, Sekiya, & Fairweather, 1995). The motor program is an abstract representation of the task (Mulder, 1993; Schmidt, 1988) that is updated by a large set of feedback loops (Mulder, 1993). If the movement is well controlled or well programmed, the motor program may not rely heavily on feedback loops to correct the ongoing movement. Consequently, the path of the movement will be more direct (less total displacement) (Ada, O'Dwyer, & Neilson, 1993; von Hofsten, 1992); the time for execution of movement will be shorter (shorter movement time) (Ada et al., 1993; Kluzik, Fetters, & Coryell, 1990; Mathiowetz & Wade, 1995); the movement will be faster (higher peak velocity) (Wu, Trombly, & Lin, 1994) and smoother (fewer movement units) (Brooks, Cooke, & Thomas, 1973; Brooks, Kennedy, & Ross, 1983; Brooks & Watts, 1988); and the percentage of reach where peak velocity occurs will be greater (Marteniuk, MacKenzie, Jeannerod, Athenes, & Dugas, 1987; Nagasaki, 1989; Wu, 1995).

Hypotheses

The following hypotheses were generated on the basis of the ecological view on object affordances (Gibson, 1966, 1977, 1982), empirical findings of research in this area, and the concept of motor program (Mulder, 1993), to test the effects of object affordances on reaching kinematics:

1. The condition of enriched object affordances would elicit better performance of movements than that of impoverished object affordances.
2. Better performance of movements would be reflected by the kinematic variables, including shorter movement time, less total displacement, higher peak velocity, greater percentage of reach where peak velocity occurs, and fewer movement units.
Method

Participants

After giving informed consent, 14 persons with CVA (9 men, 5 women, 39–84 years of age \(M = 61.79\) years) and 24 age-matched adults who were neurologically intact (7 men, 17 women, 37–81 years of age \(M = 63.20\) years) participated in this study. All participants were right-handed. Participants who were neurologically intact volunteered for this study, and none of them reported a history of cerebral disease. Recruitment of these persons was community based. Participants with CVA were not hospitalized and were recruited from CVA clubs. They were able to understand and respond to directions given by the experimenter and had movement of the proximal part of their impaired arm.

To enhance the interpretation of the results, clinical measures of spasticity, joint sense, and visuospatial neglect were administered to the participants with CVA. Spasticity of the upper extremity was measured by the modified Ashworth Scale (Bohannon & Smith, 1987); sensory awareness of the impaired limb was measured by the Perception of Joint Position Sense Test (Leo & Soderberg, 1981); and visuospatial neglect was detected by the line bisection test (Lin, Cermak, Kinsbourne, & Trombly, 1996). The relevant information regarding persons with CVA is summarized in Table 1.

Instruments

This study involved detailed kinematic analyses of reaching movements during the chopping task under two different affordances. A food chopper, with a bottom 7 cm in diameter and disk-shaped handle 4 cm in diameter, and a fresh mushroom were used as the target objects.

The OPTOTRAK/3020, a three-dimensional, active infrared motion analysis system, was used to track the movement of the infrared light emitting diodes (LEDs) taped in two positions: on the head of the fifth metacarpal and on the handle of the chopper as a reference LED. The OPTOTRAK is a precalibrated and noncontact system capable of recording high-velocity motion in three dimensions with .1 mm accuracy at a distance of 2.5 m. The three infrared sensors (cameras) are permanently mounted in a 1.52 m-long housing. This instrument was placed approximately 2 m from the participant during recording.

As the participant moved, the instantaneous position of each LED was digitized at a sampling rate of 100 Hz. Any occluded points were flagged and the data interpolated, if necessary. Fewer than 7% of missing points in a trial was acceptable for interpolation. The raw data were converted to three-dimensional coordinates by a direct linear transformation algorithm. Reliability for this system has been established (intraclass correlation > .99) (Trombly, Wu, & Cope, 1994).

The use of one switch and the reference LED defined landmarks of the reaching task. The participant's hand rested on a 6.3-cm-diameter switch before movement initiation. The beginning of movement was recorded when the hand lifted off the switch. The end of movement was determined as the reference LED moved, that is, the participant started to push down the handle of the chopper.

Design

A counterbalanced repeated-measures design (see Rosenthal & Rosnow, 1991) was used. Each participant recruited for the study was randomly assigned to one of the following sequences: AB and BA, where A represents the enriched condition and B represents the impoverished condition (see Table 2).

Procedure

Each participant performed two experimental conditions. Each condition was repeated 10 times. The two experimental conditions are described as follows:

1. The condition of enriched affordances: The experimenter instructed the participant to reach forward to a chopper and push down on the handle to chop a mushroom. Before the participant performed the task, he or she held the chopper with his or her unaffected hand to stabilize the chopper.

2. The condition of impoverished affordances: The participant reached forward to a chopper without anything in it and then pushed the handle down. The participant held the chopper with his or her unaffected hand before the start of the task. The chopper was covered with blue cardboard so that the shape and content of the chopper were not fully apparent to the participant.

Each participant sat on a chair (45.1 cm in height) in front of a table (73.7 cm in height) in the same testing room. The participant placed his or her hand at the starting position, which was in front of the shoulder, and pressed against the switch. The center of the chopper was 20 cm away from the body and in line with the participant's midline. The experimenter said “ready” to remind the participant of resting his or her hand on the switch and then said “go” to indicate the start of a trial.

The participants with CVA reached out with the impaired arm and the participants without CVA reached out with whichever arm the matched participant with CVA.
Table 1
Demographic and Clinical Characteristics of Participants With CVA

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Sex</th>
<th>Number of Months After CVA</th>
<th>Side of Lesion</th>
<th>Ashworth a</th>
<th>Sensory Awareness b</th>
<th>Bias Index on c Line Bisection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69</td>
<td>M</td>
<td>27.8</td>
<td>Left</td>
<td>7.5</td>
<td>10</td>
<td>-0.02</td>
</tr>
<tr>
<td>2</td>
<td>39</td>
<td>M</td>
<td>46.0</td>
<td>Right</td>
<td>19.0</td>
<td>12</td>
<td>0.05</td>
</tr>
<tr>
<td>3</td>
<td>64</td>
<td>F</td>
<td>40.3</td>
<td>Right</td>
<td>0</td>
<td>14</td>
<td>-0.062</td>
</tr>
<tr>
<td>4</td>
<td>51</td>
<td>M</td>
<td>11.0</td>
<td>Both</td>
<td>0</td>
<td>12</td>
<td>0.12</td>
</tr>
<tr>
<td>5</td>
<td>66</td>
<td>M</td>
<td>NA</td>
<td>Right</td>
<td>0</td>
<td>6</td>
<td>0.12</td>
</tr>
<tr>
<td>6</td>
<td>54</td>
<td>F</td>
<td>69 d</td>
<td>Left</td>
<td>0</td>
<td>14</td>
<td>0.0097</td>
</tr>
<tr>
<td>7</td>
<td>51</td>
<td>M</td>
<td>5.0</td>
<td>Left</td>
<td>3.0</td>
<td>8</td>
<td>0.015</td>
</tr>
<tr>
<td>8</td>
<td>45</td>
<td>M</td>
<td>174.5</td>
<td>Right</td>
<td>44.5</td>
<td>18</td>
<td>0.093</td>
</tr>
<tr>
<td>9</td>
<td>83</td>
<td>M</td>
<td>5.0</td>
<td>Right</td>
<td>0</td>
<td>12</td>
<td>0.02</td>
</tr>
<tr>
<td>10</td>
<td>84</td>
<td>M</td>
<td>50.0</td>
<td>Left</td>
<td>2.0</td>
<td>14</td>
<td>-0.167</td>
</tr>
<tr>
<td>11</td>
<td>61</td>
<td>M</td>
<td>58.3</td>
<td>Left</td>
<td>0</td>
<td>18</td>
<td>0.0517</td>
</tr>
<tr>
<td>12</td>
<td>80</td>
<td>F</td>
<td>13.0</td>
<td>Left</td>
<td>0</td>
<td>18</td>
<td>-0.0583</td>
</tr>
<tr>
<td>13</td>
<td>46</td>
<td>F</td>
<td>98.0</td>
<td>Left</td>
<td>8.0</td>
<td>6</td>
<td>0.0584</td>
</tr>
<tr>
<td>14</td>
<td>72</td>
<td>F</td>
<td>15.0</td>
<td>Left</td>
<td>0</td>
<td>16</td>
<td>-0.058</td>
</tr>
</tbody>
</table>

Note. CVA = cerebrovascular accident; NA = not available.

a Ranks muscle spasticity of the upper extremity. Fourteen upper-extremity motions are examined. Scores range from 0 (normal tone) to 4 (rigidity) for each motion (Bohannon & Smith, 1987).
b Detects the patient's joint position sense of the impaired limb. Six combinations of shoulder, elbow, and forearm placement are tested. Scores range from 6 (difficulty in finding the tape attached on the impaired hand in each of the six positions) to 18 (direct and accurate movements to touch the tape in the six positions) (Leo & Soderberg, 1981).
c Indicates the degree of bisection bias from the real center. The index can range from -1 to 1, with 0 representing no bias toward either side and with a positive value indicating a rightward bias. A bias index of .055 or more indicates left neglect (Lin, Cermak, Kinbourne, & Trombly, 1996).
d Indicates the time since the first CVA. This participant had three separate CVAs.

used. The participant with lesions in both hemispheres used his left hand. Consequently, 6 participants used their impaired right-dominant arms to perform the tasks, and 8 used their impaired left arms. For the age-matched participants without CVA, 13 used their right arms, and 11 used their left arms.

Data Reduction

The three-dimensional data were filtered using a second-order Butterworth filter at a frequency of 5 Hz. The data were then processed using WATKA, a custom-written program that reduced the filtered data to provide kinematic information on the reaching performance.

Data Analysis

A 2 × 2 mixed (i.e., one between factor and one repeated factor) analysis of variance (ANOVA) was used to test the a priori hypothesis. The between factor refers to sequence and the repeated factor to order. This practice allows the use of a more precise error term by removing the confounding effects of sequence and order (Rosenthal & Rosnow, 1985). The treatment effect was embedded in the interaction effect of sequence with order. Each group was analyzed separately and each dependent variable was analyzed using a separate ANOVA.

The data were analyzed with the SAS computer package (Cody & Smith, 1991). To demonstrate the degree to which object affordances have an influence on reaching kinematics, the effect size r was calculated for each dependent variable using procedures described by Rosenthal and Rosnow (1985).

The data were collapsed across the testing conditions to perform additional analyses that may provide better understanding of the nature of participant performance. Pearson product-moment correlations were used to examine the relationship between kinematic variables and clinical tests (i.e., the modified Ashworth Scale and the Perception of Joint Position Sense Test). Independent t tests were performed to examine the differences in movement performance between the neurologically intact and CVA groups.

Results

Analyses of the Effects of Experimental Conditions

Condition means with standard deviation. Table 3 shows the means of the kinematic variables associated with each testing condition for the participants with and without CVA. In general, the patterns of mean data in both populations were consistent with the a priori hypotheses, that is, the enriched condition would produce shorter movement time and total displacement, higher peak velocity, greater percentage of reach where peak velocity occurs, and fewer movement units than the impoverished condition.

Findings for the CVA group. The sources of variance in the 2 × 2 mixed ANOVA for each kinematic variable are presented in Table 4. Results of the sequence-by-order analyses showed significant and moderate to large en-

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Table 3
Summary Statistics for the Kinematic Variables for Each Condition Across Participants With and Without CVA

<table>
<thead>
<tr>
<th>Variable</th>
<th>Participants with CVA (n = 14)</th>
<th>Kinematic Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Enriched</td>
<td>Impoverished</td>
</tr>
<tr>
<td>Movement time</td>
<td>1.07</td>
<td>0.44</td>
</tr>
<tr>
<td>Total displacement</td>
<td>452.87</td>
<td>64.97</td>
</tr>
<tr>
<td>Peak velocity</td>
<td>842.82</td>
<td>264.74</td>
</tr>
<tr>
<td>Percentage of reach where peak velocity occurs</td>
<td>37.30</td>
<td>10.97</td>
</tr>
<tr>
<td>Movement units</td>
<td>2.48</td>
<td>1.71</td>
</tr>
<tr>
<td>Participants without CVA (n = 24)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Movement time</td>
<td>0.51</td>
<td>0.13</td>
</tr>
<tr>
<td>Total displacement</td>
<td>398.59</td>
<td>52.72</td>
</tr>
<tr>
<td>Peak velocity</td>
<td>1260.79</td>
<td>304.64</td>
</tr>
<tr>
<td>Percentage of reach where peak velocity occurs</td>
<td>42.35</td>
<td>7.67</td>
</tr>
<tr>
<td>Movement units</td>
<td>0.73</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Note. CVA = cerebrovascular accident.

riched affordances effects for movement time, $F(1, 12) = 4.86, r = .54, p = .0239$; for total displacement, $F(1, 12) = 3.48, r = .47, p = .0433$; and for movement units, $F(1, 12) = 6.24, r = .58, p = .0140$. A marginally significant and moderate effect was found in the variable of percentage of reach where peak velocity occurs, $F(1, 12) = 2.10, r = .39, p = .0864$, and a nonsignificant and small effect in the variable of peak velocity, $F(1, 12) = .37, r = .17, p = .2784$.

Findings for the neurologically intact group. Sequence-by-order results showed significant and moderate to large enriched affordances effects for movement time, $F(1, 22) = 10.57, r = .57, p = .0019$, and for percentage of reach where peak velocity occurs, $F(1, 22) = 5.96, r = .46, p = .0116$. A marginally significant and moderate effect was found in the variable of total displacement, $F(1, 22) = 2.57, r = .32, p = .0617$, and a nonsignificant and modest effect in the variable of peak velocity, $F(1, 22) = .13, r = .08, p = .3614$. There was almost no effect on movement units, $F(1, 22) = 0, r = 0, p = .4749$. A significant sequence effect in movement time, $F(1, 22) = 8.09, p = .0094$; a marginally significant sequence effect in peak velocity, $F(1, 22) = 3.77, p = .0651$; and a significant order effect in movement time, $F(1, 22) = 9.34, p = .0058$ were found. Although significant or marginally significant sequence and order effects were found, significant effects of condition (order by sequence) were obtained after removing the order and the sequence effects and, thus, was not confounded by these effects (see Table 4).

Further Analyses
Independent of the conditions, the examinations involved correlations between kinematic variables and clinical tests. They also involved the differences in movement kinematics between the neurologically intact group and the CVA group.

Correlations with clinical tests. Moderate Pearson product-moment correlations between the scores of the Ashworth Scale and several kinematic variables were found, including movement time, $r = .45, p = .1027$; movement units, $r = .65, p = .0125$; and peak velocity, $r = -.42, p = .1346$. As the level of spasticity increased, it took longer to perform the movement, and the smoothness of the movement (i.e., movement units) and peak velocity decreased.

Differences between the neurologically intact group and the CVA group. The group effects were significant and moderate to large for movement time, $t$ for unequal variances $= -5.27, df = 14.6, r = .81, p = .0001$; total displacement, $t = -2.57, df = 36, r = .39, p = .0144$; peak velocity, $t = 4.25, df = 36, r = .58, p = .0001$; and movement units, $t = -3.92, df = 13.4, r = .73, p = .0016$. The neurologically intact group performed movements with shorter movement time and total displacement, higher

Table 4
Results of Sequence-by-Order Mixed Analysis of Variance on Kinematic Variables for Participants With and Without CVA

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MT</th>
<th>TD</th>
<th>PV</th>
<th>PPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants with CVA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sequence</td>
<td>1</td>
<td>1.47</td>
<td>12</td>
<td>2.01</td>
<td>0.08</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td>(2.19)</td>
<td>(956.92)</td>
<td>(153.76)</td>
<td>(5.82)</td>
</tr>
<tr>
<td>Within</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Order</td>
<td>1</td>
<td>1.00</td>
<td>1.13</td>
<td>0.80</td>
<td>0.46</td>
</tr>
<tr>
<td>Order x sequence</td>
<td>1</td>
<td>4.86*</td>
<td>3.48*</td>
<td>0.37</td>
<td>2.10</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td>(0.430)</td>
<td>(1366.01)</td>
<td>(179.31)</td>
<td>(50.65)</td>
</tr>
<tr>
<td>Participants without CVA</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>(14674.24)</td>
<td>(87.30)</td>
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<td>(561.87)</td>
<td>(1204.75)</td>
<td>(9.58)</td>
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</table>

Note. Values enclosed in parentheses represent mean square errors. CVA = cerebrovascular accident; MT = movement time; TD = total displacement; PV = peak velocity; PPV = percentage of reach where peak velocity occurs; MU = movement units.

* $p < .05$; ** $p < .01$.  

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peak velocity, and fewer movement units than the CVA group across both testing conditions.

Discussion
Affordances Effects on Kinematic Parameters
In general, the results support the a priori hypothesis that the enriched condition would elicit better kinematic performance than the impoverished condition. These results support the perspective of object affordances that different object affordances could engender different movement performances (Bajcsy, 1994; Gibson, 1966, 1977, 1982; Newell, 1986). In the CVA group, the participants reached for the chopper more efficiently (shorter movement time), more directly (less total displacement), and more smoothly (fewer movement units) while performing the functional task of chopping a mushroom (the enriched condition) than while performing the pushing movement (the impoverished condition). They also tended to use a more programmed strategy (a higher percentage of reach where peak velocity occurs) in the functional task than in the simulated task. In the neurologically intact group, participants' reaching movements were more efficient (shorter movement time) and more programmed (a higher percentage of reach where peak velocity occurs) in the functional task than in the simulated task. They tended to generate a more direct trajectory (less total displacement) in the enriched condition than in the impoverished condition. However, the two experimental conditions did not affect their movement smoothness (i.e., movement units). For both groups, the testing conditions elicited similar amplitudes of peak velocity. The finding that object affordances had negligible effects on peak velocity suggests that this variable probably is not sensitive to changes in affordances or is not part of the motor program.

Possible accounts for the beneficial effects of object affordances on most kinematic variables for both groups are that enriched affordances provided more complete and concrete perceptual information on how to engage in an activity and afforded a higher level of functional purpose for the task to be performed than did the impoverished object affordances. Complete and concrete perceptual information may drive the performance of the task and help scale the amplitude of the movement appropriately (Clark et al., 1994; Poizner et al., 1995). A high level of functional purpose may enhance human performance (Nelson, 1988) and assist in optimizing movement organization (Charlton, 1992). In other words, enriched perceptual information and higher functional purposes may elicit better movement kinematics than impoverished information and lower functional purposes.

The overall effects of affordances on movement kinematics seem larger in the CVA group (mean effect size $r = .44$) than in the neurologically intact group (mean effect size $r = .30$), suggesting that persons with CVA might be more susceptible to the influences of affordances than adults who are neurologically intact. Providing a sufficient number of objects and functional information on the objects in the enriched condition might have encouraged participants to draw on past experience. Past experience or knowledge may help produce internal representation of the relationship between the person and the objects and thus diminish the disadvantage of sensorimotor problems in an impaired arm. It follows that the enriched affordances elicited better performance than the impoverished affordances.

In contrast, past experience may not be so important for participants in the neurologically intact group to perform a functional task. The visual information of the position of the actual object existing in both conditions might have served a major role in guiding planning and execution of movements for these participants, which led to a smaller difference in kinematic variables between the two conditions for the neurologically intact group than for the CVA group. These smaller effects of affordances could be evidenced by the variables of total displacement and movement units, suggesting that the presence of objects helped the participants in the neurologically intact group organize their trajectory and reduce distinct direction changes during task performance.

Given that the neurologically intact group almost equally used the visual information on object position under both experimental conditions to plan the spatial relationship in advance, the degree of reliance on external or on-line feedback to correct the ongoing movements should be similar for both conditions. Therefore, the deceleration phase should be similar between the two conditions; that is, participants who were neurologically intact should have produced a smaller effect on the variable of percentage of reach where peak velocity occurs than participants with CVA. This speculation seems to contradict our finding that the affordances' effect on percentage of reach where peak velocity occurs in the neurologically intact group is greater than in the CVA group. However, an inspection of the average percentages in the two groups reveals that the difference in the condition means of the neurologically intact group (44.53% and 42.35%) is much smaller than that of the CVA group (41.20% and 37.30%). In contrast, the variation within each condition in the CVA group is larger than that in the neurologically intact group, which may account for the smaller effect sizes for the CVA group. The fact that the variability of percentage of reach where peak velocity occurs was larger in the CVA group than in the neurolog-
ically intact group indicates that use of feedback was more variable for the CVA group.

Movement time is the only dependent variable in which effects of affordances are similar for both groups. In other words, the experimental conditions did not affect either group differently in the change in time spent performing the movement under different affordances. This finding suggests that movement time might be a sensitive variable capable of detecting effects of affordances across different populations. It also indicates that motor program might regulate the variable of movement time to respond to the changes in the enrichment of the environment, regardless of population.

Relationship Between Participant Characteristics and Kinematic Performance

Compared with the neurologically intact group, the CVA group generated less efficient (longer movement time), less direct (greater total displacement), less smooth (more movement units), and slower (lower peak velocity) movements. The poorer performance by participants with CVA might have resulted from the problem of spasticity. The data show that the level of spasticity was moderately correlated with kinematic variables, including movement time, peak velocity, and movement units. Spasticity is a state of excess tone (Trombly, 1995) and may lead to disturbances in muscle and interjoint coordination during task performance (Pedersen, 1974). That is, the spasticity may prevent persons with CVA from determining the optimal set of relationships between muscle and limb segments needed to perform an efficient, fast, and smooth coordinated movement (Levin, 1996). Therefore, the participants with CVA generated lower quality of movements than the participants who were neurologically intact.

However, spasticity did not have an impressive impact on the kinematic parameters in a similar study (Wu, Trombly, Lin, & Tickle-Degnen, 1997) that used a scooping task that involved fewer degrees of freedom in joint movements than the chopping task used in the present study. For example, the scooping task (reaching forward to scoop coins off the table into the other hand) did not require scapular stabilization with shoulder flexion, whereas the chopping task required the shoulder to be moved up to at least the height of the chopper and then moved down against resistance to push down the handle of the chopper. When fewer degrees of freedom are involved and no resistance is required for performing a functional task, such as scooping coins, the disturbance in joint coordination caused by spasticity may not play an important role in movement kinematics. Further work is needed to identify the functional tasks that are most sensitive and specific to disturbance of movement resulting from spasticity.

Implications for Clinical Practice

The clinical implication of this study is that functional motor training of persons with CVA should use enriched affordances that include natural objects because performing simulations of a task is not equivalent to performing the actual task. For example, occupational therapists may give persons with CVA a comb rather than a simulated object to train the functional task of dressing the hair. Therapists may also provide suggestions for caregivers in assisting persons with CVA to use real objects in activities of daily living.

The effects of enriched affordances may vary with population. Because the overall effect of affordances was smaller in the neurologically intact group than in the CVA group, providing enriched affordances to persons who are neurologically intact may not be as effective in terms of kinematic performance as providing them to persons with CVA, except for the time spent completing a movement (i.e., movement efficiency). Both groups in this study performed movements more efficiently when enriched affordances and functional meaning were provided. This indicates that choosing real objects and setting functional purposes might not be so important for persons who are neurologically intact (e.g., persons with orthopedic problems) in order to enhance the overall quality of movement but still might be crucial to increase movement efficiency.

Directions for Future Research

The present study included only one functional task (chopping). Future research should include other tasks, such as sequential tasks, to determine whether the results of this study can be generalized to other types of functional tasks. Further studies investigating affordances also need to use different clinical populations to examine the generalizability of the findings. The results of these future studies would affect both the evaluation and treatment of diverse clinical populations. In addition, future studies might explore other types of object affordances (e.g., the precision requirements of the objects used to perform a functional task) that might affect functional movement performance. Such exploration may facilitate the validation of the assumptions underlying object affordances, one aspect of action theory (Gibson, 1966, 1977, 1982). Studies comparing the performance of persons with right CVA and persons with left CVA (Winstein & Pohl, 1995) or comparing the performance of the involved and non-impaired upper extremities in persons with CVA may further the knowledge of control strategies of movements.

Conclusion

The present study showed the positive effects of enriched
object affordances on movement kinematics in both persons who are neurologically intact and persons with CVA. These effects demonstrate the importance of affordances given that the participants performed movements with seemingly similar biomechanical and motor control demands between the two conditions of enriched affordances and impoverished affordances. Moreover, participants might have imagined that they were doing a functional task (i.e., chopping a mushroom) when they performed the simulated task in the impoverished condition (i.e., pushing movements). The findings also indicated that types of occupational form, a term proposed by Nelson (1988) in his model of occupation, could be expanded in that materials-based occupation could be further differentiated by the functional levels of object support (or object affordances). The naturalistic and functional occupational forms, as opposed to simulated and nonfunctional occupational forms, provide an opportunity for the person to develop desired occupational performance or adaptive response.

The clinical implication of the findings is that providing natural objects for completing a task and providing functional information on the objects may enhance the performance of persons with CVA. These findings should be replicated and extended to allow for generalization regarding different types of affordances, populations, and functional tasks. In addition, more studies comparing performance between normal groups and different disability groups might be needed because they would have theoretical implications concerning the mechanisms of movement control. ▲

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References


