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Efficiency of Reach in Persons with and without Stroke in Bimanual and Unimanual Tasks:

Occupationally Embedded Exercise versus Rote Exercise

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Abstract

Objective: This study investigated movement efficiency in persons with and without stroke during unilateral and bilateral occupationally embedded and rote exercise conditions.

Method: Twenty-five participants aged 36 to 69 years (12 with stroke and 13 healthy controls) were randomly instructed to experience both OE and Rote testing conditions involving reaching forward unimanually and bimanually. Outcome measures included the kinematic variables of movement time, movement units, peak velocity, percentage of movement time to peak velocity, and total displacement.

Results: Control subjects elicited greater movement efficiency than participants with stroke and rote exercise produced some significantly more efficient movement dynamics than occupationally embedded exercise. In stroke participants, the paretic limb demonstrated prolonged movement time and less direct movement when compared to the nonparetic limb. Finally, the majority of the unimpaired limb variables were more efficient ($p < .05$) in unilateral trials than bilateral trials but there was no difference in movement efficiency of the impaired limb between tests.

Conclusion: There are marked differences in motor performance between individuals who have and have not experienced a stroke and the amount of risk perceived in a situation can affect movement efficiency. Also, in persons with stroke, the movements of one limb can influence the movement dynamics of the other. Occupational therapists should use this knowledge to create meaningful interventions that will maintain and enhance motor function of the paretic limb through the just right challenge. More research is needed to examine how task demands influence coordination and to generalize these findings.

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Literature Review

Since the beginning of occupational therapy, the profession has used occupation as a means to improve performance. Because of this foundation, there have been a number of studies investigating the premise that occupationally embedded exercise is more beneficial than rote exercise (Bloch, Smith, & Nelson, 1989; Heck, 1988; Licht & Nelson, 1990; Miller & Nelson, 1987; Sietsema, Nelson, Mulder, Mervau-Scheidel, & White, 1993; Steinbeck, 1986; Thibodeaux & Ludwig, 1988; van der Weel, van der Meer, & Lee, 1991; Yoder, Nelson, & Smith, 1989). There is also a great deal of literature available comparing occupationally embedded exercise (OE) to rote exercise (Rote) as well as imagery-based occupation (DeKuiper, Nelson, & White, 1993; Hsieh, Nelson, Smith, & Peterson, 1996; Lang, Nelson, & Bush, 1992; Wu, Trombly, & Lin, 1994).

Occupationally embedded exercise refers to the pursuit of a goal in a way that is both purposeful and meaningful to an individual. It occurs within the context of an occupation; exercise is the by-product of the task. Rote exercise, the alternative to OE, involves repetitive movements and has a strong emphasis on those actions. No end product is present after partaking in this form of exercise and it is often characterized as unmotivating (Nelson & Peterson, 1989).

Kircher (1984) was the first to analyze the effects of purposeful activity compared to nonpurposeful activity. She found that jumping with a rope (occupationally embedded exercise) generated a significantly higher heart rate at a given rate of perceived exertion than jumping without a rope (rote exercise) in 26 healthy women. Although no noteworthy difference was

found in the duration of jumping, she concluded that purposeful activity was more motivating and rewarding to subjects.

In a meta-analysis performed by Lin, Wu, Tickle-Degnen, and Coster (1997), 17 studies were analyzed based on specific inclusion criteria. A majority of the studies dealt with subjects who were neurologically intact. Regardless of the type of participants though, it confirmed that materials-based occupations have advantages over both rote exercise and imagery-based occupations and that there is a relationship between occupational form and occupational performance.

Since occupational therapists spend most of their time working with special populations, several studies have shown the relationship between OE and rote exercise in these groups (Hsieh et al., 1996; Nelson et al., 1996; Sietsema et al., 1993). For instance, in a study with persons with hemiplegia, Hsieh et al. (1996) discovered that an added purpose occupation elicited a higher number of repetitions in a dynamic standing balance occupation than rote exercise. Furthermore, Nelson et al. (1996) concluded that in survivors of cerebral vascular accident with pronator spasticity, OE resulted in increased range of motion in supination.

A growing number of studies have analyzed kinesthetic performance in regards to occupational performance because kinematic analysis is useful for effectively examining the efficiency of movement. Rice, Alaimo, and Cook (1999) recruited 39 healthy females in a grasping and placing occupation. These researchers discovered significant differences in the occupationally embedded and non-occupationally embedded conditions such that the OE condition demonstrated fewer movement units. Wu et al. (1994) examined the difference between reaching performance in three conditions (materials-based occupation, imagery-based occupation, and rote exercise). The materials-based condition demonstrated a higher, more

efficient, preprogrammed, and precise quality of movement as displayed through less total displacement, shorter movement time, shorter reaction time, and fewer movement units. In a replication of Wu et al. (1994), Ross and Nelson (2000) found similar results further demonstrating the differences between occupationally embedded and rote movements.

Another factor known to play a role in movement efficiency is perceived risk, or the amount of danger one associates with an occupational form. Rice and Thomas (2000) studied the quality of movement in healthy adults during a pouring task with two degrees of water temperature (hot and cold). This study concluded that participant performance was significantly different between the two conditions such that pouring hot water (higher risk) elicited more displacement, movement time, and movement units than pouring cold water (lower risk). An extension of this study with well-elderly individuals found similar results (Thomas & Rice, 2002).

While the positive effect of OE and negative effects of perceived risk on kinematic variables is shown above, these studies only involved neurologically intact individuals. Trombly and Wu (1999) recruited 14 survivors of stroke to participate in two different experiments. For the first experiment, in a randomly assigned order, participants reached forward toward a piece of preferred food (goal-directed condition) and to a spatial location (rote exercise condition). For the second experiment, the participants engaged in three contextually based conditions: natural, partial, and simulated. Four of the five dependent kinematic variables were significantly different between the two conditions such that the occupationally embedded condition (reaching for food) created smoother, faster, more preplanned, and more forceful movements. No significant differences were found with the second experiment. This is just one of a limited number of

studies analyzing the kinematics of movement in special populations (Gasser-Wieland & Rice, 2002; Mathiowetz & Wade, 1995; Trombly, 1992).

Gasser-Wieland and Rice (2002) studied the kinematic effects of occupationally embedded exercise on survivors of stroke. Each of the 16 participants participated in an OE condition (reaching and placing a labeled soup can) and a Rote condition (reaching and placing a nonrepresentational mass of clay) with both their affected and unaffected extremities. The dependent variables included movement time, movement units, total displacement, peak velocity, and percentage of movement time where peak velocity occurred. Movement time and movement units were notably lower in the occupationally embedded condition. However, differences between hands were not substantial. Even though Gasser-Wieland and Rice (2002) did not find significant differences in the other dependent variables, it was noted that the OE condition had a smaller displacement total and a lower percentage of movement time to peak velocity than the Rote condition. The results of this study indicate that occupationally embedded tasks can promote greater motor performance in survivors of cerebral vascular accidents (CVA).

Perceived risk on movement dynamics of persons with stroke was studied by Fuller, Thomas, and Rice (2002). Twenty-eight individuals with CVA participated in two upper extremity tasks, one involving a higher amount of risk than the other. The condition associated with a higher amount of risk (moving raw eggs) produced statistically significantly longer movement times than the lower risk condition (moving plastic eggs), but there was no difference found between movement units. Regardless, the researchers concluded that occupational forms with varying levels of perceived risk will produce different movement dynamics.

Additional research on kinesthetic performance in special populations exists that has found significant differences in movements between people with and without cerebral vascular

accident (Fasoli, Trombly, Tickle-Degnen, & Verfaellie, 2002; Murphy, Willen, & Sunnerhagen, 2011; Wu, Trombly, Lin, Tickle-Degnen, 1998; Wu, Trombly, Lin, & Tickle-Degnen, 2000).

Wu et al. (2000) investigated the effects of context on reaching in 14 persons with stroke and 25 healthy adults. Movements were analyzed for both conditions of the independent variable: the presence of an object (coins) and the absence of an object (no coins). In both the stroke and control group, when coins were present, the movements produced were more direct, efficient, programmed, and smoother as demonstrated by less total displacement, shorter movement time, greater percentage of reach where peak velocity occurred, and a smaller number of movement units. When comparing the two groups of participants, the researchers found that persons with stroke elicited slower and less direct, smooth, and efficient movements than the neurologically intact adults. The findings of this study emphasize the idea that materials-based conditions generate more proficient movements than rote exercise.

Murphy et al. (2011) analyzed kinematic variables in 19 individuals with stroke and 19 neurologically intact adults during a reaching and drinking task. These researchers discovered similar results as Fasoli et al. (2002), Wu et al. (1998) and Wu et al. (2000) in which movements between persons with stroke and healthy controls are considerably different. For instance, Murphy et al. (2011) reiterated the fact that time to complete a task is significantly slower in individuals with stroke. Likewise, they recognized that healthy adults produce continuous movements with one major peak while persons with stroke display fluctuating velocity outlines with multiple peaks, which further differentiates the kinematics of the two groups.

Trombly (1992) was the first to study differences between stroke survivor's affected and unaffected limbs. In a pilot study of reaching with individuals with left hemiparesis, she found that in the unimpaired arms of subjects, reaching strategies were 'normal' and continuous.

However, when examining the impaired limb, there were significantly higher movement units, which demonstrated a discontinuous movement pattern. Furthermore, movement time in the affected arm was notably longer than in the unaffected arm. Additionally, although not significant, four of the five subjects' impaired arms displayed lower amplitude of peak velocity than their unimpaired arms.

Although the aforementioned studies were only concerned with unimanual conditions, other literature deals with bimanual situations (Cunningham, Phillips Stoykov, & Walter, 2002; Kazennikov, Perrig, & Wiesendanger, 2002; Lewis & Byblow, 2004). For instance, Wu, Chou, Chen, Kuo, Lu, and Fu (2009), found that in a functional and sequential bimanual task, individuals with stroke showed significantly less smooth, less efficient, and less forceful movement than the healthy controls. They found that onset synchronization was lower in the stroke group as well.

After a stroke, many individuals are affected in a way that leaves them unable to perform tasks bimanually due to upper extremity paresis or weakness. Because many daily occupations involve the use of both arms in a coordinated manner, people with CVAs often experience impaired motor performance when attempting to engage in these occupations. In order to find evidence-based rehabilitation techniques to retrain the affected limb, a number of studies have investigated movement dynamics and/or interlimb coupling in bilateral tasks for people with hemiplegia (Chang, Tung, Wu, & Su, 2006; Harris-Love, Waller, & Whitall, 2005; Kilbreath, Crosbie, Canning, & Lee, 2006; Rice & Newell, 2001; Rice & Newell, 2004; Rose & Winstein, 2005; Waller, Harris-Love, Liu, & Whitall, 2006; Wu, Chou, Kuo, Chen, Lu, & Fu, 2008).

Rice and Newell (2001; 2004) completed two studies in which participants were analyzed on their ability to oscillate their arms in a coordinated manner in both unilateral and bilateral

conditions. In their first study, they reported that the unimpaired limb adapted its movements from one condition to the other while the impaired limb did not. In particular, the unaffected limb performed a significantly greater number of oscillations and had an extensively higher peak velocity during the unimanual condition. Conversely, there were no differences between the two conditions in the control group.

In their second study, Rice and Newell (2004) explored the ability of persons with and without stroke to simultaneously oscillate their arms at various frequencies (1-to-1 and 2-to-1). Within groups, movement patterns were determined to be similar, but there was a considerable difference between groups. For example, the majority of the stroke survivors favored the in-phase (1-to-1) movement pattern. Additionally, they had a difficult time remaining in the antiphase (2-to-1) pattern regardless of the movement task. In contrast, the control group performed more in the unstable (2-to-1) pattern than the simpler (1-to-1) pattern. From these results, Rice and Newell (2004) concluded that individuals with CVA might perform better in upper extremity tasks that require symmetrical as compared to asymmetrical movements.

Rose and Winstein (2005) used kinematics to study reaction time, movement time, peak resultant velocity, and time to and after peak resultant velocity in three aiming tasks (bimanual, unimanual with left/paretic arm, and unimanual with right/nonparetic arm). Upon seeing a visual cue, 30 healthy adults and 30 adults with stroke reached forward to touch a switch as quickly as possible. When comparing movement time and time to peak velocity between the conditions, both groups had prolonged times in the bimanual condition. Then, in the bimanual aiming condition when comparing the two limbs, the nonparetic limb had a longer reaction time. Interestingly, in the stroke survivors, Rose and Winstein (2005) discovered that in the bimanual aiming condition, the nonparetic limb had a lower peak velocity and the paretic limb had a

higher peak velocity. Regardless of this difference, the limbs were able to hit the intended target nearly simultaneously. Because of this, the researchers concluded that a nonparetic limb changes its movement strategy when paired with a paretic limb in bimanual tasks.

In a study performed by Harris-Love et al. (2005), 32 individuals with cerebral vascular accident participated in unilateral and bilateral reaching tasks. When instructed, each subject reached to the sides of a box as fast as possible. Harris-Love et al. (2005) noted that when compared to the unilateral conditions, both affected and unaffected limbs exhibited a higher peak velocity and acceleration in the bilateral condition. However, in the unilateral conditions, peak velocity and acceleration were significantly lower in the paretic arm compared to the nonparetic arm while the values did not significantly differ between limbs in the bilateral condition. When looking at the intralimb effects of the bilateral reaching task, a majority of the participants had an increase in peak acceleration and peak velocity of the paretic limb. Moreover, the nonparetic limb demonstrated longer movement time and higher peak acceleration. There was no difference in the nonparetic peak velocity between conditions. The researchers concluded that interlimb coupling can be exploited to improve the reaching performance of a stroke survivor's affected limb.

The abovementioned studies (Harris-Love et al., 2005; Rice & Newell, 2001; Rose & Winstein, 2005) come to a consensus that one limb can influence the movement dynamics of the other when performing bilateral movements. Additionally, they conclude that there are striking differences in the kinematics of each limb during bimanual tasks. However, these reports lack an occupationally embedded approach to rehabilitation, as their conditions are rote exercise in nature and are missing “meaning” and “purpose”. To date, there are no published studies

comparing OE and Rote exercise in a bimanual task. Because of this discrepancy, there was great need to conduct this research.

The purpose of this study was to compare movement dynamics in individuals with and without stroke during unilateral and bilateral occupationally embedded exercise and rote exercise conditions. Based on the literature discussed above, five hypotheses were considered:

1. Regardless of group, occupationally embedded exercise will elicit more efficient movement dynamics than rote exercise.
2. People with CVA will produce less efficient movement dynamics than the control group.
3. In people with CVA, the unaffected limb will elicit more efficient movement dynamics than the affected limb.
4. In people with CVA, the unaffected limb will demonstrate greater movement efficiency during the unilateral conditions than during the bilateral condition.
5. In people with CVA, there will be no difference in the movement efficiency of the affected limb between the unilateral and bilateral conditions.

Method

Participants

Based on the differences Rose and Winstein (2005) found between people with and without stroke on peak velocity during a reach movement, it was anticipated that with a mean difference of approximately 25 cm/s and a standard deviation of 30 cm/s, as well as an $\alpha = 0.05$ and $\beta = 0.8$, a sample size of 30 people would provide sufficient statistical power for this project to demonstrate a difference between the two populations. A total of 25 individuals aged 36–69 (15 female, 10 male) participated in this study. Via written and verbal invitation, 12 stroke

survivors (mean age = 57.75 years, SD = 8.48) and 13 age-matched neurologically intact adults (mean age = 58.62 years, SD = 8.39) were recruited from the Northwest Ohio community.

All participants were able to understand and follow simple directions without difficulty as demonstrated by receiving a score of at least 24 out of 30 on the Mini-Mental State Examination (M = 28.25, SD = 1.64) (Folstein, Folstein, & McHugh, 1975). Furthermore, all participants scored, at minimum, two out of five on a standard shoulder flexion, shoulder abduction, elbow extension, elbow flexion, and wrist extension manual muscle test, had at least 30 degrees of active shoulder flexion, at least 100 degrees of active elbow extension, and received a score of 3 or less on the Modified Ashworth Scale of Muscle Spasticity (Bohannon & Smith, 1987). Finally, for participants with CVA, the stroke he or she experienced was their first; that is, these participants did not have any stroke prior to the stroke they most recently incurred. The relevant demographic information regarding persons with stroke is summarized in Table 1.

Instruments

The Mini-Mental State Examination is an assessment designed to measure cognition. It covers orientation, memory, and attention as well as a person's ability to name, follow directions, and write. It has concurrent validity with both Verbal and Performance scores of the Wechsler Adult Intelligence Scale ($r = 0.776$; $r = 0.660$) and high test-retest reliability ($r = 0.887$) (Folstein, Folstein, & McHugh, 1975). The Modified Ashworth Scale of Muscle Spasticity is an ordinal scale that measures muscle spasticity. It has face validity and good interrater reliability ($.847$, $p < 0.001$) (Bohannon & Smith, 1987).

Apparatus

A three-dimensional Motion Analysis system (Cortex version 3.0¹) was used to collect kinematic data and prior to each data collection session, the system was calibrated. Data were

sampled at 200 Hz. Eight Owl Digital Cameras recorded the movements of 18 reflective markers placed on various body landmarks of the participant's hands, arms, torso, and head. Specifically, the markers were placed on the head of the sternum, left clavicle, and the right and left forehead, shoulder, upper arm, elbow, forearm, wrist, second metacarpophalangeal (MCP) joint, and fifth MCP joint. Follow up data reduction occurred in Visual 3D Professional Version 4.96.10².

The research setup included a chair, table, and two lamps on either side of a second table located five feet in front of the first table (Figure 1). The table was marked with a line of tape five centimeters from the edge of it in order to indicate the starting/ending hand position. Two Big Red Switches® that sat 25 centimeters apart were placed 20 centimeters in front of the line. The switches were momentary in nature.

Procedure

This study was approved by The University of Toledo Biomedical Institutional Review Board and data were collected from July to November of 2012. After informed consent was obtained, each subject completed a revised version of the Edinburgh Handedness Inventory in order to determine hand dominance (Williams, 2010). Then, using a randomized algorithm, participants experienced both conditions of the independent variable in varying orders of presentation during the same testing session.

For the occupationally embedded condition, participants were seated in front of the table with the switches and were instructed to place both of their hands on the marked start positions. Their forearms were in pronation, elbows were at 90 degrees of flexion, and wrists were in 0 degrees of flexion/extension and abduction/adduction. After a verbal explanation of the task and a demonstration by the researcher, subjects were given one practice trial before data were collected.

To indicate the start of a trial, the researcher said “Go.” Following this verbal cue, subjects reached forward with one limb to touch the Big Red Switch® on the corresponding side as their arm. When touched, the lamp on same side of the table as the switch illuminated. Then, the participants returned their hand to the starting position. After a 30 second rest, the subjects completed the same movement but with their opposite limb. Finally, after an additional 30 second rest, participants completed the reaching task with both hands. No specific instructions were given as to how the participant was to coordinate their bimanual movements (i.e. performing the movement simultaneously or not). Participants were simply told, “Please reach forward with both hands to touch both of the switches.” The motion capture program collected the movement data of the reflective markers during these reach sequences.

The rote exercise condition was completed in the exact same way as the OE condition except that when the Big Red Switch® was touched, nothing happened; that is, the lamps did not illuminate. It was assumed that in the OE condition, touching the switch to turn on the light would have a greater meaning than touching the switch in the Rote condition and nothing happening. There was a one-minute rest between conditions of the independent variable.

Dependent Variables

The dependent variables of interest in this study included: movement time, movement units, peak velocity, percentage of movement time to peak velocity, and total displacement. Movement time was the time elapsed from when the subject lifted his or her hand off the starting position to when he or she touched the Big Red Switch®. Measured in seconds, this dependent variable indicated the overall efficiency and speed of the movement. Previous research has revealed that smaller movement times are connected to greater movement efficiency (Fitts & Peterson, 1964). The initiation of movement was calculated as when the velocity of the

movement surpassed 2% of peak velocity (Murphy et al., 2011). Cessation of the movement occurred when the maximum excursion occurred in the x-axis; in other words, it was determined at the participant's maximum reach forward (x-axis).

Movement units reflected the smoothness of the movement and the amount of error corrections that occurred during the movement. In general, the fewer number of units, the smoother the movement. The measurement of peak velocity demonstrated the maximum velocity that occurred during the reaching task. It also described the force generated during the movement. Percentage of movement time to peak velocity was calculated by dividing the time when peak velocity occurred by the overall movement time. Past studies have shown that, with simple reaches, the greater the peak velocity (Georgopoulos, 1986) and the higher the percentage of movement time to peak velocity (Marteniuk, MacKenzie, Jeannerod, Athenes, & Dugas, 1987), the more efficient the movement. The final dependent variable, total displacement, which is measured in millimeters, indicated the directness of a reaching movement path in three-dimensional space. Generally, the less the displacement, the more precise the movement (Kluzik, Fethers, & Coryell, 1990).

Data Analysis

This study used a repeated measures research design. For the first two hypotheses, a 2 x 2 (population x OE/Rote) analysis of variance (ANOVA) was employed for each dependent variable with the OE/Rote factor being repeated. For Hypotheses 3 through 5, parametric *t*-tests were used. However, the majority of the movement unit calculations did not pass the Kolmogorov-Smirnov, D'Agostino & Pearson omnibus, or Shapiro-Wilk normality test. Because of this, non-parametric tests were used (i.e. Mann-Whitney *U*) for this particular dependent variable on Hypotheses 3 through 5. In order to determine if order effects were present, a

multivariate analysis of variance (MANOVA) was used. The data were analyzed using IBM SPSS Statistics Version 19 and Graph Pad Prism Version 4.02. For all statistical analyses, alpha was set at 0.05.

Effect sizes (d) were also calculated for each comparison to determine the magnitude of the relationship. Effect sizes are considered small when d is greater than or equal to 0.2, medium when d is greater than or equal to 0.5, and large when d is greater than or equal to 0.8 (Cohen, 1988).

Results

Results of the data were calculated using $n = 25$ (12 stroke survivors; 13 healthy adults). A significant order effect in movement time with the right arm, $F(2, 49) = 4.402, p = .018$, and displacement with the arm, $F(2, 49) = 4.498, p = .016$, were detected. However, there was no order effect for the remaining eight dependent variables.

The means and standard deviations of all of the kinematic variables associated with each testing condition for the participants with and without stroke are presented in Table 2. The patterns of the data are consistent with the second hypothesis; that is, control subjects would elicit shorter movement time, less total displacement, greater peak velocity, higher percentage of movement time to peak velocity, and fewer movement units than stroke survivors. However, the data patterns are inconsistent with the first hypothesis which was that occupationally embedded exercise would produce more efficient movement dynamics than rote exercise regardless of group.

Table 3 displays the 2 x 2 ANOVA for each kinematic variable for both stroke and control participants and provides the statistical results for Hypotheses 1 and 2. The within conditions analyzed Hypothesis 1, in that movement time, displacement, peak velocity, and

movement units were all significantly more efficient in the left bilateral trial. All other trials for each variable, both unilateral and bilateral, were not significant in terms of movement efficiency. The between conditions analyzed Hypothesis 2, in that movement time, displacement, and movement units were significantly different between the two populations in the left unilateral, and left and right bilateral trials. Furthermore, right bilateral peak velocity and right unilateral percentage of movement time to peak velocity of the stroke group were significantly less than the control group. These findings support the aforementioned second hypothesis. To more clearly exemplify the differences in kinematics between the OE and rote conditions and unilateral and bilateral trials for persons with and without stroke, group mean comparisons are illustrated in Figure 2. The condition by population interaction was not significant across all dependent variables.

Effect size (d) results between populations for each condition are given in Table 4. Large effect sizes are present for all trials of movement time and displacement with the exception of the right unilateral OE and rote conditions which demonstrate medium effects. For right bilateral OE and rote conditions, all dependent variables but percentage of movement time to peak velocity indicated a large effect size. Moreover, for unilateral right OE and rote conditions, most of the dependent variables expressed a medium effect with the exclusion of percentage of movement time to peak velocity on both conditions and peak velocity during the rote condition.

The third hypothesis addressed individuals with stroke and predicted that the unaffected limb would produce more efficient movement dynamics than the affected limb. The mean differences of the affected and nonaffected limbs as well as the t -test and effect size results of movement time, displacement, peak velocity, and percentage of movement time to peak velocity for this hypothesis are shown in Table 5. Results support this hypothesis. Unilateral OE and rote

conditions for movement time and displacement were significantly different between the limbs with a large effect size such that the nonaffected limb demonstrated more efficient movement than the affected limb. The bilateral rote condition for displacement was approaching significance and had a medium effect size. A small effect size was present for the bilateral OE and rote conditions of movement time and the bilateral OE condition of displacement. For the dependent variable of peak velocity, a large effect size was noted for the unilateral rote condition and a small effect size was found for the unilateral OE condition. Both bilateral OE and rote conditions demonstrated an effect opposite of that originally anticipated. A moderate effect was discovered for the unilateral OE condition of percentage of movement time to peak velocity while the remaining conditions' effect sizes were opposite of that expected. In regards to movement units, the unilateral and bilateral OE conditions were significantly different between limbs with a large effect size found for the unilateral trial and a negative effect size found for the bilateral trial. The unilateral rote condition was not significant with a large effect size and the bilateral rote condition was not significant with a medium effect size (See Table 6). While not statistically significant, in both situations, the nonparetic limb demonstrated greater movement efficiency. It is a possible that a Type II error occurred with these specific analyses.

The fourth hypothesis predicted that the unaffected limb of people with stroke would demonstrate greater movement efficiency during the unilateral conditions than the bilateral ones. Table 7 displays the *t*-test and effect size results of movement time, displacement, peak velocity, and percentage of movement time to peak velocity for this hypothesis and Table 6 gives the movement unit test and effect size results. The results support this hypothesis such that all variables and conditions were significantly more efficient in unilateral than bilateral trials except rote percentage of movement time to peak velocity and rote movement units. Large effects were

noted in both OE and rote conditions of all dependent variables with the exception of percentage of movement time to peak velocity which displayed a medium effect for the OE condition and no effect for the rote condition.

The final hypothesis, that there would be no difference in the movement efficiency of a stroke participant's affected limb between the unilateral and bilateral trials, was supported. The *t*-test and effect size results of movement time, displacement, peak velocity, and percentage of movement time to peak velocity for this hypothesis are given in Table 8 and the movement unit test and effect size results are displayed in Table 6. None of the dependent variables produced significant results and effect sizes were either nonexistent (e.g., <0.2) or small for all kinematic variables. Figure 3 provides graphic illustrations of stroke participant group means for affected and nonaffected limbs in all conditions for movement time, displacement, peak velocity, and percentage of movement time to peak velocity.

Due to the multiple statistical tests run, Type I experimental errors are plausible. In order to determine the number of statistically significant results that were the products of chance, Ottenbacher's (1998) Percent Error Rate was calculated. For Hypotheses 1 and 2, 20% of the significant results are the consequence of chance. For Hypothesis 3, about 14% of the significant results are the result of chance. Finally, approximately 6.25% of the significant results for Hypothesis 4 are the product of chance. Therefore, of the 15 statistically significant results for Hypothesis 1 and 2, three may be the product of chance. Furthermore, 1 of 7 statistically significant results for Hypothesis 3 may be the result of chance. Lastly, for Hypothesis 4, of the 8 statistically significant results, 0.5 are due to chance and such a small number demonstrates that it is unlikely that any of these results were Type 1 errors.

Discussion

The purpose of this study was to compare movement efficiency in persons with and without stroke during unilateral and bilateral occupationally embedded exercise and rote exercise conditions. The first hypothesis, that OE would produce more efficient movement, as indicated by decreased movement time, displacement, and movement units and increased peak velocity and percentage of movement time to peak velocity, was not supported. However, the remaining four hypotheses were confirmed, at least in part. The ramifications of each hypothesis will be discussed in further detail below.

Regardless of group, the results of Hypothesis 1 displayed a trend that rote exercise was more efficient than OE. In fact, in the left bilateral trial, rote exercise was statistically significantly more efficient in terms of movement time, displacement, peak velocity, and movement units. These findings are contradictory to a substantial number of past studies which argue that OE produces more positive outcomes than rote exercise (Gasser-Wieland & Rice, 2002; Rice, Alaimo, & Cook, 1999; Ross & Nelson, 2000; Trombly & Wu, 1999; Wu et al., 1994; Wu et al., 2000). These studies were based on the assumption that individuals would have more intrinsic motivation to complete a purposeful activity than exercise. Perhaps in this study participants did not find significant meaning associated with the task because it was not truly naturalistic; that is, it is not common to turn on a household lamp using a Big Red Switch® and this study took place in a research laboratory, not a home.

However, it is plausible that although the participants did not associate considerable meaning to the condition when the lights responded to the Big Red Switches®, they did associate significant meaning to the situation when the lights did not respond to the switches. This explanation may be because the participants have not had any prior experience controlling lights with Big Red Switches®. Moreover, these switches functioned in a momentary fashion, not in a

latched mode as is the case with normally functioning house lamps. As such, they may not have perceived the situation when the Big Red Switches® controlled the lights as an ordinary circumstance; rather they may have perceived it as contrived. If no natural association was made between the function of the Big Red Switches® and the function of the lights, the participants may have found the condition when the switches did not control the lights to be more contextually relevant.

Another reason why the OE condition did not produce more efficient movement than the Rote condition might be attributed to the differences between the present study and past studies. The present study involved an upper-extremity movement in which each participant simply reached forward, tapped the Big Red Switch®, and returned their arm to the starting position with no gross grasp movement. However, in several previous studies analyzing movement kinematics, grasp was involved (Gasser-Wieland & Rice, 2002; Rice, Alaimo, & Cook, 1999; Ross & Nelson, 2000; Trombly & Wu, 1999; Wu et al., 1994; Wu et al., 2000). It is possible that participants modify their movements based on whether or not grasping, transporting, and placing an object is involved in a task.

Yet another explanation may be that participants did, in fact, ascribe meaning to the OE condition, but it was meaning associated with personal risk and not goal-directedness as was originally anticipated. For instance, participants felt that touching the Big Red Switch® to turn on a light was more dangerous than touching it and nothing happening because electricity was involved. In order for the light to illuminate in the OE condition, an electric circuit was active. The researchers suggest that participants in both groups deemed the light condition to be more risky than the rote condition because of this circuit. To elaborate, participants perceived an inherent danger to themselves when the Big Red Switch® controlled the light. Therefore, as in

Rice and Thomas (2000), Thomas and Rice (2002), and Fuller et al. (2006), due to the increased personal risk, participants adjusted their movements in order to be more careful. This cautiousness was indicated by the higher number of movement adjustments, increased movement time, less direct movement, and decreased peak velocity and suggests that people both with and without stroke regulate their movements to match the amount of risk perceived in a situation.

The second hypothesis was that people with CVA would produce less efficient movement dynamics than the control group and this hypothesis was supported by displacement, movement units, and movement time results. Specifically, there were significant differences between the stroke participants and the healthy participants during the left unilateral trial and both bilateral trials for these variables indicating individuals with stroke had less efficient (longer movement time), less direct (more displacement), and less smooth (larger movement units) movements when reaching unilaterally as well as bilaterally. In addition, although not all significant, a trend was present with peak velocity and percentage of movement time to peak velocity such that the control group completed movements faster and used less feedback for correcting movements than the stroke group. These results authenticate the adverse effects CVAs have on motor performance and coincide with the findings from past studies between people with and without stroke (Kilbreath et al., 2006; Murphy et al., 2011; Wu et al., 1998; Wu et al., 2000).

Hypothesis 3, the unaffected limb will elicit more efficient movement dynamics than the affected limb in people with CVA, was supported. Trombly (1992) found reaching strategies to be normal and continuous for the unaffected limb, but discontinuous for the affected limb of people with CVA. This difference between limbs is confirmed in the present study. Particularly, significant differences were noted between the affected and unaffected limbs during one or both of the unilateral trials of movement time, displacement, peak velocity, and movement units. It is

probable that this lower quality of movement of the impaired limb was brought about by the stroke the individual incurred and is the result of an upper-motor neuron lesion. Specifically, the lesion caused absent or weakened voluntary movement and muscle spasticity to some degree; these changes have been shown to negatively influence movement patterns in past research (Fasoli et al., 2002; Murphy et al., 2011; Wu et al., 1998; Wu et al., 2000; Wu et al., 2009).

Significant differences between limbs were not found for any of the bilateral trials except one (OE condition of movement units), though the majority of the results demonstrated a small to medium effect. Since many everyday occupations naturally involve the use of both arms in a coordinated manner, a probable cause for this indifference in the bilateral conditions is the premise that limbs perform more efficiently when working together. This finding coincides with Rice and Newell (2004) as well as Lewis and Byblow (2004) whom concluded that patients with stroke have greater success when engaging in bilateral tasks that require synchronous movement patterns. However, in Harris-Love et al. (2005), paretic movement time significantly differed from the nonparetic in the bilateral condition despite the shift toward symmetry. The reason for this variation in findings could be attributed to study differences because the Harris-Love et al. study had participants reach as fast as possible to a target whereas the present study did not.

Despite motor disparities between limbs, Rose and Winstein (2005) speculated that the goal of an individual's nervous system is for his or her two hands to reach intended targets simultaneously. Thus, this study found no significant difference between the unaffected and the affected limb during bilateral trials because the human nervous systems tended to perform the bilateral movements in a coordinated fashion; that is, participants tended to tap the Big Red Switch® simultaneously with both of their hands. Interestingly, this thought emerged without explicit instructions from the researcher. Expressly, it is assumed that each participant engaged

in the bilateral trial with the perceived goal of reaching the switch at the same time with both hands, hence improving synchrony between the limbs. This, in turn, emphasizes the idea of coupling between limbs. Coupling refers to bilateral coordination of limbs of which there are various degrees, for example: in-phase and antiphase. In the in-phase coupling pattern, limbs perform movements in synchrony (e.g., using both limbs to roll out dough on a tabletop using a rolling pin). In contrast, in the antiphase coupling pattern, limbs perform movements opposite to one another (e.g., using both hands to turn a steering wheel back and forth in a clockwise/counterclockwise fashion).

Rice and Newell (2004) concluded that individuals with hemiplegia are constrained to a more stable interlimb coupling movement pattern than control subjects. Based on this conclusion and the present study's findings, stroke survivors may be more coupled than healthy adults when performing bilateral tasks. This is because individuals with stroke have affected motor skills due to their compromised neuronal representation and are likely bound to movement patterns that are simple and economical (e.g., coordinated). Expressly, with the motor challenges brought about by a CVA, stroke survivors have limited degrees of freedom compared to healthy adults; therefore, they are constrained to uncomplicated movement patterns (i.e. movements that occur in synchrony, not opposition).

The fourth hypothesis, that the unaffected limb of people with stroke would demonstrate greater movement efficiency during the unilateral conditions than during the bilateral condition, was supported by significant differences and large effect sizes on all five dependent variables. In particular, the reach movement of the unimpaired limb was less efficient, less smooth, less direct, more forceful, and more adjusting in the bilateral condition. Perhaps the reason for this difference is because individuals wanted to perform a synchronized movement, so they sacrificed

their efficiency for coordination. This finding is similar to Rose and Winstein (2005) who discovered that the bimanual condition of an aiming trial caused prolonged movement time and lower peak velocity in the unaffected limb and Rice and Newell (2001) who determined that the unaffected limb of a person with stroke would accommodate its movements to match the constraints brought about by the paretic limb. However, Harris-Love et al. (2005) found that although there was some deterioration in unaffected arm performance during bilateral reaching, peak acceleration of the nonparetic arm actually increased during a task involving reaching toward the sides of a box. Additionally, Wu et al. (2009) noted that patients with stroke did not lose motor control of their unaffected limb when performing a bimanual task, though their task involved sequential movements and this study did not.

Regardless of these inconsistencies, the discoveries of the present study are not uncommon from other literature findings because of the bilateral deficit phenomenon. This trend suggests that there is a decline in limb performance when completing bilateral tasks (Rice & Newell, 2001; Rose & Winstein, 2005). Specifically, in people with stroke, the nonparetic limb seems to be dictated by the paretic limb thus leading toward less efficient movement dynamics of the unaffected limb.

Hypothesis 5, which tested whether there would be no difference in the movement efficiency of the affected limb between the unilateral and bilateral conditions in people with CVA, was supported such that there were no significant differences found between the paretic limb in any trial. It is possible that the affected limb was unable to change its movement dynamics regardless of the task demands because of compromised brain neurons due to the stroke. This result is congruent with Rice and Newell (2001) who also found no noteworthy differences between the paretic limb in people with stroke during unilateral and bilateral trials.

Yet, there is evidence available that contrasts the findings of the present study and suggests improved paretic arm performance in a bilateral task (Harris-Love et al., 2005). A likely explanation for the difference in findings is the task constraints. Harris-Love et al. (2005) used a reaching task involving maximal speed while the present study used a reaching task with no specification regarding movement speed. This momentum constraint may have caused the difference in findings because previous evidence that has found that greater movement speeds demonstrate increased interlimb coupling effects (Cunningham et al., 2002).

Implications

This research strongly suggests that meaning can play a large role in kinematics. In particular, the natural association made between object and task can influence movement dynamics; therefore, it is important to promote task relevancy when facilitating motor recovery in order for occupations to be meaningful and purposeful. In addition, the amount of personal risk an individual perceives in a task can influence movement dynamics such that a task considered more dangerous elicits more forceful and less efficient, smooth, and direct movement. Occupational therapists can use this information to synthesize interventions that include risk as a way of increasing or decreasing the amount of challenge associated with an occupation. By varying the amounts of perceived risk and contextual relevance of a task, therapists can help people develop appropriate movement strategies.

Another implication of this research is the notion that bimanual tasks influence movement dynamics, particularly in persons with stroke. This finding can be exploited by therapists in order to create interventions that may benefit rehabilitation and recovery. Because this study indicates that both the unaffected and affected limb in people with stroke like to perform movements in harmony, completing movements bilaterally rather than unilaterally is

essential so as to preserve motor control of the paretic limb. Although the nonparetic arm may perform tasks less efficiently, occupational therapists should encourage their patients to use both extremities when engaging in activities of daily living since many tasks done throughout the day involve the use of two arms. For instance, removing dishes from a cupboard with both hands will maintain paretic arm performance as opposed to just reaching unilaterally with the nonparetic arm. The same can be said for taking baked goods out of the oven, pushing in chairs, making a bed, wiping tables with a rag, and pulling paper towels from a public paper towel dispenser.

Limitations

A limitation of this study was that the researcher conducting the experiment was not blind to the hypotheses. It is therefore possible that bias could have been introduced into the study. Nevertheless, strict protocols were followed so as to maintain consistency between participants. Another concern of the present study was the multiple statistical tests run as well as the two order effects found. Percent Error Rate calculations were computed in order to deal with the potential of chance results, but the order effects still could have confounded the outcomes. Additionally, because of a small sample size and largely heterogeneous population, this study's results must be generalized with caution. A final limitation to this study was not having a condition with obvious, robust meaning contrasted with a condition with weak meaning. This was a drawback of this study because it was not clear which condition was more meaningful to participants when they engaged in the OE and Rote trials.

Future Research

Further study, including replication of the present study, is needed to substantiate these findings. Additionally, future research should focus on perceived risk in bimanual and unimanual tasks that involve reaching. For instance, it would be valuable to contrast the difference in

movement kinematics of reaching when placing a glass serving dish on a shelf versus a plastic one. Future research could also center on occupationally embedded bilateral training in persons with stroke to determine whether improvement of the paretic limb is possible over an extended period of time using meaningful occupations as opposed to rote exercise. Finally, further studies should investigate interlimb coordination in a variety of functional bimanual tasks to see how task demands influence synchrony. With a better understanding of how bilateral and unilateral tasks influence movement dynamics, occupational therapists can strengthen their efficacy and their role in the rehabilitation process.

Conclusion

In conclusion, the results of this study suggest that perceived risk may play a role in how people both with and without stroke adjust their movements and that stroke adversely affects motor function in terms of efficiency. Additionally, in people with stroke, findings indicate that there are marked differences in the motor performance of the unimpaired limb during bimanual tasks compared to unimanual tasks and stroke survivors have difficulty executing smooth, coordinated movements with their paretic limb. Occupational therapists should use this information to synthesize meaningful interventions that will benefit people who have experienced a CVA, thus helping them maintain efficiency. Specifically, performing functional, contextually relevant tasks will allow limbs to work in harmony. Overall, this study adds to the knowledge of motor control deficits after stroke but further research is needed in order to adequately generalize its findings.

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Footnotes

¹Motion Analysis Corporation, 3617 Westwind Boulevard, Santa Rosa, CA 95403

²C-Motion, Inc., 20030 Century Boulevard, Suite 104A, Germantown, MD 20874

Table 1
Demographic and Clinical Characteristics of Participants with Stroke

| Subject | Age | Sex | Race | Months Post Stroke | Location of Stroke | Side Affected | Mini-Mental ^a | Modified Ashworth ^b | Handedness Inventory ^c |
|---------|-----|-----|------|--------------------|--------------------|---------------|--------------------------|--------------------------------|-----------------------------------|
| 1 | 52 | F | C | 104 | R ACA | L | 30 | 3 | +400 |
| 2 | 58 | F | C | 49 | L PCA | R | 27 | 1 | -325 |
| 3 | 64 | F | C | 1 | Brainstem | R | 29 | 0 | +400 |
| 4 | 69 | M | C | 135 | Brainstem | R | 25 | 1+ | -400 |
| 5 | 69 | M | C | 133 | R MCA | L | 28 | 1+ | +400 |
| 6 | 56 | F | C | 63 | R ACA | L | 29 | 1 | +400 |
| 7 | 56 | F | C | 144 | Basal Ganglia | L | 27 | 0 | +375 |
| 8 | 54 | F | C | 253 | R ACA | L | 30 | 2 | +400 |
| 9 | 64 | F | C | 54 | L MCA | R | 25 | 0 | -400 |
| 10 | 59 | M | AA | 87 | L MCA | R | 25 | 3 | -400 |
| 11 | 56 | M | C | 17 | R MCA | L | 30 | 1+ | +375 |
| 12 | 36 | F | C | 24 | L PCA | R | 30 | 2 | -400 |

Note. C=Caucasian; AA=African American; L=Left; R=Right; ACA=Anterior Cerebral Artery; MCA=Middle Cerebral Artery;

PCA=Posterior Cerebral Artery

^aThe Mini-Mental State Examination is a brief questionnaire used to screen for cognitive deficits. Scores range from 0 (severely impaired) to 30 (normal) (Folstein, Folstein, & McHugh, 1975).

^bThe Modified Ashworth Scale ranks muscle spasticity of the upper extremity. Scores range from 0 (no increase in muscle tone) to 5 (complete rigidity) (Bohannon & Smith, 1987).

^cThe Revised Version of the Edinburgh Handedness Inventory is a measurement scale used to assess hand dominance. Scores range from -400 (complete left handedness) to +400 (complete right handedness) (Williams, 2010).

Table 2

Analysis of Variance Descriptive Statistics of Kinematic Variables for Stroke and Control Subjects

| Variable | <i>n</i> | OE | | Rote | |
|----------------------|----------|----------|-----------|----------|-----------|
| Condition | | <i>M</i> | <i>SD</i> | <i>M</i> | <i>SD</i> |
| Movement Time (s) | | | | | |
| L U | | | | | |
| Stroke | 12 | 1.10 | 0.56 | 1.02 | 0.57 |
| Control | 13 | 0.68 | 0.16 | 0.68 | 0.16 |
| R U | | | | | |
| Stroke | 12 | 1.11 | 0.94 | 1.03 | 0.99 |
| Control | 13 | 0.66 | 0.14 | 0.63 | 0.14 |
| L B | | | | | |
| Stroke | 12 | 1.17 | 0.55 | 1.01 | 0.39 |
| Control | 13 | 0.74 | 0.19 | 0.67 | 0.18 |
| R B | | | | | |
| Stroke | 12 | 1.20 | 0.46 | 1.14 | 0.50 |
| Control | 13 | 0.72 | 0.16 | 0.67 | 0.17 |
| Displacement (mm) | | | | | |
| L U | | | | | |
| Stroke | 12 | 369.20 | 193.16 | 342.19 | 197.49 |
| Control | 13 | 227.72 | 54.56 | 217.01 | 54.17 |
| R U | | | | | |
| Stroke | 12 | 342.77 | 295.77 | 316.81 | 309.82 |
| Control | 13 | 199.71 | 42.59 | 191.69 | 44.40 |
| L B | | | | | |
| Stroke | 12 | 393.48 | 187.27 | 336.42 | 135.89 |
| Control | 13 | 250.74 | 64.77 | 226.39 | 61.57 |
| R B | | | | | |
| Stroke | 12 | 363.92 | 140.95 | 348.63 | 152.72 |
| Control | 13 | 218.59 | 51.51 | 203.94 | 51.32 |
| Peak Velocity (mm/s) | | | | | |
| L U | | | | | |
| Stroke | 12 | 529.21 | 205.80 | 540.08 | 212.66 |
| Control | 13 | 581.56 | 219.44 | 608.54 | 155.10 |
| R U | | | | | |
| Stroke | 12 | 518.43 | 199.57 | 583.39 | 263.70 |
| Control | 13 | 629.96 | 204.04 | 670.47 | 224.24 |
| L B | | | | | |
| Stroke | 12 | 507.06 | 245.83 | 544.32 | 173.65 |

| | | | | | |
|-------------------------------------|----|--------|--------|--------|--------|
| Control | 13 | 507.55 | 132.33 | 584.78 | 193.06 |
| R B | | | | | |
| Stroke | 12 | 413.75 | 186.56 | 437.50 | 178.18 |
| Control | 13 | 626.55 | 172.44 | 671.92 | 210.26 |
| % of Movement Time to Peak Velocity | | | | | |
| L U | | | | | |
| Stroke | 12 | 0.45 | 0.15 | 0.45 | 0.12 |
| Control | 13 | 0.41 | 0.10 | 0.43 | 0.10 |
| R U | | | | | |
| Stroke | 12 | 0.37 | 0.12 | 0.43 | 0.17 |
| Control | 13 | 0.49 | 0.09 | 0.49 | 0.08 |
| L B | | | | | |
| Stroke | 12 | 0.37 | 0.14 | 0.41 | 0.13 |
| Control | 13 | 0.44 | 0.10 | 0.43 | 0.10 |
| R B | | | | | |
| Stroke | 12 | 0.41 | 0.16 | 0.44 | 0.16 |
| Control | 13 | 0.44 | 0.10 | 0.46 | 0.07 |
| Movement Units | | | | | |
| L U | | | | | |
| Stroke | 12 | 3.33 | 2.23 | 3.00 | 3.05 |
| Control | 13 | 1.15 | 0.38 | 1.38 | 0.77 |
| R U | | | | | |
| Stroke | 12 | 3.67 | 6.29 | 3.50 | 6.29 |
| Control | 13 | 1.00 | 0.00 | 1.08 | 0.28 |
| L B | | | | | |
| Stroke | 12 | 3.67 | 2.64 | 2.08 | 0.90 |
| Control | 13 | 1.69 | 0.75 | 1.31 | 0.48 |
| R B | | | | | |
| Stroke | 12 | 3.42 | 2.75 | 3.17 | 2.76 |
| Control | 13 | 1.08 | 0.28 | 1.08 | 0.28 |

Note. R=Right; L=Left; U=Unimanual; B=Bimanual; OE=Occupationally Embedded Exercise

Table 3

Condition x Population Analysis of Variance on Kinematic Variables for Stroke and Control Participants

| Variable | Sum of Squares | <i>dF</i> | Mean Square | <i>F</i> | <i>p</i> |
|------------------------|----------------|-----------|-------------|----------|----------|
| L U Movement Time (s) | | | | | |
| Within | | | | | |
| Condition | 0.04 | 1 | 0.04 | 2.50 | 0.128 |
| Condition x Population | 0.01 | 1 | 0.01 | 0.51 | 0.482 |
| Error | 0.35 | 23 | 0.02 | | |
| Between | | | | | |
| Population | 1.96 | 1 | 1.96 | 6.21 | *0.020 |
| Error | 7.26 | 23 | 0.32 | | |
| R U Movement Time (s) | | | | | |
| Within | | | | | |
| Condition | 0.04 | 1 | 0.04 | 1.34 | 0.258 |
| Condition x Population | 0.01 | 1 | 0.01 | 0.30 | 0.587 |
| Error | 0.65 | 23 | 0.03 | | |
| Between | | | | | |
| Population | 2.27 | 1 | 2.27 | 2.58 | 0.112 |
| Error | 20.19 | 23 | 0.88 | | |
| L B Movement Time (s) | | | | | |
| Within | | | | | |
| Condition | 0.17 | 1 | 0.17 | 5.85 | *0.024 |
| Condition x Population | 0.03 | 1 | 0.03 | 0.96 | 0.339 |
| Error | 0.68 | 23 | 0.03 | | |
| Between | | | | | |
| Population | 1.79 | 1 | 1.79 | 8.13 | *0.009 |
| Error | 5.06 | 23 | 0.22 | | |
| R B Movement Time (s) | | | | | |
| Within | | | | | |
| Condition | 0.03 | 1 | 0.03 | 2.03 | 0.167 |
| Condition x Population | 0.00 | 1 | 0.00 | 0.00 | 0.955 |
| Error | 0.38 | 23 | 0.02 | | |
| Between | | | | | |
| Population | 2.85 | 1 | 2.85 | 12.22 | *0.002 |
| Error | 5.36 | 23 | 0.23 | | |
| L U Displacement (mm) | | | | | |
| Within | | | | | |

| | | | | | |
|--------------------------|------------|----|-----------|-------|--------|
| Condition | 4438.88 | 1 | 4438.88 | 2.51 | 0.127 |
| Condition x Population | 829.33 | 1 | 829.33 | 0.47 | 0.501 |
| Error | 40735.85 | 23 | 1771.12 | | |
| Between | | | | | |
| Population | 221857.23 | 1 | 221857.23 | 5.87 | *0.024 |
| Error | 869609.74 | 23 | 37809.12 | | |
| R U Displacement (mm) | | | | | |
| Within | | | | | |
| Condition | 3603.86 | 1 | 3603.86 | 1.43 | 0.244 |
| Condition x Population | 1003.40 | 1 | 1003.40 | 0.40 | 0.534 |
| Error | 57918.45 | 23 | 2518.19 | | |
| Between | | | | | |
| Population | 224382.53 | 1 | 224382.53 | 2.57 | 0.122 |
| Error | 2005651.47 | 23 | 87202.24 | | |
| L B Displacement (mm) | | | | | |
| Within | | | | | |
| Condition | 20498.44 | 1 | 20498.44 | 6.10 | *0.021 |
| Condition x Population | 3409.71 | 1 | 3409.71 | 1.01 | 0.324 |
| Error | 77350.50 | 23 | 3363.07 | | |
| Between | | | | | |
| Population | 198781.17 | 1 | 198781.17 | 7.53 | *0.012 |
| Error | 607405.17 | 23 | 26408.92 | | |
| R B Displacement (mm) | | | | | |
| Within | | | | | |
| Condition | 2961.40 | 1 | 2961.40 | 1.89 | 0.183 |
| Condition x Population | 0.16 | 1 | 0.16 | 0.00 | 0.992 |
| Error | 36108.49 | 23 | 1569.93 | | |
| Between | | | | | |
| Population | 264002.72 | 1 | 264002.72 | 12.09 | *0.002 |
| Error | 502418.00 | 23 | 21844.26 | | |
| L U Peak Velocity (mm/s) | | | | | |
| Within | | | | | |
| Condition | 4.00 | 1 | 4.00 | 0.65 | 0.430 |
| Condition x Population | 1.00 | 1 | 1.00 | 0.12 | 0.736 |
| Error | 159.00 | 23 | 7.00 | | |
| Between | | | | | |
| Population | 46.00 | 1 | 46.00 | 0.63 | 0.437 |
| Error | 1670.00 | 23 | 73.00 | | |
| R U Peak Velocity (mm/s) | | | | | |
| Within | | | | | |
| Condition | 35.00 | 1 | 35.00 | 2.16 | 0.155 |

| | | | | | |
|---|---------|----|--------|------|--------|
| Condition x Population | 2.00 | 1 | 2.00 | 0.12 | 0.736 |
| Error | 369.00 | 23 | 16.00 | | |
| Between | | | | | |
| Population | 123.00 | 1 | 123.00 | 1.46 | 0.239 |
| Error | 1937.00 | 23 | 84.00 | | |
| L B Peak Velocity (mm/s) | | | | | |
| Within | | | | | |
| Condition | 41.00 | 1 | 41.00 | 4.37 | *0.048 |
| Condition x Population | 5.00 | 1 | 5.00 | 0.53 | 0.473 |
| Error | 215.00 | 23 | 9.00 | | |
| Between | | | | | |
| Population | 5.00 | 1 | 5.00 | 0.08 | 0.775 |
| Error | 1439.00 | 23 | 63.00 | | |
| R B Peak Velocity (mm/s) | | | | | |
| Within | | | | | |
| Condition | 15.00 | 1 | 15.00 | 2.09 | 0.162 |
| Condition x Population | 1.00 | 1 | 1.00 | 0.21 | 0.655 |
| Error | 164.00 | 23 | 7.00 | | |
| Between | | | | | |
| Population | 624.00 | 1 | 624.00 | 9.86 | *0.005 |
| Error | 1455.00 | 23 | 63.00 | | |
| L U % of Movement Time to Peak Velocity | | | | | |
| Within | | | | | |
| Condition | 0.00 | 1 | 0.00 | 0.24 | 0.631 |
| Condition x Population | 0.00 | 1 | 0.00 | 0.14 | 0.709 |
| Error | 0.14 | 23 | 0.01 | | |
| Between | | | | | |
| Population | 0.01 | 1 | 0.01 | 0.54 | 0.469 |
| Error | 0.52 | 23 | 0.02 | | |
| R U % of Movement Time to Peak Velocity | | | | | |
| Within | | | | | |
| Condition | 0.01 | 1 | 0.01 | 0.99 | 0.330 |
| Condition x Population | 0.01 | 1 | 0.01 | 0.91 | 0.351 |
| Error | 0.23 | 23 | 0.01 | | |
| Between | | | | | |
| Population | 0.10 | 1 | 0.10 | 5.34 | *0.030 |
| Error | 0.42 | 23 | 0.02 | | |
| L B % of Movement Time to Peak Velocity | | | | | |
| Within | | | | | |
| Condition | 0.00 | 1 | 0.00 | 0.14 | 0.708 |
| Condition x Population | 0.01 | 1 | 0.01 | 1.08 | 0.310 |

| | | | | | |
|---|--------|----|-------|------|--------|
| Error | 0.19 | 23 | 0.01 | | |
| Between | | | | | |
| Population | 0.02 | 1 | 0.02 | 1.22 | 0.280 |
| Error | 0.45 | 23 | 0.02 | | |
| R B % of Movement Time to Peak Velocity | | | | | |
| Within | | | | | |
| Condition | 0.01 | 1 | 0.01 | 0.99 | 0.329 |
| Condition x Population | 0.00 | 1 | 0.00 | 0.13 | 0.726 |
| Error | 0.22 | 23 | 0.01 | | |
| Between | | | | | |
| Population | 0.01 | 1 | 0.01 | 0.36 | 0.555 |
| Error | 0.52 | 23 | 0.02 | | |
| L U Movement Units | | | | | |
| Within | | | | | |
| Condition | 0.03 | 1 | 0.03 | 0.03 | 0.862 |
| Condition x Population | 0.99 | 1 | 0.99 | 0.93 | 0.344 |
| Error | 24.49 | 23 | 1.07 | | |
| Between | | | | | |
| Population | 44.93 | 1 | 44.93 | 7.33 | *0.013 |
| Error | 140.95 | 23 | 6.13 | | |
| R U Movement Units | | | | | |
| Within | | | | | |
| Condition | 0.03 | 1 | 0.03 | 0.05 | 0.823 |
| Condition x Population | 0.19 | 1 | 0.19 | 0.38 | 0.545 |
| Error | 11.30 | 23 | 0.49 | | |
| Between | | | | | |
| Population | 80.83 | 1 | 80.83 | 2.16 | 0.155 |
| Error | 859.30 | 23 | 37.36 | | |
| L B Movement Units | | | | | |
| Within | | | | | |
| Condition | 12.08 | 1 | 12.08 | 9.58 | *0.005 |
| Condition x Population | 4.48 | 1 | 4.48 | 2.56 | 0.072 |
| Error | 29.00 | 23 | 1.26 | | |
| Between | | | | | |
| Population | 23.60 | 1 | 23.60 | 8.21 | *0.009 |
| Error | 66.13 | 23 | 2.88 | | |
| R B Movement Units | | | | | |
| Within | | | | | |
| Condition | 0.20 | 1 | 0.20 | 0.09 | 0.772 |
| Condition x Population | 0.20 | 1 | 0.20 | 0.09 | 0.772 |
| Error | 52.13 | 23 | 2.27 | | |

| | | | | | |
|------------|--------|----|-------|-------|--------|
| Between | | | | | |
| Population | 61.22 | 1 | 61.22 | 12.11 | *0.002 |
| Error | 116.30 | 23 | 5.06 | | |

Note. R=Right; L=Left; U=Unimanual; B=Bimanual; OE=Occupationally Embedded Exercise

* $p < .05$

Table 4

Effect Size (d) Results Between Populations

| Variable | OE | | | | Rote | | | |
|--------------------------------|-------|------|-------|-------|-------|------|-------|-------|
| | L U | R U | L B | R B | L U | R U | L B | R B |
| Movement Time | 1.02 | 0.68 | 1.05 | 1.39 | 0.89 | 0.57 | 1.09 | 1.28 |
| Displacement | 1.00 | 0.68 | 1.02 | 1.37 | 0.86 | 0.57 | 1.04 | 1.28 |
| Peak Velocity | 0.25 | 0.55 | 0.00 | 1.18 | 0.37 | 0.36 | 0.22 | 1.20 |
| % of Movement to Peak Velocity | -0.31 | 1.08 | 0.58 | -0.27 | -0.20 | 0.46 | 0.15 | -0.13 |
| Movement Units | 1.36 | 0.60 | -1.02 | 1.20 | 0.73 | 0.54 | -1.07 | 1.07 |

Note. R=Right; L=Left; U=Unimanual; B=Bimanual; OE=Occupationally Embedded Exercise

Table 5

Hypothesis 3 t-test and Effect Size (d) Results of Kinematic Variables

| Variable | <i>n</i> | <i>M</i> | <i>SD</i> | 95% CI | <i>t</i> | <i>df</i> | <i>p</i> (one tailed) | <i>d</i> |
|----------------------|----------|----------|-----------|-------------------|----------|-----------|-----------------------|----------|
| Movement Time (s) | | | | | | | | |
| U OE | | | | | | | | |
| A vs. NA | 12 | 0.79 | 0.94 | [0.20, 1.39] | 2.92 | 11 | *0.01 | 1.21 |
| U Rote | | | | | | | | |
| A vs. NA | 12 | 0.80 | 0.96 | [0.19, 1.41] | 2.87 | 11 | *0.01 | 1.16 |
| B OE | | | | | | | | |
| A vs. NA | 12 | 0.16 | 0.49 | [-0.15, 0.47] | 1.13 | 11 | 0.14 | 0.32 |
| B Rote | | | | | | | | |
| A vs. NA | 12 | 0.20 | 0.47 | [-0.10, 0.50] | 1.48 | 11 | 0.08 | 0.46 |
| Displacement (mm) | | | | | | | | |
| U OE | | | | | | | | |
| A vs. NA | 12 | 264.22 | 300.87 | [73.05, 455.38] | 3.04 | 11 | *0.01 | 1.27 |
| U Rote | | | | | | | | |
| A vs. NA | 12 | 261.12 | 309.71 | [64.34, 457.89] | 2.92 | 11 | *0.01 | 1.18 |
| B OE | | | | | | | | |
| A vs. NA | 12 | 61.08 | 161.81 | [-41.73, 163.89] | 1.31 | 11 | 0.11 | 0.37 |
| B Rote | | | | | | | | |
| A vs. NA | 12 | 71.47 | 140.89 | [-18.05, 160.98] | 1.76 | 11 | 0.05 | 0.51 |
| Peak Velocity (mm/s) | | | | | | | | |
| U OE | | | | | | | | |
| A vs. NA | 12 | -70.62 | 274.10 | [-244.77, 103.54] | -0.89 | 11 | 0.20 | 0.35 |
| U Rote | | | | | | | | |
| A vs. NA | 12 | -160.37 | 240.73 | [-313.32, -7.42] | -2.31 | 11 | *0.02 | 0.71 |
| B OE | | | | | | | | |
| A vs. NA | 12 | 76.41 | 282.77 | [-103.25, 256.08] | 0.94 | 11 | 0.18 | -0.35 |

| | | | | | | | | | |
|--------------------------|----|-------|--------|-------------------|-------|----|------|-------|--|
| B Rote | | | | | | | | | |
| A vs. NA | 12 | 47.78 | 245.52 | [-108.22, 203.77] | 0.67 | 11 | 0.26 | -0.26 | |
| % of MT to Peak Velocity | | | | | | | | | |
| U OE | | | | | | | | | |
| A vs. NA | 12 | -0.08 | 0.21 | [-0.21, 0.06] | -1.26 | 11 | 0.12 | 0.56 | |
| U Rote | | | | | | | | | |
| A vs. NA | 12 | 0.04 | 0.24 | [-0.12, 0.19] | 0.52 | 11 | 0.31 | -0.25 | |
| B OE | | | | | | | | | |
| A vs. NA | 12 | 0.04 | 0.20 | [-0.09, 0.17] | 0.70 | 11 | 0.25 | -0.27 | |
| B Rote | | | | | | | | | |
| A vs. NA | 12 | 0.03 | 0.18 | [-0.08, 0.14] | 0.53 | 11 | 0.30 | -0.18 | |

Note. Mean and Standard Deviation are difference scores. CI=Confidence Interval; A=Affected; NA=Non-affected; U=Unimanual;

B=Bimanual; OE=Occupationally Embedded Exercise; MT=Movement Time

* $p < .05$

Table 6

Nonparametric test and Effect Size (d) Results of Movement Units

| Comparison | Sum of Ranks | Mann-Whitney <i>U</i> | <i>p</i> (one tailed) | <i>d</i> |
|-------------------------|--------------|-----------------------|-----------------------|----------|
| Hypothesis 3 | | | | |
| A U OE vs. NA U OE | 192, 108 | 30.0 | *0.008 | 0.90 |
| A U Rote vs. NA U Rote | 140, 160 | 62.0 | 0.291 | 0.94 |
| A B OE vs. NA B OE | 198, 102 | 24.0 | *0.003 | -0.09 |
| A B Rote vs. NA B Rote | 175.5, 124.5 | 46.5 | 0.073 | 0.62 |
| Hypothesis 4 | | | | |
| NA U OE vs. NA B OE | 110, 190 | 32.0 | *0.011 | 1.19 |
| NA U Rote vs. NA B Rote | 123, 177 | 45.0 | 0.060 | 0.84 |
| Hypothesis 5 | | | | |
| A U OE vs. A B OE | 164, 136 | 58.0 | 0.433 | 0.42 |
| A U Rote vs. A B Rote | 157.5, 142.5 | 64.5 | 0.686 | 0.44 |

Note. A=Affected; NA=Non-affected; U=Unimanual; B=Bimanual; OE=Occupationally Embedded Exercise

**p* < .05

Table 7

Hypothesis 4 t-test and Effect Size (d) Results of Kinematic Variables

| Variable | <i>n</i> | <i>M</i> | <i>SD</i> | 95% CI | <i>t</i> | <i>dF</i> | <i>p</i> (one tailed) | <i>d</i> |
|--------------------------|----------|----------|-----------|-------------------|----------|-----------|-----------------------|----------|
| Movement Time (s) | | | | | | | | |
| NA OE | | | | | | | | |
| U vs. B | 12 | -0.40 | 0.34 | [-0.61, -0.18] | -4.06 | 11 | *0.001 | 1.36 |
| NA Rote | | | | | | | | |
| U vs. B | 12 | -0.35 | 0.36 | [-0.58, -0.12] | -3.31 | 11 | *0.004 | 1.25 |
| Displacement (mm) | | | | | | | | |
| NA OE | | | | | | | | |
| U vs. B | 12 | -124.28 | 106.06 | [-191.67, -56.90] | -4.06 | 11 | *0.001 | 1.45 |
| NA Rote | | | | | | | | |
| U vs. B | 12 | -107.85 | 111.29 | [-178.56, 37.14] | -3.36 | 11 | *0.003 | 1.25 |
| Peak Velocity (mm/s) | | | | | | | | |
| NA OE | | | | | | | | |
| U vs. B | 12 | 136.93 | 175.88 | [25.18, 248.68] | 2.70 | 11 | *0.011 | 0.83 |
| NA Rote | | | | | | | | |
| U vs. B | 12 | 174.90 | 236.19 | [24.83, 324.97] | 2.57 | 11 | *0.013 | 0.99 |
| % of MT to Peak Velocity | | | | | | | | |
| NA OE | | | | | | | | |
| U vs. B | 12 | 0.08 | 0.14 | [-0.01, 0.17] | 1.97 | 11 | *0.037 | 0.62 |
| NA Rote | | | | | | | | |
| U vs. B | 12 | 0.01 | 0.14 | [-0.08, 0.10] | 0.18 | 11 | 0.430 | 0.07 |

Note. Mean and Standard Deviation are difference scores. CI=Confidence Interval; A=Affected; NA=Non-affected; U=Unimanual;

B=Bimanual; OE=Occupationally Embedded Exercise; MT=Movement Time.

* $p < .05$

Table 8

Hypothesis 5 t-test and Effect Size (d) Results of Kinematic Variables

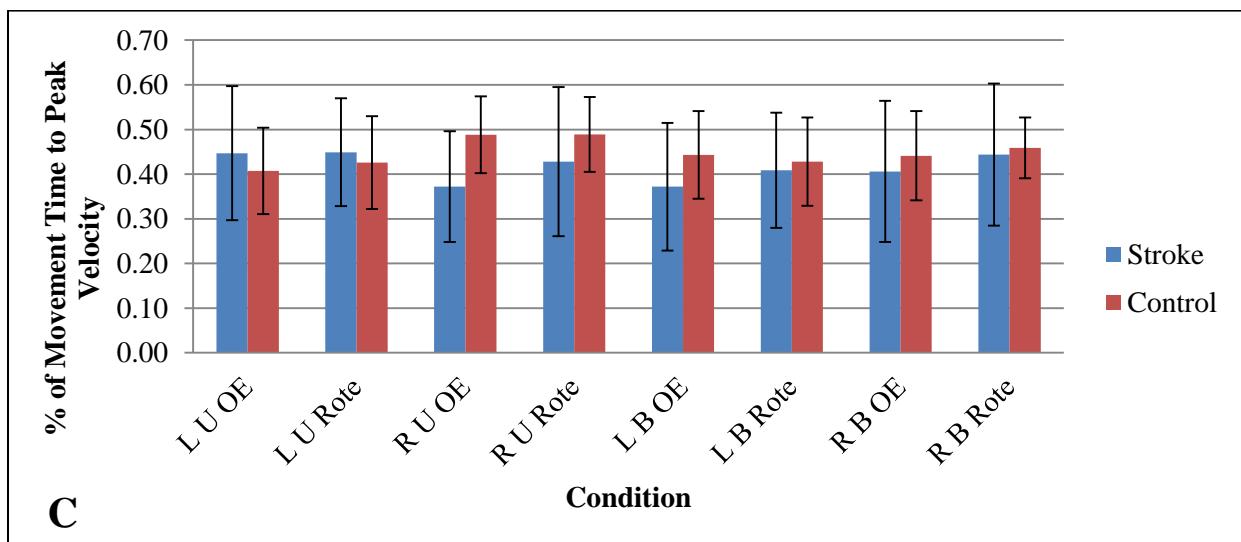
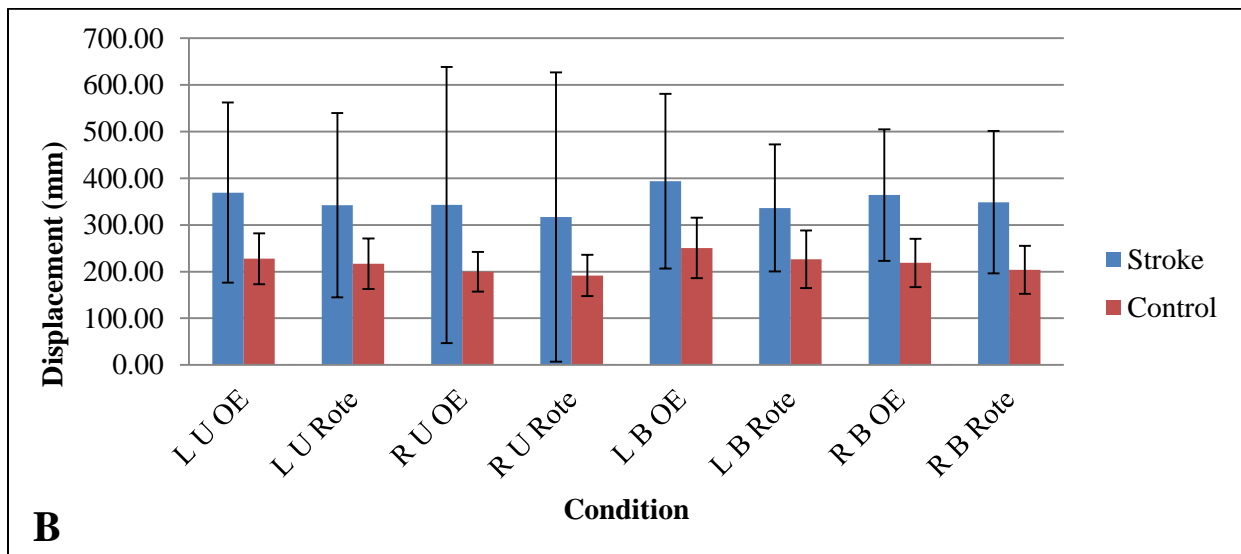
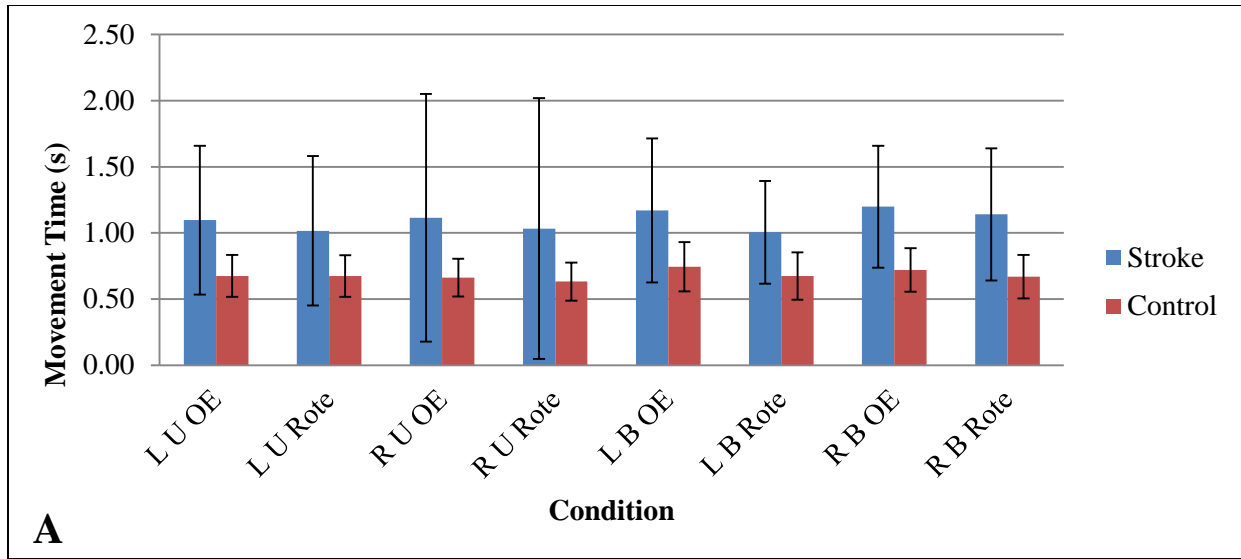
| Variable | <i>n</i> | <i>M</i> | <i>SD</i> | 95% CI | <i>t</i> | <i>dF</i> | <i>p</i> (two tailed) | <i>d</i> |
|--------------------------|----------|----------|-----------|------------------|----------|-----------|-----------------------|----------|
| Movement Time (s) | | | | | | | | |
| A OE | | | | | | | | |
| U vs. B | 12 | 0.24 | 0.64 | [-0.17, 0.65] | 1.27 | 11 | 0.229 | 0.31 |
| A Rote | | | | | | | | |
| U vs. B | 12 | 0.25 | 0.57 | [-0.11, 0.61] | 1.51 | 11 | 0.160 | 0.32 |
| Displacement (mm) | | | | | | | | |
| A OE | | | | | | | | |
| U vs. B | 12 | 78.85 | 204.35 | [-50.98, 208.69] | 1.34 | 11 | 0.209 | 0.31 |
| A Rote | | | | | | | | |
| U vs. B | 12 | 81.80 | 186.09 | [-36.44, 200.03] | 1.52 | 11 | 0.156 | 0.33 |
| Peak Velocity (mm/s) | | | | | | | | |
| A OE | | | | | | | | |
| U vs. B | 12 | -10.10 | 132.75 | [-94.45, 74.24] | -0.26 | 11 | 0.797 | 0.04 |
| A Rote | | | | | | | | |
| U vs. B | 12 | -33.25 | 158.41 | [-133.90, 67.40] | -0.73 | 11 | 0.482 | 0.14 |
| % of MT to Peak Velocity | | | | | | | | |
| A OE | | | | | | | | |
| U vs. B | 12 | -0.04 | 0.25 | [-0.20, 0.12] | -0.53 | 11 | 0.609 | 0.24 |
| A Rote | | | | | | | | |
| U vs. B | 12 | 0.02 | 0.32 | [-0.18, 0.22] | 0.18 | 11 | 0.860 | -0.09 |

Note. Mean and Standard Deviation are difference scores. CI=Confidence Interval; A=Affected; NA=Non-affected; U=Unimanual;

B=Bimanual; OE=Occupationally Embedded Exercise; MT=Movement Time



Figure 1. Motion Analysis Laboratory Setup



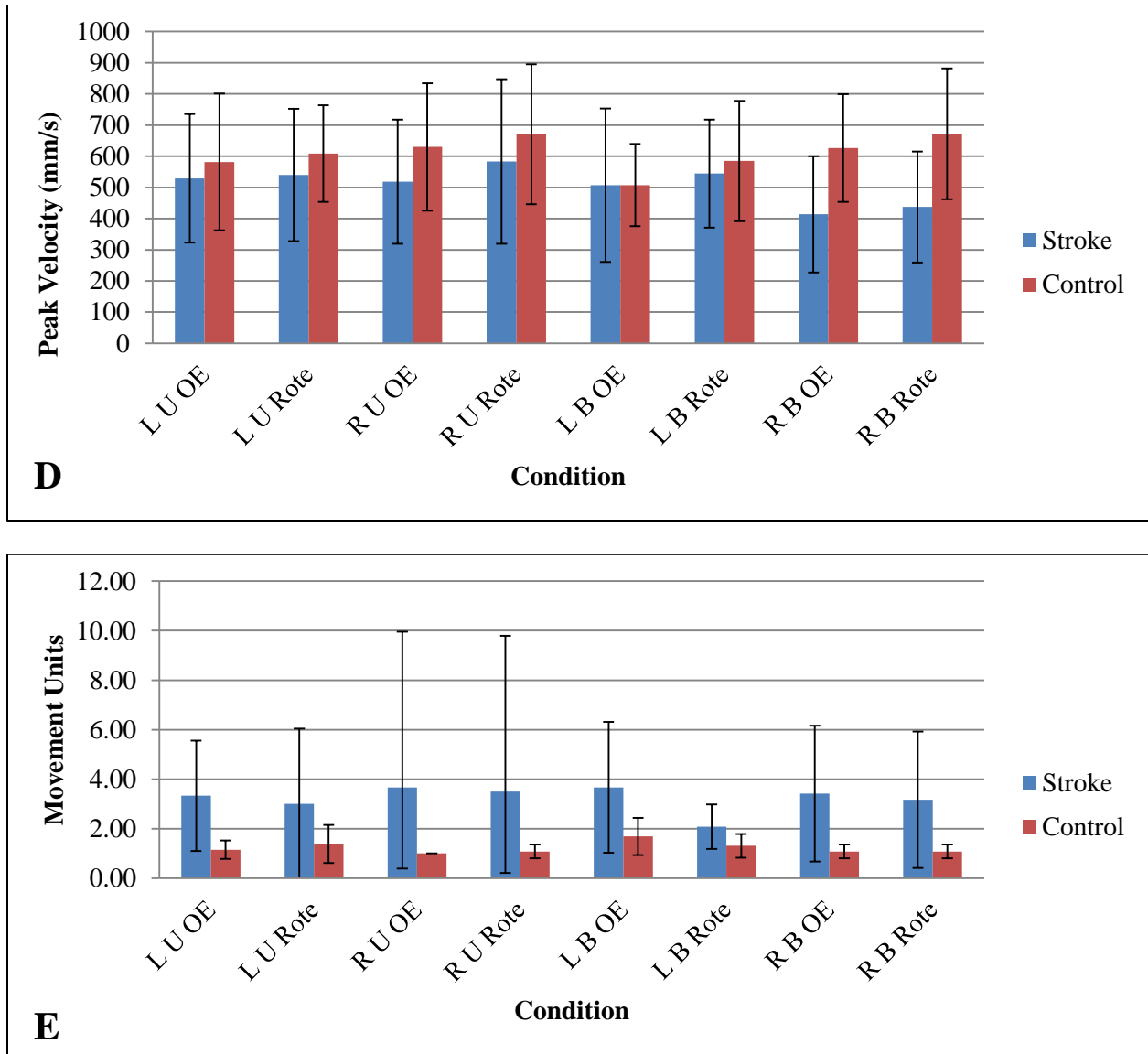
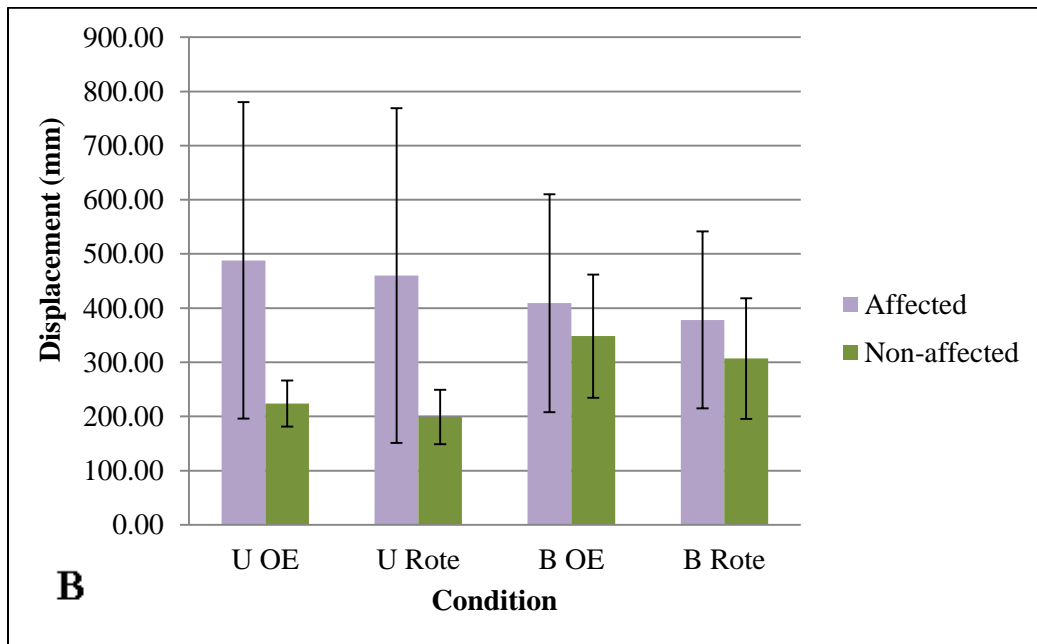
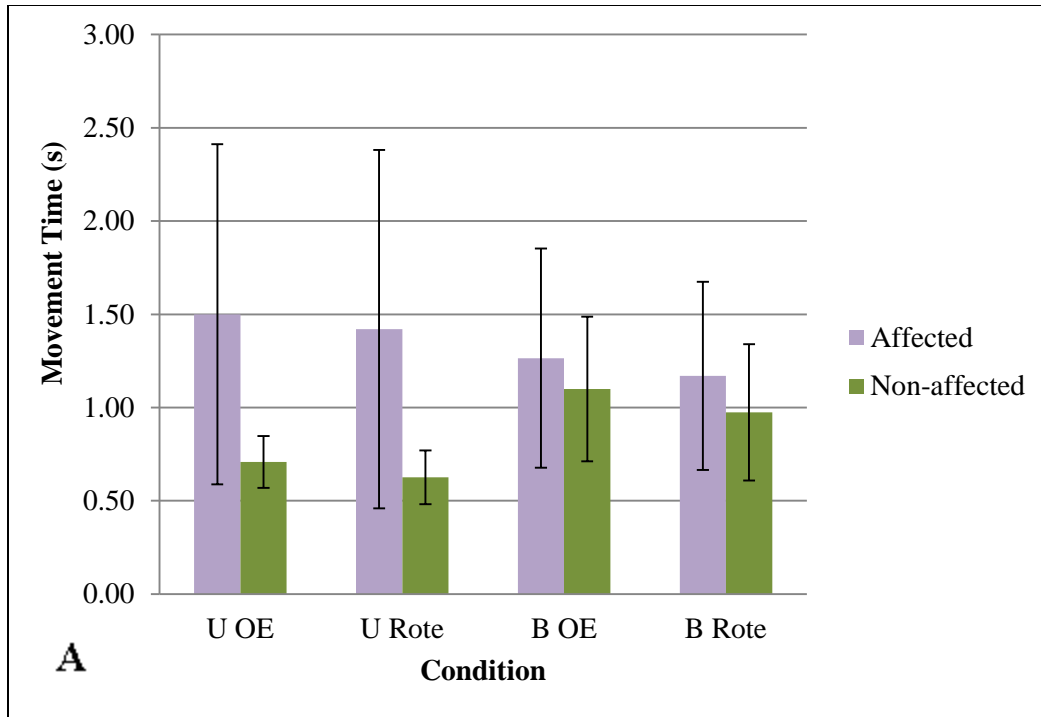


Figure 2. Bar Graphs of Stroke and Control Participant Group Means in all Conditions for (A) Movement Time, (B) Displacement, (C) % of Movement Time to Peak Velocity, (D) Peak Velocity, and (E) Movement Units. Error bars represent the standard error of the mean.



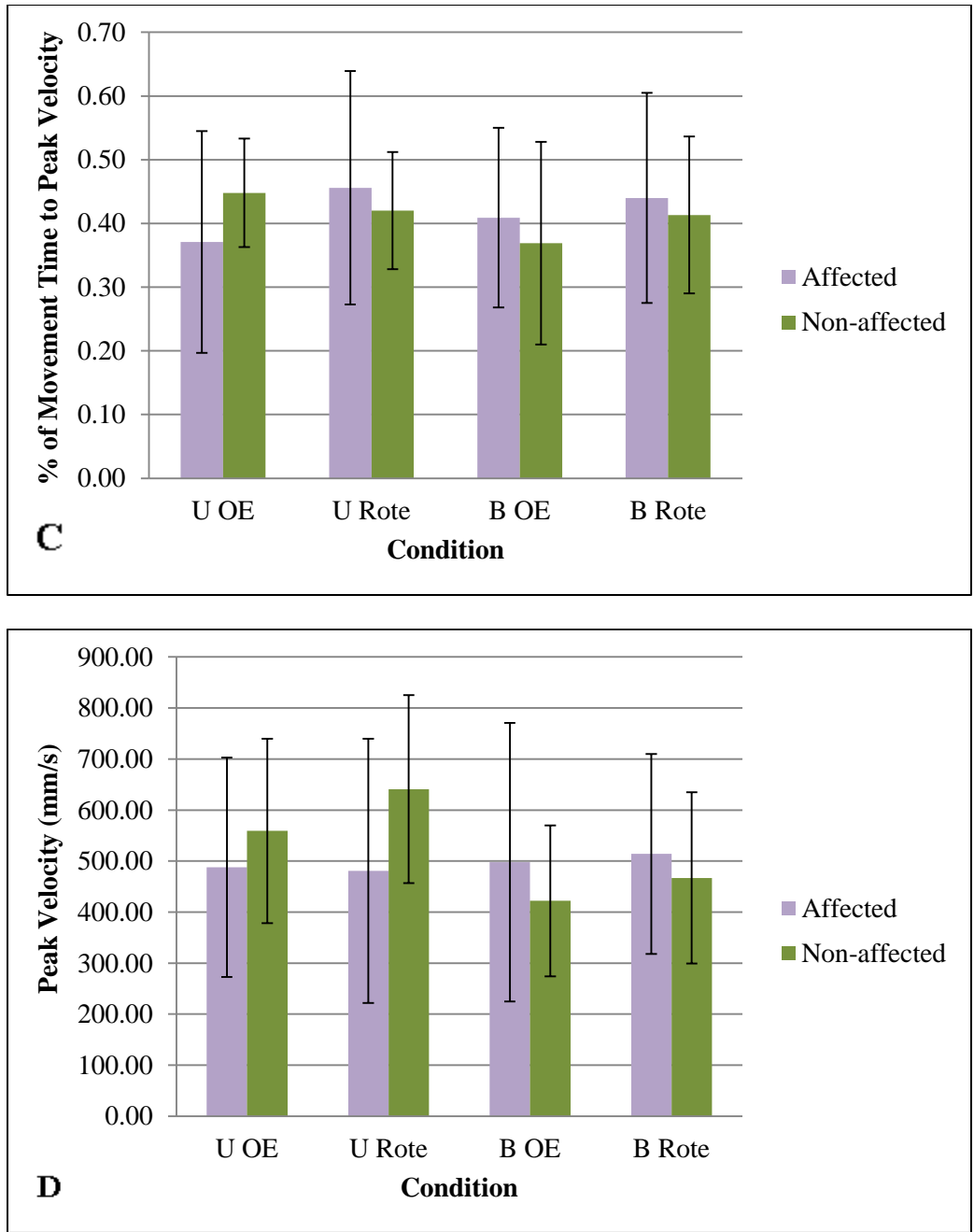


Figure 3. Bar Graphs of Stroke Participant Group Means in all Conditions for (A) Movement Time, (B) Displacement, (C) % of Movement Time to Peak Velocity, and (D) Peak Velocity. Error bars represent the standard error of the mean.