Cross-Transfer Effects in the Upper Extremity During an Occupationally Embedded Exercise

Marica Juratovic Nagel, Martin S. Rice

Key Words: human activities and occupations • laterality • motor control

Objective. Cross-transfer effects were investigated during an occupationally embedded task that involved learning a fine motor skill. Cross-transfer is a phenomenon that occurs when an untrained limb receives some of the same benefits in performance from unilateral training that the contralateral limb received. It was hypothesized that cross-transfer would occur after a unilateral training regime using an occupationally embedded task.

Method. Forty-eight participants (mean age = 24.4 years) volunteered for this repeated-measures study. Participants were randomly assigned to a training or control group and were asked to complete a toy maze with their right and left hands for the pretest and posttest. Whereas participants in the control group did not train, participants in the training group completed a toy maze three times a day for 7 days with their left hands. All participants returned in 1 week to complete the posttest portion of the experiment. Dependent variables included movement time, movement units, force oscillations, and average force.

Results. Significant decreases in movement time and force oscillations were found for the untrained limbs \((p < .0125)\) in the training group. No significant differences were found in movement units or average force. The improved movement time and force oscillations in the untrained limb provides evidence suggesting that cross-transfer occurred.

Conclusion. This study indicates that with a population without impairments, cross-transfer can occur during an occupationally embedded task. This phenomenon may prove useful to the field of occupational therapy to rehabilitate immobilized extremities. Further research is needed to test this phenomenon with special populations.

bilitate persons with hemiplegia, including neurodevelopmental treatment (Bobath, 1978), movement therapy (Brunnstrom, 1970), and motor relearning (Carr & Shepherd, 1983). Although these treatment approaches attempt to remediate the effects of hemiplegia, they also attempt to cause a change holistically within the person that facilitates better motor control of the affected extremities. There is a dearth of research, however, on restorative strategies specifically aimed at improving the motor control of the affected extremities. Coupled with an occupationallty embedded task, the present study examined the effects of a unilateral training regime on improving motor control in an untrained limb in a healthy population.

**Literature Review**

Cross-transfer is a phenomenon that occurs when an untrained limb receives some of the same benefits in performance from unilateral training that the contralateral limb received. As early as 1894, Scripture, Smith, and Brown demonstrated that the training of one hand could increase the performance of the other, untrained hand. The first part of Scripture et al.'s study involved fine motor training that required repeated touching of a target area with a probe. After the 2,000-trial training regime, data indicated that accuracy increased in both the trained and the untrained limbs. In the same study, the researchers examined upper-extremity muscle strength. They found that practicing dumbbell curls with one arm increased muscle strength in the trained arm as well as in the untrained arm.

Since Scripture et al.'s (1894) contribution, other investigations of cross-transfer have been performed. Hellebrandt, Parrish, and Houtz (1947) examined heavy-resistance knee-extension exercises of the right quadriceps muscles and their effects on the practiced and nonpracticed lower extremities of healthy women. The findings indicated increased muscle strength in the trained and untrained limbs. The increase seen in the untrained leg either equaled or surpassed the strength increase in the trained leg. Hellebrandt et al. noted that during knee-extension exercises, one participant displayed “powerful isometric tension...in the symmetric muscles of the unexercised side” (p. 83). In other words, even though the untrained leg was not exercised, the muscles were still contracting and thereby not “at rest” during the contralateral training regime. In the same study, the researchers investigated cross-transfer effects from heavy-resistance hand-curl exercises with one arm. Again, they found an increase in muscle strength in the trained and untrained limbs. However, the increase in muscle strength of the untrained limb did not exceed that of the trained limb.

Rider (1971) investigated cross-transfer effects in children 6 to 13 years of age with and without bilateral upper-extremity spasticity. She used the Rood (1962) method of proprioceptive neuromuscular facilitation on these children daily for 2 weeks. Half the children were facilitated on their preferred side and the other half on their nonpreferred side. At the end of the 2-week period, the results indicated an increase in muscle strength in both the facilitated and the unfacilitated limbs.

Kannus et al. (1992) investigated cross-transfer effects on strengthening in the lower extremities of 20 healthy adult men and women. The training regime involved strength training of the quadriceps and hamstring muscles in one leg three times a week for 7 weeks. Unlike in previous studies that did not control for isometric contractions, participants were instructed to keep the untrained limb “completely immobile and as relaxed as possible during the training” (p. 119). Even with the untrained limb’s isometric activity being controlled, the results indicated a cross-transfer effect in the untrained limb’s muscle strength, power, and endurance.

Rice (1998) investigated the occupational embeddedness and cross-transfer effects of movement time in the forearm muscles of healthy adults. Participants in the practice group were asked to practice daily for 6 days unilaterally turning wing nuts on an apparatus. The control group was told not to practice. The results indicated a performance increase in both arms in the practice group. As expected, the muscle group in the untrained limb homologous to the contralateral, practiced muscle group showed an increase in performance (i.e., if the participant turned the wing nuts inward using the right supinator muscles, the cross-transfer effect was seen in the left supinator muscles). However, a greater cross-transfer effect was noted in the untrained limb’s nonhomologous muscle group (i.e., if the participant turned the wing nuts inward using the right supinator muscles, a cross-transfer was seen in the left pronator muscles). Rice suggested that the effects from the unilateral training were not bound to specific homologous muscle groups; rather, the goal (i.e., turning the wing nuts in or out) contributed to the cross-transfer effect in the untrained limb.

The reason why cross-transfer occurs is poorly understood. Some researchers believe that a neuroanatomical basis for cross-transfer may exist. For instance, about 85% to 90% of the corticospinal tract crosses in the medulla so that the left primary motor cortex controls the right voluntary muscles and vice versa (Barr & Kiernan, 1993). The 10% to 15% of the axons that do not cross continue to travel through the medulla. The majority of these pathways eventually cross at several spinal cord levels and thus serve the contralateral muscles (Tortora, 1995). However, not all of the anterior corticospinal tracts cross; some (up to 3%) serve the ipsilateral muscles (Waxman & deGroot, 1995, p. 52). Hence, motor impulses arising from one of the cerebral hemispheres innervates both the contralateral and, to a lesser extent, the ipsilateral sides.

Brinkman and Porter (1979) recorded the electromyographic activity of neurons in the supplemental motor area...
connections or both. Brinkman and Porter suggested that the contralateral and ipsilateral extremities. The activation of these neurons produced movements of movement neurons were active during contralateral and ipsilateral movements. The neurons associated with the proximal joints fired at nearly the same rate during contralateral and ipsilateral movements. The neurons associated with the distal joints fired more during contralateral movements than during ipsilateral movements. In the same experiment, the researchers stimulated the pyramidal tract neurons in the SMA at the level of thepons and medulla oblongata border. Only 5% of these neurons were activated. The activation of these neurons produced movements in both the contralateral and the ipsilateral extremities. Brinkman and Porter suggested that the contralateral and ipsilateral movements may be due to cortical or subcortical connections or both.

De Guise et al. (1999) tested 11 participants without an intact corpus callosum and 11 participants without impairments on visuomotor bimanual and unimanual tasks. These researchers found that participants in the acollosal group were unable to learn the bimanual key-pressing task. Acollosal group participants who also had unilateral hemispheric damage were unable to learn the unimanual task when using the limb contralateral to the damaged hemisphere. Contrarily, the acollosal group participants with otherwise intact bilateral hemispheres were able to learn the unimanual task as well as the control group. These results support the idea that interhemispheric communication occurs through the visual system and hence facilitates the learning of bimanual and unimanual tasks.

With few exceptions, much of the cross-transfer research reported in the literature is at least 20 years old (Hellebrandt et al., 1947; Komi, Viitasalo, Rauramaa, & Vihko, 1978; Moritani & DeVries, 1979; Rider, 1971; Scripture et al., 1894). Whereas much of this research along with more recent studies (Kannus et al., 1992; Rice, 1998) focused on limb movements that depended on larger muscle groups, in the study reported here, we examined cross-transfer with a meaningful and purposeful occupation that involved a fine motor skill. The purpose of this study was to investigate whether performance improvements in an untrained limb would occur after unilateral training using an occupationally embedded fine motor task. The overall hypothesis of this study was that training would improve performance in both the trained and the untrained limbs; no such improvement would be noted in the control group. To operationalize this statement, the following hypotheses were developed:

1. The training and control groups’ movement time, movement units, force oscillations, and average force would not be different for the pretest.
2. The training and control groups’ movement time, movement units, force oscillations, and average force would be different for the posttest.
3. There would be a difference in the training group’s pretest and posttest movement time, movement units, force oscillations, and average force for each limb.
4. There would be no difference in the control group’s pretest and posttest movement time, movement units, force oscillations, and average force for each limb.

**Method**

**Design**

We used a repeated-measures design with both a training and a control group to investigate cross-transfer training effects during a fine motor occupation. The occupation in this experiment was chosen on the basis of some of the underlying tenets of occupational therapy (i.e., using interesting and productive occupations as a method of training). It was assumed that playing a maze-type game would be meaningful and purposeful to the participants.

For the purposes of this study, movement time was defined as the amount of time needed to complete the toy maze (i.e., move the metal ball from the upper-right-hand corner of the maze to the center and then back to the upper-right-hand corner) and was operationalized by measuring the time from when the participant picked up the maze from the starting position on the table to the time he or she set it back down in the same location. In tasks where the goal is to complete the task as fast as possible, the dependent variable of movement time is useful in determining performance (i.e., shorter movement times are associated with increased performance).

Movement units are used to measure the “smoothness” of movements. A movement with a greater number of movement units is less smooth than one with fewer movement units. A movement unit is one acceleration and one deceleration in succession. For example, one movement unit on an acceleration profile is when the acceleration curve crosses the zero line from a positive to a negative value and then back again to a positive value. The movement units were derived from the reflective marker’s position throughout the trial. The position time series from the reflective marker for each trial was calculated by taking the square root of the sum of the squared x, y, and z coordinates for each data sampling. Acceleration was calculated from the positional time series by dividing the change in velocity by the change in time. Once the acceleration was calculated for the trial acceleration, oscillations of $\pm 5 \text{ mm/s}^2$ or greater were counted to determine the number of movement units (Kluzik, Fetters, & Coryell, 1990).

Average force was determined by calculating the aver-
age thumb force the participant applied to the force sensing resistor (FSR) while completing the maze. Force oscillations were used as a measurement of the isometric force variability within each trial. More specifically, a single force oscillation is when the force tracing crosses back and forth over its median value one time. The fewer the force oscillations, the more efficient the movement.

Participants

A convenience sample of 48 graduate and undergraduate students was recruited via brochures and word of mouth from the numerous schools and departments at the Medical College of Ohio, The University of Toledo, and Bowling Green State University. Included in the sample were 13 men with a mean age of 23.23 years ($SD = 2.39$) and 35 women with a mean age of 24.83 years ($SD = 4.91$). All participants were self-reported right-hand dominant, and all denied having any neurological or orthopedic condition that would adversely affect their performance in this study. Participants were randomly assigned to either the training or the control group, with 24 in each group.

Apparatus

The training and testing devices were plastic toy mazes with a metal ball (see Figures 1 and 2). A flat, wooden stem approximately 6 in. long was permanently fastened to the back of each toy. Participants grasped the stem to control the maze. The stem on the testing device included an FSR. Force sensing data were collected using a sampling frequency of 60 Hz on a Gateway 2000 Solo 166 MHz Pentium Laptop computer using Test Point data acquisition software version 3.2B1 with a 16-bit KPCMCIA-16A1 analog-to-digital PCMCIA data acquisition card.

Four strobe-equipped Cohu 4915 cameras6 were used to record the movements of the reflective marker (2 cm in diameter) at a sampling frequency of 60 Hz. A Motion Analysis Corporation Hi-Resolution system with EVa HiRES software version 4.07 was used for the three-dimensional motion analysis data acquisition.

---

1Model #16-1959, Dillon Importing Company, 300 N. MacArthur Boulevard, Oklahoma City, Oklahoma 73127.
2Interlink Electronics, 546 Flynn Road, Camarillo, California 93012.
3Gateway, PO Box 2000, 610 Gateway Drive, North Sioux City, South Dakota 57049.
4Capital Equipment Corporation, 900 Middlesex Turnpike, Building #2, Billerica, Massachusetts 01821.
5Keithley Instruments, Inc., 28775 Aurora Road, Cleveland, Ohio 44139.
6Cohu, Inc., Electronics Division, 5755 Kearny Villa Road, San Diego, California 92123.
7Motion Analysis Corporation, 3617 Westwind Boulevard, Santa Rosa, California 95403.
motor control (e.g., arm movements, postural stability). In addition, the placement of the marker along with the arrangement of the four cameras provided optimal data capture throughout the entire task. Participants were given the following instructions:

Stand inside of the black box on the floor. Take the handle of the maze in your [right, left] hand and place your thumb on the top [on the FSR] and the side of your index finger on the bottom like this [experimenter demonstrates a lateral key pinch]. When I say, “Begin,” I want you to move the ball through the maze. When the ball gets to the center, move the ball back to the beginning. You must get the ball all the way to the center of the maze before returning it to the beginning. While you are doing this, I want you to relax your other arm. This is a timed task, so work as quickly as you can. Do you have any questions? Ready? Begin.

On completion of the task, the reflective marker was removed. After a 5-min break, the reflective marker was placed on the other thumb. Participants were asked to perform the occupation again using this other hand. This completed the pretest portion of the experiment.

Participants in the training group were given a training toy maze (identical to the test maze, except no FSR was attached), an instruction sheet, and verbal instructions. These participants were asked to complete the occupation three times a day for 7 days using their left hands and to relax their right limbs while doing so. The participants were then instructed to sign scorecards each time they properly completed the daily training. All participants were asked to return to the testing site in 1 week to complete the posttest portion of the experiment. The posttest followed the same procedure as the pretest.

The left hand was chosen for the training regime in an attempt to reduce the chances of reaching a “ceiling effect,” which we based on the assumption that the left limb is not the preferred limb to perform unilateral fine motor tasks and, therefore, would be less likely to plateau as quickly in its learning curve compared with the dominant right hand. This assumption is based on the work of Tan and Kutlu (1992) who examined unilateral fine motor tasks on each hand in right-handed adults. They found that the participants performed the fine motor task faster with their preferred hand than with their nonpreferred hand. In addition, it has been demonstrated that during a bimanual task, the nondominant limb influences the dominant limb more so than visa versa (Ibbotson & Morton, 1981; Walter & Swinnen, 1990).

Data Analysis

Data for hypotheses 1 and 2 were found to be skewed; therefore, the Mann Whitney U test, a nonparametric test for independent samples, was used to analyze these data. Alpha was set at .05 for both analyses. Data for hypotheses 3 and 4 were also skewed; therefore, the Wilcoxon signed rank test, a nonparametric test for related samples, was used to analyze these data. Bonferroni corrections at the .0125 alpha level were applied to these comparisons because there were four comparisons per dependent variable.

Results

Data from two participants in the control group were eliminated from the analysis because of a computer hard disk failure. Hypothesis 1 was supported in that no significant difference was found for the movement time, movement units, force oscillations, or average force between the training group pretest and the control group pretest (see Table 1).

Significant differences in movement time, movement units, and force oscillations were found during the posttest between the training and control groups, and hence, hypothesis 2 was supported. However, no difference was found in average force during the posttest between the two groups (see Table 1).

The training group demonstrated a significant decrease in movement time between the pretest and posttest for both the trained and the untrained limbs, thereby supporting hypothesis 3 (see Table 2). A significant difference was also found in the number of force oscillations in the untrained limb; however, no significant force oscillation difference was found in the trained limb (see Table 2). In addition, no significant difference in movement units or average force was found between the training group’s pretest and posttest performances for each limb (see Table 2).

Hypothesis 4 was supported in that no significant decrease between the pretest and posttest in movement time, movement units, force oscillations, or average force was found in the left or right hands for the control group (see Table 2). No significant difference was found for the order of presentation (i.e., right→left, left→right) on any of the dependent variables ($p > .05$).

Discussion

Data from this study show that the control and training groups performed at about the same levels for the pretest portion of the experiment, but the training group took significantly less time, used significantly fewer movement units, and used significantly fewer force oscillations than the control group for the posttest portion of the experiment. These results suggest that the changes seen in the training group were due to the unilateral training regime and not extraneous variables.

Our findings, like those in the past (e.g., Hellebrandt et al., 1947; Kannus et al., 1992; Komi et al., 1978; Moritani & DeVries, 1979; Rice, 1998; Rider, 1971; Scripture et al., 1894), demonstrate that unilateral training can improve the performance in the untrained, contralateral limb. As hypothesized, movement time was found to decrease in both the trained and the untrained limbs; additionally, the amount of force oscillations decreased in the untrained limb. The data indicate that practicing with the left hand caused a decrease in the amount of time needed to complete the toy maze with the left hand. The data also indicate that just by practicing with the left hand, partici-
pants were able to decrease the movement time and force oscillations needed to complete the toy maze with the untrained (i.e., right) hand. Thus, cross-transfer occurred in the right limb as evidenced by the decreased movement time and force oscillations.

These results are similar to the findings from Rice (1998) in that both studies found a decrease in movement time of the untrained upper extremity during a timed task. Although the task in the earlier Rice study involved turning resistive wing nuts, requiring upper-extremity strength and endurance, the current study involved a fine motor task that depended more on the intrinsic muscles of the hand for successful completion.

Following Hellebrandt et al.’s (1947) suggestions for the cause of cross-transfer, one would assume that a decrease in force oscillations would be apparent in the trained and untrained limbs. Although not significant, the mean force oscillation for the trained limb showed a decrease from the pretest to the posttest and thus followed the same trend as the untrained limb. It is unclear why the force oscillation results for the untrained limb had a greater decrease than the trained limb. It is important to note that similar findings were reported by Hellebrandt et al. They reported that the strength of the untrained quadriceps muscle actually surpassed that of the trained quadriceps muscle. Perhaps in the current study, the untrained limb (i.e., the right hand) of these right-handed participants was more efficient in fine motor use and, therefore, the amount of force used was more controlled. More controlled use of the left limb may have been apparent if the training regime lasted longer than 7 days. Data showed that the average force for the training group actually increased slightly. Perhaps the average force was more a measurement of stabilizing the maze, which was learned relatively quickly, whereas the force oscillation was more an indicator of the slight adjustments between the thumb and index finger to control the tilt of the maze.

Results for movement units and average force indicated that the unilateral training did not significantly affect these dependent variables, although a slight decrease in movement units was apparent in both the trained and the untrained limbs. It is possible that the actual control of the maze occurred distal to where the marker was placed on the thumb. That is, the maze was controlled by slight movements between the thumb and index finger, with little or no range of motion occurring at the interphalangeal joints.

This study had several limitations. First, the take-home instructions given to the training group did not specify that the participant stand while practicing the maze. Some participants may have chosen to stand, whereas others may have trained while sitting. Therefore, the training conditions could have been different from the testing conditions (i.e., the arm may have been positioned differently during the training and testing conditions). Second, although training group participants were given a scorecard, the training regimen was otherwise unmonitored. Another limitation was that the researcher was aware of the hypotheses and may have unknowingly influenced participant performance. Lastly, even though the type of maze was a relatively common toy, it was assumed that the participants in this study did not have recent experience with the maze before participating in this study.

Much more research is needed in the cross-transfer...
arena. It would be beneficial to study cross-transfer effects in a variety of fine motor and gross motor occupations, particularly those that are occupationally embedded. It is also necessary to examine cross-transfer effects as they relate to different age groups and to groups with disabilities. Researching the duration of training time needed for cross-transfer effects to occur is another area that has not yet been investigated.

Implications for Practice
Although these results are based on a population without disabilities and, therefore, cannot be generalized to special populations, cross-transfer is a viable option in occupational therapy practice. Consider the patient during the first few days after surgical repair of muscles, tendons, or both in one upper or lower extremity. It is possible to begin unilateral training on the healthy limb to start the therapeutic process immediately after surgery. Maintenance of surrounding muscle integrity as well as recovery of muscle strength could occur by involving the nonaffected limb in a variety of tasks. Cross-transfer methods may also apply to neurological injuries, for example, those found in persons with hemiplegia due to cerebral vascular accident. Even though paresis is present in the affected side, it may be possible to enhance the affected limb’s performance by asking the person to use his or her unaffected limb to practice specific types of occupations.

Findings from this study suggest that in a sample of healthy young adults, cross-transfer effects occur in terms of movement time and force oscillations during an occupationally embedded fine motor task. Although practitioners can employ the concept of cross-transfer in treatment contexts, more research is needed to corroborate these findings. ▲

Acknowledgments
This study was provided support by a grant from the Medical College of Ohio Graduate School. This study was completed in partial fulfillment for the degree of Master of Occupational Therapy from the Medical College of Ohio by the first author.

References


