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Asymmetrical Transfer of Training between Hands: Implications for Interhemispheric Communication in Normal Brain

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Two experiments are presented which investigated claims of asymmetrical transfer of training between the hands/hemispheres. In Experiment 1, 96 right- and left-handed male undergraduates practiced an inverted–reversed printing task with either the right or the left hand. Transfer to the opposite hand was then compared to same-hand transfer, in a between-subject design. In Experiment 2, 176 right-handed boys and girls were tested at ages 7, 9, and 11 years. For right-handed subjects in both experiments, the left hand benefited more from opposite-hand training than did the right. The reverse was true for left-handers in Experiment 1, although one group (who wrote with the "inverted" position) showed little transfer in either direction. Two current models of interhemispheric interaction do not satisfactorily explain these findings. A third model, based on cross-activation, may provide a more effective alternative.

Practicing a novel task with one hand typically facilitates subsequent performance of the opposite, untrained hand in the same task. This phenomenon is known as lateral transfer of training, or, in the older literature, "cross-education." Transfer from left to right hands and from

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right to left hands has been observed for a wide variety of manual tasks (see reviews by Bray, 1928; Wieg, 1932; Ammons, 1958), although few studies have looked at transfer in both directions within the same experiment. Two recent motor laterality studies (Hicks, 1974; Taylor & Heilman, 1980) have done this, using inverted–reversed printing and sequential finger movement tasks, respectively. In both, lateral transfer was found to be asymmetrical in that the right hand benefited more than the left from opposite-hand training (see also Welch, 1898; Freeman, 1938; Briggs & Brogden, 1953; Meier & French, 1965). To explain their findings, these authors have invoked what might be called a (callosal) *access* model which links the direction of greater transfer with hemispheric specialization for these tasks, specifically of the left hemisphere (which controls the right hand). Taylor and Heilman (1980) argued that "The right hand [has] direct access to skills learned by the left hand (and stored in the left hemisphere) whereas the left hand [has] only indirect access, across the callosum, to skills learned by the right hand (and also stored in the left hemisphere)" (p. 558).

Detailed examination of the literature reveals, however, several studies in which the left hand benefited more than the right from opposite-hand training in mirror-drawing, rotor pursuit, and fast tapping tasks (Ewert, 1926; Ammons & Ammons, 1951; Ammons, 1958; Laszlo, Baguley, & Bairstow, 1970). These authors referred to the greater proficiency of the right hand for most unimanual skills, due either to left hemispheric specialization or perhaps to greater practice. They have presented a *proficiency* model, arguing that the more proficient hand (hemisphere) learns more "elements" during training (Ammons, 1958) or perhaps forms a better standard (Laszlo et al., 1970) which then can be used to advantage by the untrained hand.

That directional effects in the transfer of training between hands may be linked to brain organization, and specifically to hemispheric specialization of function, is a provocative idea. More importantly, these data suggest that use of the lateral transfer paradigm may shed light on the interaction of left and right hemispheres in the performance of complex behaviors.

In this article, we present two experiments which look at the issue of directional effects in transfer. Both studies use the inverted–reversed printing task described by Hicks (1974). In Experiment 1, data from left- and right-handed adults are compared. Data from right-handed children at ages 7, 9, and 11 years are then considered in Experiment 2.

According to the (direct versus indirect callosal) *access* model, lateral transfer should favor the right hand (in right-handed subjects). Also, performance should correlate more highly in the right-to-left transfer condition than the reverse. The *proficiency* model generates the converse prediction, that the left hand should benefit more than the right from opposite-hand training. Possibly, correlations should also differ in the converse direction.

We chose a between-subject design which permitted us to compare same-hand and opposite-hand training separately for left and right hands. This made quantification of the amount of transfer or "gain" attributable to opposite-hand training possible, expressed as a percentage of the average gain observed for that hand under same-hand training conditions. Use of the between-subject design also eliminated hand order effects, as transfer was assessed in only one direction for any given subject.

In Experiment 1, the focus was on right- and left-handed adults. Because our previous research had elicited differences in manual performance between left-handers who used the "inverted" writing position (left-inverters (LIs)) and those who did not (left-noninverters (LNs)) (Parlow, 1978; Parlow & Kinsbourne, 1981; see also Levy & Reid, 1976, 1978), we chose to include both groups in our sample. On the basis of this work (cf. Parlow & Kinsbourne, 1981), we predicted that LN subjects would perform opposite to right-handers, whereas asymmetries would be less pronounced in LI subjects. To simplify the design, only males were tested.

EXPERIMENT 1

Method

Subjects

Ninety-six male undergraduates (including 48 right-handers and 48 left-handers) participated. Information on handwriting posture, familial sinistrality, and hand preference was obtained from each subject. Left-handers who wrote with the pen nib facing the body and the wrist inverted with the hand above the line of writing were classed as LIs. Those who wrote with wrist held straight and the hand below the line of writing, so that the pen nib faced away from the body (or vertically), were classed as LNs. Two subjects were discordant for pen and/or wrist position. These subjects were asked to adopt an exaggerated form of both postures and subsequently stated a preference for the LN posture. In the final sample, half of the left-handed subjects used the LN posture, and half the LI posture. One right-hander tested used an inverted, "clubbed" handwriting position and was omitted from the study. The remaining right-handers all used the noninverted writing position. LI and LN subjects did not differ significantly in reported familial sinistrality ($t = 1.16$) or in the extent of left-hand preference as indicated on a 15-item handedness questionnaire ($t < 1$). Twelve of the LN subjects (50%) and 16 of the LI subjects (66.7%) reported at least one left-handed sibling, parent, or other close relative (grandparent or aunt/uncle by blood); 9 of the right-handers (18.8%) reported such a history. LN subjects indicated a left-hand preference for an average of 11.1 and LI subjects, 11.0 common tasks (e.g., writing, using scissors or a toothbrush, dealing cards). In contrast, a left-hand preference was rarely endorsed by right-handers ($M < 1$).

Apparatus and Materials

Subjects were provided with two wide-ruled, legal size sheets of paper (33.5 × 21.0 cm) and a pencil. Ten- and fifteen-second time intervals were established by two linked electronic timers (Hunter Manufacturing, Model 111-C, Series D) connected to a Mallory Sonalert audible signal.

Procedure

Subjects within each handedness group were assigned randomly in equal numbers to one of four experimental groups. The groups were R–R, R–L, L–R, and L–L, with the first letter indicating the hand used (right or left, R or L) in the first phase of the session (trials 1–10) and the second letter the hand used in the second or test phase (trials 11–20).

One to four subjects were tested at a time and instructed to print the uppercase letters of the alphabet in inverted–reversed orientation as rapidly as possible. Subjects printed from the lower right corner of the page to the left, and from the bottom of the page to the top. Some subjects within each session were asked to begin with the preferred hand and some with the nonpreferred hand. All subjects were advised to concentrate on improving their own performance and not to be concerned with the performance of others.

Two blocks of ten 30-sec trials were given, 20 trials in all. The beginning and end of each trial were indicated by a tone. Upon completing a trial, subjects were instructed to mark two closely spaced diagonal lines to the left of the last letter completed, and they were permitted to turn the page 180° to check for errors. After 15 sec, a timer sounded the beginning of the next trial. With the paper in its original position, the next trial began on the same line with the letter of the alphabet which immediately followed the last letter completed in the previous trial. This procedure ensured that subjects completed the entire alphabet before beginning again with the letter A, and also that subjects did not copy preceding lines. A 2-min rest interval was provided between trials 10 and 11.

Two dependent measures were recorded for each test trial (11–20): (1) the number of letters printed in the correct orientation (inverted and reversed) and, (2) the number of letters incorrectly printed. A letter was considered to be in error if it was printed in any orientation other than the required one, or if it was incomplete. Complete but poorly formed letters were scored as correct, if they were in the required orientation. After completing the training trials, subjects made few errors and this measure was subsequently dropped from the analysis.

Results

To simplify analysis, left- and right-hand scores were recoded to accommodate hand preference. Preliminary investigations then established (1) that handwriting posture had not influenced the performance of left-handers during the test trials, either as a main effect or in interaction with other variables (using ANOVA), and (2) that neither familial sinistrality nor preferred-hand preference scores (two potential covariates) were substantially correlated with performance for the sample as a whole. An ANOVA was then performed to assess the effects of handedness (right-handed vs. left-handed), hand (preferred vs. nonpreferred, P vs. N), type of training (same- vs. opposite-hand), and trials, with the latter the only within-subjects factor. All within-subjects effects were tested with the Greenhouse–Geisser conservative F test and when reported as significant were also significant by this test.

This analysis revealed main effects for hand, $F(1, 88) = 56.26$, $p < .001$, type of training, $F(1, 88) = 6.53$, $p < .05$, and trials, $F(9, 792) =$

23.77, $p < .001$, but not for handedness ($F < 1$). As expected, the preferred hand was superior to the nonpreferred hand, same-hand training was superior to opposite-hand training, and performance improved across trials. The trials × type of training interaction was also significant, $F(9, 792) = 2.88$, $p < .01$. This interaction had a large linear component, $F(1, 88) = 11.02$, $p < .01$, in the absence of substantial deviation from linearity ($F < 1$). A trial by trial comparison (using one-tailed t tests) indicated that the superiority of same-hand training was relatively short-lived and did not persist beyond trial 15 (Fig. 1).

The two factors of primary interest—the hand × type of training and the hand × type of training × trials interactions—were not significant, $F(1, 88) = 2.06$, $p = .15$, and $F < 1$, respectively.

Hand differences may have been obscured in this analysis, however. Groups N–P and P–N received same-hand training subsequent to the first transfer trial, complicating interpretation of their performance on these trials. In addition, the range of performance for the preferred hand was considerably greater than for the nonpreferred hand, creating a possible scaling problem. We therefore proceeded with planned com-

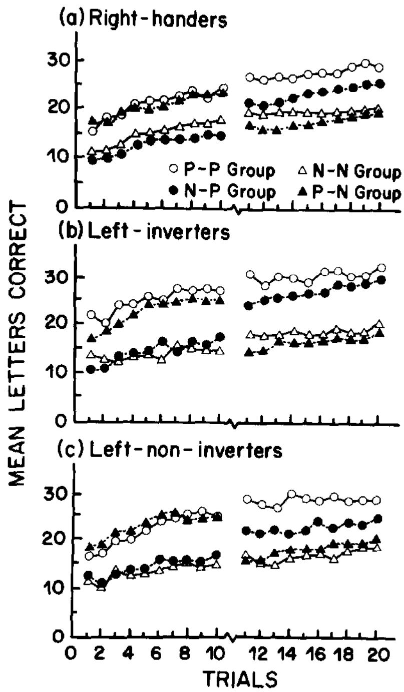

FIG. 1. Mean letters correctly printed in Experiment 1, as a function of trial and group for (a) right-handers, (b) left-inverters, and (c) left-noninverters. P, preferred hand; N, nonpreferred hand.

parisons (two-tailed) on trial 11 alone. According to the *access* model, same-hand training should have been superior to opposite-hand training for the nonpreferred but not for the preferred hand. The *proficiency* model generated the opposite prediction.

Comparisons of groups N–P and P–P (collapsed across handedness) revealed a significant difference, $t(46) = 3.30$, $p < .005$. This was not true for groups P–N and N–N, $t(46) = 1.77$, $p = .08$. The pattern was confirmed when trials 11–13 were averaged together to provide a more stable estimate of performance (N–P vs. P–P: $t(46) = 3.08$, $p < .005$; P–N vs. N–N: $t(46) = 1.48$, n.s.). Thus, same-hand training was superior to opposite-hand training for the preferred hand but not for the nonpreferred hand, supporting the proficiency model.

Transfer Gain

The preceding analysis did not take baseline differences in hand proficiency or rate of learning into account. In fact, analysis of acquisition data (using ANOVA) had revealed that preferred hand scores began at a higher level than nonpreferred hand scores and improved at a faster rate. Furthermore, possible handedness/handwriting posture group differences were noted on trial 1 (for the latter, $p < .07$). Transfer "gain" scores were therefore calculated for each hand and handedness group.

The difference between the transfer test score (averaged across trials 11–13) for each subject in groups P–N and N–P and the average score for that hand obtained by subjects in the same handedness category on trial 1 yielded an estimate of the amount of transfer (relative to the baseline or no training state) attributed to opposite-hand training. This score was then expressed as a percentage of the actual gain scores calculated for subjects in same-hand training groups. Examination of the resulting scores confirmed the detrimental effect of opposite-hand training on the preferred hand of most subjects. Gain scores for right-handers and LN subjects using the preferred hand after opposite-hand training averaged 49.7% ($SD = 57.9$) and 50.5% ($SD = 34.4$), respectively, of the gains expected after same-hand training, compared to 94.2% ($SD = 71.3$) and 72.7% ($SD = 44.9$) for the nonpreferred hand.

One group (LI subjects) showed little transfer in either direction, however ($p = 59.8\%$, $SD = 31.8$; $N = 44.1\%$, $SD = 42.0$), and such asymmetry as was apparent for this group was in the opposite direction. An ANOVA based on log 100*gain (to accommodate the fact that standard deviations were roughly proportional to means) tended to support group differences (handedness × hand, $F(2, 42) = p < .08$). The transformed means are presented in Fig. 2.

Comparison with Previous Study

Because our conclusions appeared to be inconsistent with those of Hicks (1974), we reexamined the data from that study. Means and stan-

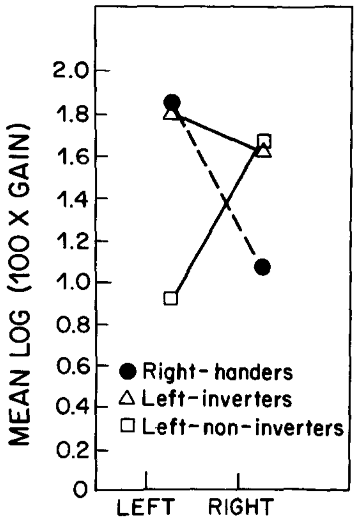

FIG. 2. Log gain scores in Experiment 1, as a function of handedness and hand.

dard deviations were not available, but visual inspection of the graphed data reveals the same discrepancy between his groups L–R and R–R on trial 11 as for our right-handers in groups N–P and P–P. In fact, the difference between groups L–R and R–R on this trial was about three times larger in Hicks' study than the difference between the scores of groups R–L and L–L. Hicks' conclusion was based on the fact that, whereas "(Group L–R) eventually performed as well as the group that printed with the right hand all along (Group R–R)...(Group R–L) never performed as well as the group that printed with the left hand all along (Group L–L)" (p. 672). This pattern was not replicated in the present study and (because same-hand training obscures the effect of opposite-hand training during later trials) is of less interest than performance early in the test phase. With respect to the latter, the results of the two studies are consistent.

Intertrial Correlations

If one excludes the data from LI subjects, our findings support a proficiency model of transfer. To test the model further, we examined the intertrial correlations, with particular attention to the correlation between trials 10 and 11. By strict interpretation of the model, greater proficiency on trial 10 should be associated with greater proficiency on trial 11, irrespective of the direction of transfer. The correlations obtained between trials 10 and 11 in the various handedness and hand-order groups are presented in Table 1.

As expected, all same-hand training groups showed high correlations between trials 10 and 11. However, the correlation was significantly lower

TABLE 1
INTERTRIAL CORRELATIONS BETWEEN TRIALS 10 AND 11 IN EXPERIMENT 1, AS A FUNCTION OF HANDEDNESS AND GROUP

	Group			
Handedness	P–P	N–P	P–N	N–N
Right-handers	.84*	.86*	.21	.94*
Left-noninverters	.89*	.60	.02	.90*
Left-inverters	.79*	.46	.89*	.95*

*$p < .05$

for right-handers in group P–N than that for the other right-handed groups (Fisher's r to z transformation, $p < .01$). In fact, the correlation was only .21 for this group, accounting for less than 5% of the observed variance. Examination of the standard deviations on trial 11 confirmed that this was not a ceiling effect. The variability observed for right-handers in group P–N ($SD = 5.43$) was comparable to that of group N–P ($SD = 5.66$). Furthermore, Hicks reported the same pattern, with a correlation of .45 in group R–L and .75 in group L–R.

A similar pattern was observed for LN subjects. However, the pattern appeared to be reversed for LI subjects, with the lowest correlation in group N–P (i.e., group R–L, as for right-handers).

Discussion

We conclude that opposite-hand training in the inverted–reversed printing task typically benefits the nonpreferred hand (i.e., the left hand for right-handers and the right hand for left-handers) more than the preferred hand. Individual differences were evident, however. LI subjects demonstrated relatively little transfer to either hand, and, if anything, opposite-hand training favored the left hand in this group (as in right-handers). This pattern of reduced (and reversed) hand differences relative to LN subjects has been observed in our lab for other tests of motor laterality.

Although the direction of greater transfer appeared at first to contradict Hicks (1974), reexamination of Hicks' data revealed the same pattern in early test trials. On later trials, the effect of opposite-hand training was necessarily obscured by same-hand training and these trials are accordingly of less interest.

These results do not support the (callosal) *access* model of hemispheric interaction. Problems with the opposing *proficiency* model were noted, however. First, it is difficult to explain the differences between LI and LN subjects on the basis of hand differences in prior proficiency. Both groups performed better in the training phase with the preferred (left) hand. Second, the intertrial correlations did not fit this model. Contrary to expectation, transfer scores were higher for groups showing poor correlations between the hands on trials 10 and 11. The two groups who produced the lowest gain scores (right-handers in group N–P and LI subjects in group P–N) showed high correlations between the hands. This pattern argues against a role for prior proficiency in the mediation of transfer, although for the latter two groups, proficiency may have served to mitigate the effect of training the "wrong" hand in individual cases.

In Experiment 2, the developmental course of asymmetrical transfer was probed in right-handed children, aged 7, 9, and 11 years. Because of time restrictions, the children completed an abbreviated version of the task in which the number of training trials was reduced from 10 to 3, one test trial was conducted, and a subset of the alphabet was practiced.

EXPERIMENT 2

Method

Subjects

A total of 195 children from three local schools agreed to participate in the study, and parental consent was obtained. Of these, 176 children were right-handed (by self-report) and their data are presented here. The sample included 63 children in Grade 2 (36 boys, 27 girls), 55 in Grade 4 (26 boys, 29 girls), and 58 in Grade 6 (24 boys, 34 girls). The average age at the time of testing was was 7 years, 9 months (SD = 6 months) in Grade 2; 9 years, 9 months (SD = 5 months) in Grade 4; and 11 years, 9 months (SD = 7 months) in Grade 6.

Right-hand preference was verified as the children pantomimed 15 unimanual tasks, which included writing, drawing, and using scissors. In this sample, the right hand was used for 14.4 (SD = 1.24) of the tasks. Additional information on familial handedness was obtained via questionnaire (completed by the parents). Seventy-five of the children (43%) were reported to have one or more left-handers among their first- and second-degree relatives, including 45% of the Grade 2, 35% of the Grade 4, and 51% of the Grade 6 sample. Handedness history was unknown in four cases (due to adoption). A rating of relative reading ability was also obtained from each child's teacher, based on four categories (1 = superior, 2 = average, 3 = below average, 4 = very poor). Most of the children were at or above grade level in reading skills, but 12 children were identified by their teachers as poor (3 or 4) readers.

Materials

A blank sheet of paper (12.7 × 20.3 cm) and an HB pencil were provided each child. An Aristo stopwatch (Appollo 12 1/2) was used to mark time intervals.

Procedure

After watching the experimenter print the letters "ABC" in inverted–reversed orientation, each child practiced printing the letters "BJLNRS" in similar fashion. This list was presented (upright) on a card in constant view. After the child had attempted each letter once and the experimenter was satisfied that the instructions had been understood, the child was asked to print the list over and over in the desired orientation. Printing began on the right side of the page and proceeded from right to left, bottom of page to top. Upon terminating a trial, the experimenter marked two slashes (//) and turned the page 180° so that the child could check the work for errors. The page was then folded under so that the preceding trial was no longer visible before beginning the next trial. Three 30-sec trials were completed in this fashion, with an intertrial interval of 15 sec. A fourth (test) trial immediately followed. The number of letters printed correctly and incorrectly (incomplete or in the wrong orientation) was recorded for each trial.

As in Experiment 1, half of the children completed the training trials with the left hand and half the right. Half of these children subsequently switched to the opposite hand for the test trial (groups L–R and R–L), and half used the same hand at test (groups R–R and L–L).

Results

Three variables—familial sinistrality, the extent of right hand preference, and reading ability—were investigated as potential covariates. Reading ability was substantially associated with correct (but not error) responses on the test trial ($r = -.24$, $p < .01$). This variable was therefore entered as a covariate in a 3 (grade) × 2 (sex) × 2 (test hand) × 2 (type of training) MANCOVA. As sphericity was not a problem (Greenhouse–Geisser $\epsilon > .90$), univariate analyses of correct and incorrect trial 4 responses were also examined.

Main effects were observed for grade, $F(4, 300) = 24.26$, $p < .001$, test hand, $F(2, 150) = 14.22$, $p < .001$, and type of training, $F(2, 150) = 7.92$, $p < .001$. Sex was not significant ($F < 1$). Univariate analyses confirmed the grade effect for both dependent measures, and the remaining effects for correct responses only. As one would expect, older students produced more correct and fewer incorrect responses than younger ones (for correct responses: (Grade 6 > Grade 4 > Grade 2; for errors: (Grade 6 = Grade 4) > Grade 2, Scheffe, $\alpha = .10$). The preferred (right) hand was superior to the nonpreferred hand for letters correctly printed, and same-hand training was better than opposite-hand training.

The factor of primary interest was the hand × type of training interaction. This was significant, $F(2, 150) = 4.51$, $p < .05$. Univariate analyses confirmed the interaction in correct ($p < .01$) and error data ($p < .05$). Analysis of the simple effects revealed that type of training affected preferred-hand correct responses ($p < .001$) and nonpreferred-hand error responses ($p < .05$). That is, the right hand produced more correct responses after same-hand training than after opposite-hand training, but the same number of errors. The left hand produced the same number of correct responses after same- and opposite-hand training and actually made *fewer* errors after opposite-hand training (see Fig. 3).

Thus, at all three ages, opposite-hand training benefited the nonpreferred (left) hand more than the preferred hand, replicating the results for right-handed adults in Experiment 1.

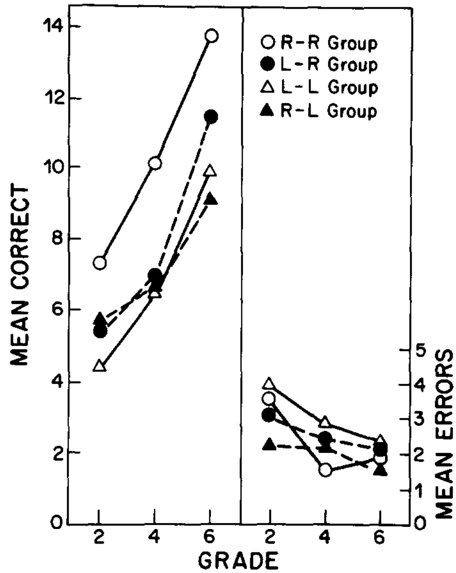

FIG. 3. Mean letters correctly and incorrectly printed by children at test in Experiment 2 (adjusted for reading ability), as a function of grade, hand, and type of training. R, right hand; L, left hand.

Gain Scores

Gain scores were calculated for correct responses, as in Experiment 1. Collapsed across age, transfer to the left hand after opposite-hand training averaged 98.7% (adjusted for reading ability and familial sinistrality) of same-hand training gains, compared to 29.9% for the right hand. An ANCOVA confirmed the hand difference, $F(1, 75) = 7.32$, $p < .01$.

Additional Analyses

1. Speed/accuracy. Because of the floor effect for errors in Experiment 1, it could not be determined whether the observed hand differences reflected changes in total output or in accuracy (or both). In the second experiment, the rate of error production was much higher ($M = 25.3\%$ on trial 4). By summing correct and incorrect responses, we obtained an index of total output (or speed); percentage errors served as an index of accuracy. A second set of gain scores was then derived for subjects in groups L–R and R–L to address this issue. For this purpose, the difference between test performance and trial 1 performance (the latter averaged across subjects) was expressed as a percentage of the baseline (trial 1) score.

After first determining that both reading ability ($r = -.34$, $p < .01$)

and familial sinistrality ($r = .29$, $p < .01$) were associated with gains in output (but not in accuracy), a MANCOVA was performed on these scores which again confirmed the effect of hand, $F(2, 74) = 6.01$, $p < .01$. Subsequent examination of the univarate effects revealed hand differences in accuracy after opposite-hand training, $F(1, 75) = 11.31$, $p < .01$, but not in speed ($F < 1$).

Both hands produced more responses after opposite-hand training (adjusted scores, right = 11.6%, left = 10.4%) but only the left hand made fewer errors (M = 13.4% of baseline errors). The right hand actually averaged 0.4% *more* errors than at baseline.

2. *Intertrial correlations.* The pattern of intertrial correlations was examined for percentage error scores on trials 3 and 4. Collapsed across age, the correlation was .70 for group R–L vs .87 for group L–R. This difference was significant (Fisher's r to z transformation, $p < .05$). As in the adult subjects, the higher correlation was observed for the group (L–R) which showed less transfer, and the lower correlation for the group which showed more transfer.

Discussion

Asymmetrical transfer was observed in all three grades, with the left hand benefiting more from opposite-hand training than the right. As with the right-handed adults tested in Experiment 1, opposite-hand training and same-hand training appeared to be equivalent for the left hand of these right-handed children. In contrast, performance by the right hand after opposite-hand training was significantly worse than expected after same-hand training.

The asymmetry affected accuracy compared to speed. Both left and right hands made somewhat more responses (about 10%) after opposite-hand training than would have been expected in the absence of training, but only the left hand showed a significant drop in the error rate on the test trial under these conditions. That the two aspects of transfer (speed and accuracy) were independent is also suggested by the fact that selected covariates (reading ability and familial sinistrality) were associated with gains in speed but not in accuracy.

The similarity of the children's behavior with that of right-handed adults in Experiment 1 was striking. Furthermore, examination of the percentage errors from trials 3 and 4 again revealed that the between-hand correlation was significantly lower for group R–L (the group which demonstrated more transfer between the hands) than for group L–R (the group which demonstrated less transfer between the hands).

GENERAL DISCUSSION

The experiments presented in this paper suggest that, contrary to Hicks' (1974) conclusion, the left hand in right-handed subjects benefits more from opposite-hand training in inverted–reversed printing than does the right. Hicks' conclusion was based on examination of performance late in the test phase, at a point when same-hand training necessarily obscured the effect of opposite-hand training. Reexamination of his data revealed in the early test trials the same nonpreferred-hand advantage here observed in male undergraduates (Experiment 1) and in boys and girls between 7 and 11 years of age (Experiment 2). The hand differences reversed for LN subjects in the first experiment, with lateral transfer again differentially benefiting the nonpreferred hand. LI subjects demonstrated relatively little transfer to either hand and reduced hand differences. We have observed similar reductions in hand differences for this group on other motor laterality tests. Inasmuch as any asymmetry was apparent, they appeared to behave more like right-handers than like LN subjects, with the left (in this case the preferred hand) showing greater transfer.

What do these data tell us about the mechanisms underlying asymmetrical transfer of training? First, the currently popular (callosal) *access* model was not supported. Second, a *proficiency* model stating that transfer should be greater from the more proficient to the less proficient hand accurately predicted the outcome for most subjects, but this model is unsatisfactory in several respects. It does not explain why LI and LN subjects behaved differently in Experiment 1, as both samples were more proficient with the preferred hand during the acquisition phase. Nor does it explain the correlational data. Proficiency prior to the test trial was substantially associated with performance on the test trial for only two of the six opposite-hand training groups (and those two had the poorest transfer). We conclude that, although hand proficiency may be a mitigating factor when transfer is in the "wrong" direction, it is probably not the mediator of transfer in the opposite direction.

So what have we learned? First, two aspects of performance—speed and accuracy—may be transferred by different (and apparently independent) mechanisms. As evidence of this, selected covariates (reading ability and familial sinistrality) in the second experiment were found to be associated with gains in total output after opposite-hand training, but were not associated with gains in accuracy. Moreover, hand differences in transfer of training were observed for accuracy and not for speed. This finding places the origin of the asymmetry squarely in the cortical realm, and not with subcortical structures which may mediate other aspects of performance.

Second, the asymmetry was not restricted to a particular level of proficiency. It was as apparent at age 7 as in adulthood. This is compatible with a basis in hemispheric specialization of function, which we know to be established early in life.

Finally, we have the correlational data. Examination of the between-hand correlations in the first experiment revealed that greater transfer between the hands was associated with lower correlations between the hands, suggesting dissimilar underlying processes. Poor transfer was associated with large correlations between the hands, suggesting similar underlying processes. This pattern was replicated in the percentage error scores obtained in the second experiment. Could it be that under certain conditions (as when the preferred hand is trained), dual "engrams" are formed, one in each hemisphere? Under other conditions (as when the nonpreferred hand is trained), a single engram might be formed. To explain why the former would facilitate the transfer of skill between hands, we speculate that activation of the "dominant" hemisphere may lead to maintaining the opposing hemisphere in a state of readiness to respond. In this state, the nondominant hemisphere learns about the task in parallel fashion, forming an independent internal representation and interpreting the information obtained from the preferred hand in its own way. Taking the performance of right-handers in group R–L as an example, this might explain why, when they switched to the left hand, performance was very nearly as good as that of subjects who had practiced with the left hand for the same number of trials, despite the fact that their scores bore little resemblance to prior performance.

In contrast, activation of the nondominant (right) hemisphere in group L–R during the acquisition phase did not lead to cross-activation, and a single internal representation was formed. This would explain why transfer scores were low in this group when they switched to the right hand/left hemisphere, despite a high correlation between hands. That this engram was formed in the right hemisphere rather than in the left is suggested by the fact that right hand scores at test were close to the levels achieved by the left hand (also at test) in other groups. Right-hemisphere dominance in LN subjects would lead to a reversal of this pattern, as was observed.

The *cross-activation* model described above represents a working hypothesis at this time and needs further explicit experimental examination. Nevertheless, it suggests an interesting explanation for the performance of LI subjects. One need only assume that the coupling of "hemispheric proficiency" (in the sense that the dominant hemisphere is usually more efficient, which is reflected in better performance by the hand that it controls) and cross-activation may be a loose one, which can be broken in certain populations. The pattern of intertrial correlations observed for LI subjects suggests that cross-activation may have been linked to right-hand performance during acquisition in this group, as in right-handed subjects. That left-hand scores were higher than right-hand scores suggests that the right hemisphere was the more proficient, as in LN subjects.

Why this decoupling should result in poor transfer for LI subjects in group R–L is not clear. At any rate, it is interesting to note that in some respects, LI subjects behaved more like right-handers than like LN subjects.

It is possible, of course, that LI subjects were at a disadvantage because posture was not controlled across hands. Switching between the inverted and noninverted postures might have handicapped their performance. In our experience, however (and see Parlow & Kaplan, 1988), LI subjects rarely choose to invert the hand (either hand) in the inverted–reversed printing task. Furthermore, they do not complain that the noninverted posture feels unnatural or uncomfortable, as they do when asked to produce normal script in this fashion.

At any rate, we believe that the present findings highlight the inadequacy of current models of interhemispheric communication.

This work may also shed some light on the origins of handedness. The hand used to write with remains the best single predictor of hand preference (Provins & Cunliffe, 1972). Our results suggest that practicing a writing skill with the right hand (for a right-hander) or the left hand (for a left-hander) is the most efficient strategy for promoting maximum skill in both hands. The handicap to the untrained hand is minimal. In contrast, the preferred hand is greatly handicapped by opposite-hand training. By adopting a strategy which benefits both hands, one may inadvertently foster the development of even stronger hand preferences. We predict that the now discredited practice of "shifting" left-handers to right-hand use for writing would have a retarding effect on the acquisition of writing skill.

Finally, we would like to note that the observation of transfer asymmetries requires comparison of same-hand and opposite-hand training. The omission of same-hand training groups may well lead to erroneous conclusions regarding lateral transfer. For example, Taylor and Heilman (1980) directly compared left- and right-hand scores after opposite-hand training. Given the different rates of improvement observed in the present study after same-hand training, such a comparison may not be meaningful and could lead to the (erroneous) conclusion that the right hand benefited more from opposite-hand training simply because it improved at a faster rate.

REFERENCES

Ammons, R. B. 1958. Le Mouvement. In G. S. Seward & J. P. Seward (Eds.), *Current psychological issues*. New York: Holt. Pp. 146–183.

Ammons, R. B., & Ammons, C. H. 1951. Bilateral transfer of rotary pursuit skill. *American Psychologist*, **6**, 294–301.

Bray, C. W. 1928. Transfer of learning. *Journal of Experimental Psychology*, **11**, 443–467.

Briggs, G. E., & Brogden, W. J. 1953. Bilateral aspects of the trigonometric relationship of precision and angle of linear pursuit-movements. *American Journal of Psychology*, **66**, 472–478.

Ewert, P. H. 1926. Bilateral transfer in mirror-drawing. *Journal of Genetic Psychology*, **33**, 235–249.

Freeman, G. L. 1938. Studies in the psycho-physiology of transfer. III. Bilateral practice effects in normal and mirror-writing. *Journal of Psychology*, **5**, 285–289.

Hicks, R. E. 1974. Asymmetry of bilateral transfer. *American Journal of Psychology*, **87**, 667–674.

Laszlo, J. I., Baguley, R. A., & Bairstow, P. J. 1970. Bilateral transfer in tapping skill in the absence of peripheral information. *Journal of Motor Behavior*, **2**, 261–271.

Levy, J., & Reid, M. 1976. Variations in writing posture and cerebral organization. *Science*, **194**, 337–339.

Levy, J., & Reid, M. 1978. Variations in cerebral organization as a function of handedness, hand posture in writing, and sex. *Journal of Experimental Psychology: General*, **107**, 119–144.

Meier, M. J., & French, L. A. 1965. Lateralization deficits in complex visual discrimination and bilateral transfer of reminiscence following unilateral temporal lobectomy. *Neuropsychologia*, **3**, 261–272.

Parlow, S. 1978. Differential finger movements and hand preference. *Cortex*, **14**, 608–611.

Parlow, S., & Kaplan, B. J. 1988. *Psychophysiological concomitants of lateral transfer of training*. Unpublished manuscript.

Parlow, S. E., & Kinsbourne, M. 1981. Handwriting posture and manual motor asymmetry in sinistrals. *Neuropsychologia*, **19**, 687–696.

Provins, K. A., & Cunliffe, P. 1972. The reliability of some motor performance tests of handedness. *Neuropsychologia*, **10**, 199–206.

Taylor, G. H., & Heilman, K. M. 1980. Left-hemisphere motor dominance in right-handers. *Cortex*, **16**, 587–603.

Welch, J. C. 1898. On the measurement of mental activity through muscular activity and the determination of a constant of attention. *American Journal of Physiology*, **1**, 283–306.

Wieg, E. L. 1932. Bilateral transfer in the motor learning of young children and adults. *Child Development*, **3**, 247–268.