Performance Difference between Hands in Children on the Motor Accuracy Test—Revised

(lateralization, sensory integration, handedness)

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This study was designed to determine the developmental trends in the difference between right-hand and left-hand skill development in children ages 4 to 9 as measured by the Motor Accuracy Test-Revised (MAC-R). There were 120 right-handers (60 males, 60 females), with 20 subjects at each age interval, and 68 left-handers (36 males, 32 females), with no less than 8 and no more than 20 subjects at each age interval. Performance was analyzed by sex, age, and handedness for the difference scores between the two hands, and the preferred and nonpreferred hand adjusted scores.

The difference scores were obtained by subtracting the nonpreferred hand scores from the preferred hand scores. Results showed the mean difference between hands for all children to be 6.7 points with a standard deviation of 4.8. This data suggests that a normative range of difference between right-hand and left-hand skill performance on the MAC-R may be from 2 to 11 points.

Left-handed children performed very similarly to right-handed children, supporting the use of right-handed norms for left-handed subjects. No significant differences in sex or handedness were found in the adjusted or difference scores. Comparison of the means and standard deviations of MAC-R normative data with these data showed no consistent significant differences.

Analysis of the relationship between manual specialization and asymmetry, and cerebral lateralization provides an index for ascertaining the type and degree of dysfunction in children with neurobehavioral deficits (1). In the right-handed population, preferred hand skill is thought to be related to the hemisphere, usually the left hemisphere, specialized for language. Although this relationship has been an important historical finding with regard to cerebral lateralization, the hemisphere responsible for language has not been found to be consistent for the left-handed population (2). Also, the degree of manual preference has been more inconsistent in the left-handed population than in the right-handed population (3). Since there is such great variability in left-handed groups, handedness has been considered to be on a continuum within the dichotomous classification of right-handed or nonright-handed (3).

Annett (4) described several proce-
dures for determining handedness: 1. hand preference for writing; 2. questionnaires that derive a laterality quotient from extreme right to extreme left; 3. performance on a spectrum of tasks that reveal right handedness, left handedness, or mixed handedness and ambidexterity; 4. use of measures of differences between hands in skills that are continuously distributed.

As early as 1948 Hildreth suggested that handedness may be determined by the degree of difference in skill with which both hands are used (5). Provins and Cunniff stated, "Not only does the degree of superiority of one hand over the other vary from task to task but also from one performance to another on all but the most highly practiced and skill demanding tasks." (6, p 204)

When determining handedness, or degree of manual specialization by using the measure of difference between hands in motor skills, the parameters that may influence the test results must be considered. For example, performance of each hand is task dependent and will vary because of exposure to the task, amount of skill or overlearned behavior, and age of the subject (6). The subject's sex and degree and type of handedness are also factors that may yield varying results (7-9).

In assessing the degree of manual asymmetry on motor tasks, it has become evident that there is manual specialization during bimanual tasks and for different types of tasks, and that the magnitude of the difference between hands on these tasks has become increasingly important (10). Denckla felt that functional asymmetries are of interest in understanding the relative contributions of each cerebral hemisphere to motor control of each side of the body under various task-dependent constraints (10). She found a common developmental pattern of hand skill in young right-hand preferred children. Functional preference of the right side is established first, then the right side develops skill in these functions that becomes markedly better than the skilled function on the left side. Finally, there is rapid increase in left-sided skill development so that, although the right side remains more skilled, by age 8 there is only a small mean right superiority within individuals. Denckla proposed three possible neurodevelopmental explanations for this progression: 1. the right hemisphere may develop later than the left; 2. interhemispherical connections develop later so that, although early development the left hemisphere truly dominates motor output of the right; 3. ipsilateral pathways of the left hemisphere control motor output on both sides (7).

Ayers has also examined the degree of manual asymmetry and looked at manual specialization; she hypothesized (11) that, if sensory integration at a brain-stem level is inadequate, each hemisphere cannot develop optimally, either separately or together. Without adequate interaction of the hemispheres, functions that require integration between the hemispheres, such as skilled hand development and reading, may be impaired.

In order to assess differences in preferred and nonpreferred hand skill, therapists certified in sensory integrative testing have used the Motor Accuracy Test (MAC) (12). The MAC requires performance of fine motor control and eye-hand coordination. It is completed by both the preferred and nonpreferred hands, thereby allowing a comparison of the difference between the hands. In one of a series of factor analytic studies (13), Ayres found that, when right- and left-hand scores on the MAC were analyzed separately, the scores tended to load as a doublet, probably because children with dysfunction tend to score similarly and quite low. Guidelines for assessing poor lateralization, using the original MAC, were less than 20 points difference between the right- and left-hand raw scores in children younger than 8 years old, and less than 10 points difference in children 8 years or older, and these guidelines were felt to be one sign that the child may not be well lateralized for skilled hand function.

Other supportive indications of a lateralization deficit used during sensory integration evaluations were: the tendency not to cross the body's midline, as indicated by the Crossing the Midline test; the Space Visualization contralateral hand use score; low right-left ear ratio on the dichotic listening test; and lack of preferred eye and hand agreement.

The Motor Accuracy Test was revised (MAC-R) in the late 1970s and republished in 1980. The MAC-R, although not changing the structure of the original test, allowed for a different administration and scoring procedure (14). Because of the excessive number of extremely low scores on the original MAC, the scoring procedure for the MAC-R has improved the validity of the test for use with dysfunctional populations by raising the standard scores for these children to a more reasonable range (Ayers, personal communication). Multiplication by a fraction, rather than by a whole number, minimized the differences between the two hands on the raw scores, to become almost equal in the normal population, and thus reduced the expected difference between the right and left hands.
According to Ayres (personal communication),

Since the revised form of the test reduces the time adjusted raw scores difference between the two hands, using the raw scores difference to help make a decision regarding the "true" difference in skill of the two hands is more difficult than it was with the original MAC. In making such a decision the probable measurement error of each hand's raw score should be considered. If a range of one standard error of measurement is applied to either side of the raw score and the two ranges do not overlap, chances are two out of three that the right and left hand timed raw adjusted scores are "truly" different. For the visual picture of the score ranges, the SEM can be translated into a proportion of a standard deviation. When a 95% probability of difference between the timed raw scores of the two hands is desired, the score ranges incorporating two standard errors of measurement on either side of both the right and left hand raw scores must not overlap.

Although Ayres documented data from the original and revised MAC, and speculated on the interpretation of right/left differences, these data have not been formally analyzed for differences between right and left hands in the normal population. Therefore, the developmental trends for right- and left-handed children need to be investigated in order to provide the range of normal performance. Ayres (14) observed that there was a greater difference between the right- and left-hand scores of the right-handed children than there was between the respective hand scores of the left-handed children. There were no appreciable differences in mean scores between sexes or for the right- and left-handed groups.

This study was designed to investigate the normal range of difference between preferred and nonpreferred hands for left- and right-handed children for the MAC-R, and to confirm the findings of a developmental performance trend and lack of significant differences in hand skill as a function of sex or handedness.

Method
Subject. The subjects consisted of 188 children: of the 120 right-handed children, who ranged in age from 4 years, 0 months to 9 years, 11 months, there were 10 males and 10 females, thus 20 subjects, in each age group (4 to 9 year olds). The 68 left-handed children ranged in age from 5 years, 0 months to 9 years, 11 months. When combining 32 males and 36 females, there were no less than 8 and no more than 20 in each age group: 5 males and 6 females in the 5-year-old group, 7 males and 7 females in the 6-year-old group, 9 males and 8 females in the 7-year-old group, 8 males and 12 females in the 8-year-old group, and 5 males and 3 females in the 9-year-old group.

According to their teachers, all the children who participated in the study were normal academic achievers and were performing at age-appropriate grade levels with no incidence of physical or intellectual handicaps. The children were from predominantly middle class neighborhood schools in and around the Boston and Cincinnati areas. The racial mixture was 46 percent Black and 54 percent white for the right-handed group and 56 percent Black and 44 percent white for the left-handed group.

Handedness was determined on the basis of preference for writing. The Harris Laterality Test (15) was also administered to determine the degree of manual preference. The children were requested to simulate 10 common unimanual tasks such as throwing a ball or turning a doorknob. One point was given for each of the 10 responses done with the hand preferred for writing. The mean score for the right-handed group was 9.7 right-handed responses with a standard deviation of 0.11 and a range of 7 to 10. The mean score for the left-handed group was 7.5 left-handed responses with a standard deviation of 2.5 and a range of 2 to 10.

Procedure. The children were individually administered the Southern California Motor Accuracy Test-Revised (MAC-R) (14), a test designed to measure the accuracy of visually directed hand use of a pen. On this test, a separate accuracy score is obtained for precision of performance for both the preferred and nonpreferred hand. An adjusted score is then computed, adjusting for the time taken to complete the task.

The test was administered and scored according to the standardized procedure described in the MAC-R Manual (14). Testing was done under the recommended 60-second time condition because the adjusted score in this condition was found to have the smallest measurement error for the preferred hands in the normal population (14). The testing and scoring were conducted by a clinician certified in the administration and interpretation of the Southern California Sensory Integration Tests.

Results
In order to determine left/right differences on the MAC-R as a function of sex, age, and handedness, a 2
(sex) by 5 (age) by 2 (hand) analysis of variance (ANOVA) was performed on the difference between preferred and nonpreferred hand accuracy score and adjusted score. Since 4-year-old left-handed children were not included in this study, the three-way ANOVA contained only five age levels. The preferred hand accuracy score, preferred hand adjusted score, nonpreferred hand accuracy score, and nonpreferred hand adjusted score were also analyzed. For the analysis on the accuracy and adjusted scores, significance was achieved on the same factors, and, the scattergram of the accuracy and adjusted scores for both the right- and left-handed groups showed no deviation from a positive linear relationship; therefore, only the adjusted scores are reported since they reflect the accuracy of performance as well as the time taken for completion of the task.

To analyze performance of 4-year-old right-handed children, a one-way ANOVA was performed with six ages for each of the dependent measures. Since sex difference was not significant in any of the three-way analyses, males and females were combined when analyzing the data for right-handed children for the inclusion of the 4-year-old group.

**Difference Scores.** In the analysis of the adjusted score difference between preferred and nonpreferred hands, age was not significant $F(1,148) = 1.692$, nor was sex, $F(1,148) = 0.014$, or handedness, $F(1,148) = 0.997$. There were no significant interactions. Table 1 presents the means and standard deviations for the difference scores as a function of age and handedness. Figure 1 displays the mean difference scores plus or minus one standard deviation for the right- and left-handed groups at each age. Since these differences were not significant as a function of age, the overall mean of 6.7 plus or minus one standard deviation, 4.8, indicates that, for the right- and left-handed children ages 4 to 9 in this study, the normal range of difference was from 1.9 to 11.5.

<table>
<thead>
<tr>
<th>Age</th>
<th>Right-Handed Mean SD</th>
<th>Left-Handed Mean SD</th>
<th>Total Mean SD</th>
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<tbody>
<tr>
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<td>4.6 6.5</td>
<td>3.1 4.3</td>
<td>5.5 5.2</td>
</tr>
<tr>
<td>5</td>
<td>6.5 5.3</td>
<td>4.4 4.4</td>
<td>7.2 4.2</td>
</tr>
<tr>
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<td>8.2 4.5</td>
<td>9.3 3.8</td>
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<tr>
<td>7</td>
<td>8.3 3.6</td>
<td>6.0 3.9</td>
<td>6.7 4.5</td>
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<tr>
<td>8</td>
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<td>6.2 6.6</td>
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<td>6.6 4.7</td>
<td>6.7 4.8</td>
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<tr>
<td>Total</td>
<td>6.8 4.8</td>
<td>6.6 4.7</td>
<td>6.7 4.8</td>
</tr>
</tbody>
</table>

In the three-way ANOVA, in which the nonpreferred hand adjusted score was considered, again age was significant $F(4,148) = 22.974$, $p < .01$. Sex was not a significant factor $F(1,148) = 0.82$ nor was handedness $F(1,148) = 2.81$. The age-by-hand interaction was $F(4,148) = 2.49$, $p < .05$.

In order to assess the age-by-hand interactions on the MAC-R adjusted scores for the preferred and nonpreferred hands, $t$-tests were performed for each age between left- and right-handed groups. Significance was achieved between right- and left-handed groups for the 8-year-olds only for both the preferred hand, $t = 3.27$, $p < .01$, and the nonpreferred hand, $t = 4.01$, $p < .01$, with the left-handed group having a higher mean than the right.

**Additional Analyses.** To enable the inclusion of the 4-year-old right-handed subjects, the one-way ANOVA revealed that, while age was not a significant factor when examining the difference score $F(5,114) = 1.37$, age was a significant factor for the preferred hand score $F(5,114) = 51.56$, $p < .01$, and the nonpreferred hand score $F(5,114) = 46.84$, $p < .01$. The Scheffe post-hoc analysis revealed significant differences in the adjusted scores between all ages at the $p < .10$ confidence interval.

In order to compare the data obtained in this study with those obtained in the normative sample for MAC-R, analyses were performed using $t$-tests, comparing the means and standard deviations for the right-handed groups in this study by 6-month intervals to the means and standard deviations obtained in the right-handed normative sample for the MAC-R. Significant differences were not found.
be the result of sampling error because of sample size. An alternative hypothesis is that the left-handed 8-year-old groups scoring significantly higher than the right-handed group may be an indication of a surge of eye-hand coordination in 8-year-old left handers. As a whole, however, this preliminary research finding suggests that it may be appropriate to compare scores of left-handed children to norms of right-handed children.

The analyses performed comparing the MAC-R normative data of right-handed subjects to these data by 6-month age increments revealed significant differences only at the 9-year-old level for the preferred hand. This finding does not appear to be significant in its isolation and is considered to be caused by sampling error. Therefore, it is suggested that the norms generated in the West coast are appropriate for use in the East coast and Midwest.

While there is evidence in the literature that there are differences in hemisphere specialization as a function of sex, and skills such as tactile spatial perception may be different in males and females, the differences between males and females in eye-hand coordination do not appear to be appreciable. Sex and handedness may affect performance on motor tasks, but not on this test within the age ranges tested.

In considering the interpretation of the difference scores for clinical use, these findings indicate that similar expectations of performance on the MAC-R may be made for both sexes and for right and left handers. Although close scores between hands on the original MAC (12) might have been an indication of dysfunction, this does not appear to be the case with the revised test (14). Comparison of the two hands in the normal population on the

Figure 1
Motor Accuracy Test-Revised Difference Scores: Means Plus or Minus One Standard Deviation for Right- and Left-Handed Subjects

The results of this study revealed that there are slight but consistent differences between the preferred and nonpreferred hands that do not significantly differ as a function of age or handedness (see Table 1). However, even though no significant differences were found between right- and left-hand preferred children or across ages on the difference scores, a trend was evident in both the right- and left-handed groups: a narrow range of difference at age 4, increasing with the greatest difference at age 7, and decreasing slightly to age 9 (see Figure 1).

In examining the normative data for the MAC-R, Ayres (14) found that the 60-second administration of the test to the left-handed children yielded norms roughly equivalent to those of right-handed children, although the difference scores were not tested statistically. In this study, comparison of right- and left-handed groups yielded significant differences on the adjusted scores only between 8-year-old groups. Since there was no other age group that was significantly different, this may
MAC-R has indicated that the preferred hand shows a slight but consistent advantage in beginning school-age children.

The expected range of difference for normal right/left differences from the results of this study is from 2 to 11 points. Based on probability, 67 percent of the population will supposedly obtain a difference score within this range. The probability that a child will obtain a difference score less than 2 points between hands or more than 11 points is less than 30 percent when compared to the normative sample. Based on the mean plus or minus two standard deviations, the probability is less than 2 percent that a child will obtain a difference score less than −3; in other words, the nonpreferred hand scored 3 points better than the preferred hand, or greater than 16.

Since no data are available on deficit populations, it may be useful to consider these norms on the difference scores in descriptive terms.

Inferences may be made when using the difference scores for diagnostic purposes if they are based on normal expectations and knowledge of dysfunctional patterns of lateralization, and if used in conjunction with other parameters of lateralization. Studies of the differences between the two hands with deficit populations have shown several patterns; overall skill development may be lowered: the differences between the two hands may be very small, or exaggerated; the nonpreferred hand will perform better than the preferred hand; or, one hand will be overlateralized for the task, as in the case of left-side neglect with the right hemisphere-damaged person (16). In some cases, these configurations of manual asymmetry may provide insight into cerebral lateralization for specialized functions. Although it is not possible to assess cerebral function on the basis of hand skill development alone, when linked with other neurobehavioral constructs, it can provide further information about the neural functioning for a better understanding of the child’s deficits.

Summary and Conclusion

This study generated normative data on the MAC-R for right- and left-handed children in order to assess the difference in skill development between the right and left hands in children ages 3 to 9. A narrow range of difference between preferred and nonpreferred hands was found to be not significantly influenced by sex or handedness, and to remain fairly constant with age. Norms were suggested that may provide a baseline of behavior for the assessment of one parameter of lateralization of motor function to which clinical populations may be compared. Consistency of norms across the United States was suggested by the comparison of these data to the standardization data of the MAC-R.

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