The Development of Manual Midline Crossing in 2- to 6-Year-Old Children

Janet M. Stilwell

Key Words: child development • laterality • sensory integration

The present study analyzed the development of manual midline crossing in a sample of one hundred sixty 2- to 6-year-old children and considered test construction factors that could affect the test design. The test construction factors addressed were (a) the effect of biasing the hand used for object manipulation and (b) the effect of distance from midline required for task completion on the frequency of manual midline crossing. A pegboard task was used to measure manual midline crossing. The results identified a developmental age trend in crossing the body midline in 2- to 6-year-old children. Biasing the hand used for object manipulation significantly increased the probability of eliciting manual midline crossing. A combination of linear and quadratic trends was found when the effect of distance from midline on the frequency of contralateral responses produced during testing was analyzed.

Deficits in manual midline crossing are frequently cited by occupational therapists during sensory integration testing (Ayres, 1972). These deficits are characterized by difficulty crossing the body midline to manipulate objects in contralateral space (which leads to a decreased frequency of contralateral hand use). Detection of midline crossing deficits is normally accomplished through clinical observation and the use of formal test measures, including the Crossing Mid-line of Body test and the Space Visualization Contralateral Use score (SVCU score) of the Space Visualization test. Both these tests are from the Southern California Sensory Integration Tests (SCSIT) (Ayres, 1976, 1980).

Unfortunately, some problems have been encountered with these tests. The Crossing Mid-line of Body test is not favored because it underidentifies children with midline crossing deficits (Ayres, 1972). Children with mild dysfunction tend to perform adequately on the test because they appear to consciously override the tendency to avoid midline crossing when verbal directions on how to perform the test are given. In contrast, when the SVCU score was used as a measure of manual midline crossing, it initially overidentified children with midline crossing deficits, because the scoring criteria did not take developmental age changes into account (Cermak, Quintero, & Cohen, 1980). Subsequent normative research on the development of manual midline crossing in 4- to 9-year-old children has allowed for refinement in the scoring criteria used in the interpretation of the SVCU score (Cermak & Ayres, 1984; Cermak et al., 1980).

The DeGangi-Berk Test of Sensory Integration, a test used to evaluate sensory integrative dysfunction in preschool-age children, also contains an item designed to evaluate manual midline crossing behavior (Berk & DeGangi, 1983). However, the literature does not contain research analyzing the development of manual midline crossing in the younger preschool-age population. Therefore, the present research was undertaken to study the development of manual midline crossing in 2- to 6-year-old children. It also analyzed factors in test design that may influence the future construction of test measures used to evaluate manual midline crossing in preschool-age children.

Literature Review

1. Development of manual midline crossing. Manual midline crossing emerges during the development of contralateral reaching, an interim stage in the development of visually guided hand movements. The initial appearance of visually guided hand movements in infancy is thought to be associated with the appearance of the asymmetrical tonic neck reflex.

Janet M. Stilwell, MS, OTR/L, is an Assistant Professor in the Department of Occupational Therapy at Louisiana State University Medical Center, New Orleans, Louisiana 70112; she also is in private practice.
(ATNR) during the 2nd and 3rd months of life. Abduction-extension of the infant's arm on the face side of the ATNR posture first brings the hand into the infant's line of vision at 4 to 6 weeks of age (White et al., 1964). Visual acuity and oculomotor control are sufficiently well developed by 8 to 10 weeks of age to allow the infant to visually fixate on the hand, when he or she is in the ATNR posture (White et al.). At this stage, the infant also makes beginning attempts to reach with his or her ipsilateral hand for suspended objects placed at shoulder level. However, these attempts are usually unsuccessful because the infant's hand is fisted and there is little coordination between eye and hand movements (White et al.). By the time the infant is 10 to 12 weeks old, the strength of the ATNR has diminished and the infant retains a symmetrical posture in supine (White et al.). Attempts at ipsilateral one-handed reaching become more successful with improvement in eye-hand coordination. The infant now glances from hand to object to assist in guiding limb movement (White et al.). This ipsilateral one-handed approach toward objects becomes oriented toward the midline by 12 to 14 weeks. Bilateral movement of the arms is usually seen during these early attempts at one-handed reaching (White et al.). Ipsilateral one-handed reaching is gradually replaced by a bilateral symmetrical approach toward objects, with the strongest period of bilaterally being seen when the infant is 16 to 18 weeks old (Provine & Westerman, 1979; White et al., 1964). By 20 weeks of age, the infant's ipsilateral one-handed reaching reappears and is characterized by improved eye-hand coordination. Initiation of the reach can now be accomplished without visual guidance and the hand opens prior to object contact (White et al.). It is also at 20 weeks of age that the infant is first able to cross the body midline to reach for an object suspended above the contralateral shoulder (otherwise known as the onset of contralateral reaching) (Provine & Westerman). By 21 weeks, slow controlled movement of the arm is seen during visually directed reaching (Bresson, Maury, Pieraut-LeBonniec, & DeSchonen, 1977; White et al.). Bilateral coordinated hand use emerges at 22 weeks of age with the appearance of one-handed indirect reaching (Bresson et al.). In one-handed indirect reaching, the infant uses the movement of one arm to direct the movement of the other arm. In this bilateral approach, one hand touches the object before the other hand reaches and manipulates it. By 28 weeks of age, the infant is able to hold an object in one hand while reaching for an object with the other hand (Sherick, Greenman, & Legg, 1976). At this stage, one-handed direct reaching (reaching with one hand without assistance from the other hand) also begins to appear, when the infant is reaching for small objects (Bresson et al.).

The infant's bilateral coordinated hand use continues to develop with the onset of two-stage transfer at 28 to 32 weeks of age (Gesell & Ames, 1947). Matching of objects at midline, one-stage transfer, and the emergence of bilateral assistance during object manipulation are seen between the ages of 36 and 52 weeks (Gesell & Ames, 1947; Sherick et al., 1976). This period is also characterized by a progressive increase in the frequency of the infant's one-handed direct reaching (Gesell & Ames). By 18 months of age, all the functional components the infant will need for mature bilateral assistance during object manipulation are present (Gesell & Ames).

The frequency with which midline crossing is seen during one-handed direct reaching in infancy or early childhood has not been studied. However, the frequency of manual midline crossing has been shown to progressively increase in children between 4 and 9 years of age (Cermak et al., 1980).

The onset of contralateral reaching may play a crucial role within the development of visually guided hand movements. As an external reflection of corpus callosum maturation, Liederman (1983) viewed midline crossing, seen within contralateral reaching at 26 weeks, to possibly signify the shift from extracallosal to callosal control of interhemispheric communication. She viewed callosal maturation as possibly being a necessary prerequisite for the development of hand preference and bilateral coordinated hand use. Liederman based her assertion on split-brain research, noting that commissurotomy patients appear to have adequate ipsilateral hand skill but that their hand preference, contralateral reaching, rapid arm movements, and complex bilateral coordinated hand use are absent or poorly developed. It is of interest that all of these skills showing a deficit emerge in development after the onset of contralateral reaching. It is also noteworthy that children who exhibit midline crossing deficits characteristically also display decreased frequency of contralateral reaching, poorly established hand preference, problems with dactylochokinesis (the ability to rapidly alternate arm movements), and poor bilateral coordinated hand use (Ayres, 1972).

compensation used to avoid midline crossing is also incorporated into the design of the Rolling Pin Activity from the DeGangi-Berk Test of Sensory Integration (Berk & DeGangi, 1983). Like the DeGangi-Berk Test of Sensory Integration, the Crossing Mid-line of Body test from the SCSIT is a standardized measure (Ayres, 1980). This test requires the child to mirror ipsilateral and contralateral hand movements to eye–ear movements made by the examiner. Although the Crossing Mid-line of Body test was designed to measure manual midline crossing behavior, extensive clinical experience with the test raised doubt as to its sensitivity (Ayres, 1972). Clinical observation has shown that children with mild dysfunction may use postural compensation to avoid midline crossing during activities that allow for spontaneous choice in hand use, but perform without apparent difficulty when verbally requested to manually cross midline on the Crossing Mid-Line of Body test.

This problem led to the development of the SVCU score as a second objective measure of manual midline crossing for use with the SCSIT (Ayres, 1976). The SVCU score is a ratio of ipsilateral to contralateral hand responses, derived from observing block manipulation during the administration of the Space Visualization test. The initial tentative scoring criteria for the SVCU score, which were based on the performance of 128 learning-disabled children, over-identified children with midline crossing deficits because it did not take developmental age changes into account (Cermak & Ayres, 1984). Subsequent normative research on the development of manual midline crossing led to a refinement in the scoring criteria used in the interpretation of the SVCU score (Cermak & Ayres, 1984; Cermak et al., 1980).

Findings obtained from the use of these tests suggest that in constructing tests designed to measure manual midline crossing in children the following needs to be considered: (a) During task completion, the child should not be aware of the requirement for manual midline crossing, (b) the test design or the scoring criteria should consider the methods of postural compensation that children use to avoid midline crossing, and (c) when test norms are determined, the developmental age changes should be taken into account.

All of the tests discussed, with the exception of the DeGangi-Berk Test of Sensory Integration, are primarily designed for use with school-age children, an age group for which research on the development of manual midline crossing is available and test effectiveness has been assessed over years of clinical use. The DeGangi-Berk Test of Sensory Integration was designed for use with pre-school-age children. For this age group, little research has been done on the development of manual midline crossing and no information exists on test construction factors that could affect test reliability. The present research was conducted to gain insight into the development of manual midline crossing in pre-school-age children and into test construction factors that could affect test performance within this age group. The study addresses the following questions:

1. Does a developmental age trend in crossing the body midline exist in 2- to 6-year-old children?
2. Does biasing the hand used for object manipulation in a spontaneous hand choice situation influence the frequency of manual midline crossing?
3. Does the distance from midline at which an object is placed during task completion affect the frequency of manual midline crossing?

Method

Subjects. The research sample was drawn from a population of Caucasian children attending eight private day-care centers, preschools, and kindergartens in the greater New Orleans metropolitan area. Subject selection was based on the availability and willingness of the children to cooperate during testing. The sample of 160 children consisted of 20 children (10 boys and 10 girls) in each of eight age groups (2, 2½, 3, 3½, 4, 4½, 5, and 5½ years). As determined by school records, none of the children exhibited a history of developmental delay, neurological or sensory disorders, or upper extremity, orthopedic involvement. They also performed within age expectations on the fine motor, language, and gross motor sectors of the Denver Developmental Screening Test. The personal-social sector of the test was not given because reported information obtained from teachers and day-care workers was viewed as potentially unreliable. Test administration and scoring were performed as described by Frankenburg, Dodds, Fandal, Kazuk, and Cohrs (1975).

Procedure. The Administration of the Test of Manual Midline Crossing was completed in a single 10 to 15 minute test session for each subject. All testing was conducted by the same examiner.

A pegboard task was used to assess manual midline crossing. Test materials included (a) a center-hinged pegboard (2% in. wide, 27% in. long, ¾ in. high) containing two sets of ¾ in. centered holes (2 in., 4 in., 6 in., 8 in., 10 in., and 12 in. to the right and left of the hinged center), (b) a wooden hand placement board (3% in. wide, 10½ in. long, ¾ in. high) with a row of three ¾ in. holes evenly spaced above sites for hand placement (2 in. by 2 in. dog faces spaced 3½ in. apart), (c) one peg (2/16 in. wide and 3 in. long) and (d) 11 peg studs (each 2/16 in. wide and 1
in. long). The pegboard, peg studs, and hand placement board were painted white and the inside of the holes and peg were painted orange. The test materials are displayed in Figure 1.

Testing was administered at a child-sized table, with the subject seated across the table from the examiner. The subject was positioned a short distance from the table's edge. This distance allowed the subject 80 to 85 degrees of elbow flexion, when his or her hands were placed on the hand placement board. The seat height was as high as possible while still allowing for leg clearance (4 to 6 in. between the chair seat and table top). A sheet of 8½ in. by 11 in. white paper was taped to the table at the table's edge. It contained a black mark 8 in. from the table's edge, which aided in pegboard placement. The hand placement board was centered on top of the paper and taped to the table's edge nearest to the subject. The pegboard was placed on the paper and centered with the black mark on the paper and the center of the hand placement board. When the subject was seated, his or her midline was aligned with the center of the hand placement board.

The 36-item Test of Manual Midline Crossing consisted of three trials, during each of which 12 peg placement items were used. For each item, the subject was asked to place the peg (located in one of the three holes in the hand placement board) into a designated hole in the pegboard. The visualization of the designated location of peg placement was enhanced by the placement of peg studs in all but one of the holes in the pegboard. For each trial, the designated location for peg placement in the pegboard was randomly sequenced. The sequencing of test items was predetermined and different for each subject. The location of the peg placement in the hand placement board was such that an even–odd selection of six peg placement items for each of the three trials included demand for midline crossing (peg placed in the hole in the hand placement board located above the hand contralateral to the designated pegboard hole) and six peg placement items for each trial lacked demand for midline crossing (peg placed in the center hole in the hand placement board).

The Test of Manual Midline Crossing was presented in the following manner. With the subject's hands symmetrically placed on the hand placement board, the examiner demonstrated the peg placement task (moved the peg from the center hole in the hand placement board to the center left hole in the pegboard). During task demonstration the subject was instructed to “place the peg in the hole.” As the first test item was presented, the subject was told “now you put the peg in the hole.” Verbal directions (“put the peg here”) and pointing to the designated pegboard hole or pointing to the peg followed by the designated pegboard hole were repeated for each of the succeeding test items. The hand used for peg manipulation was left to the subject's discretion. The subject's hands were placed symmetrically on the hand placement board between test items. The subject was assisted with hand placement on the hand placement board and with repositioning him- or herself in the chair as needed between test items. Assistance in placing the peg into the pegboard hole was also given as needed. The time span between test items (5 to 10 seconds) was used for scoring and rearrangement of the peg and peg studs (peg stud preceded peg placement).

The subject's responses were marked as contralateral or ipsilateral based on whether midline crossing was observed during either grasping of the peg or placement of the peg in the pegboard. Scores tabulated for each subject included a demand test score (frequency of contralateral hand responses produced on test items containing demand for midline crossing), a nondemand test score (frequency of contralateral hand responses produced on test items lacking demand for midline crossing), and a total contralateral hand response score (frequency of contralateral hand responses for demand and nondemand test items combined). The hand used for peg manipulation was recorded, but this information was not used in the data analysis. Eighteen subjects, mixed by age and sex were used to measure interrater reliability. Computation resulted in a correlation of \( r = .91 \).

Results

The reliability of the Test of Manual Midline Crossing was demonstrated before the research questions were tested. Two measures of internal consistency were performed on the data, Spearman-Brown split half and the Cronbach's Alpha tests. Results of both tests fell
into the moderate range of reliability (Spearman-Brown, $r = .883$; Cronbach’s Alpha, $r = .843$), indicating that subjects in the study generally performed in a consistent manner throughout the test.

**Developmental Age Trend in Midline Crossing**

The frequency of manual midline crossing showed a progressive increase with age in the 2- to 6-year-old children studied. A $2 \times 8$ analysis of variance with age group (2, 2½, 3, 3½, 4, 4½, 5, and 5½ years) and sex (male and female) as between variables revealed a significant effect for age group ($F = 21.08, p < .0001$). Because there was no significant sex effect, all further analyses were performed with the data combined by age group and sex. A subsequent linear trend analysis was also significant ($F = 130.98, p < .0001$) with a deviation of .75 to 3.65 contralateral responses between age groups (see Figure 2).

**Influence of Hand Biasing on Spontaneous Hand Choice and Manual Midline Crossing**

The frequency of manual midline crossing produced during testing was greater in the demand test condition (peg placed in the hole in the hand placement board located above the hand contralateral to the designated pegboard hole) than in the nondemand test condition (peg placed in the center hole of the hand placement board). A $2 \times 8$ analysis of variance was performed. Factors analyzed were age group and test condition, with test condition being a repeated measure. Results were significant for age group ($F = 51.83, p < .0001$), test condition ($F = 830.93, p < .0001$), and age group/test condition interaction ($F = 7.79, p < .0001$). Figure 3 shows greater frequency of manual midline crossing in the demand test condition than in the nondemand test condition. To further analyze the age group/test condition interaction, linear and quadratic trends were analyzed for the two test conditions. Results showed that the linear trends differed for the two test conditions, with the frequency of manual midline crossing increasing more rapidly with age in the demand test condition than in the nondemand test condition ($F = 51.16, p < .0001$).

**Effect of the Distance From Midline on Manual Midline Crossing**

The frequency of manual midline crossing showed a linear increase as the distance from midline increased from 2 in. to 6 in. and a decline from 8 in. to 12 in. A $2 \times 8$ analysis of variance was performed on the data. Factors analyzed were age group and peg hole location (2, 4, 6, 8, 10, and 12 in. from midline), with peg hole location being a repeated measure. Results were significant for age group ($F = 69.21, p < .0001$) and peg hole location ($F = 3.32, p < .0001$). The age group/peg hole location interaction was not significant, thus the age group data were combined for the purpose of graphic representation (see Figure 4). Subsequent trend analysis for peg hole location found significant linear and quadratic trends with the quadratic component being stronger than the linear component (quadratic trend, $F = 41.45, p < .0001$; linear trend, $F = 6.65, p < .0099$).

**Discussion**

The presence of a developmental age trend in crossing the body midline in 2- to 6-year-old children was confirmed by the research findings. This serves as an
The location of peg placement in the pegboard was an additional factor affecting the frequency of manual midline crossing observed during testing. The frequency of contralateral responses progressively increased from a peg hole distance in the pegboard of from 2 in. to 6 in. from midline and then gradually decreased from a peg hole distance in the pegboard of 8 in. to 12 in. from midline. This finding is in contrast to that cited by Atwood and Cermak (1986), who found a decrease in contralateral responses with increasing distance from midline. Distances studied were 0.75 in., 3.0 in., and 6.0 in. between block placements on the Space Visualization test (0.375 in., 1.5 in., and 3.0 in. from midline).

There were two major differences between the design of the present study and the design of the study by Atwood and Cermak (1986) that may account for the difference in research findings. The first difference relates to variation in the scoring criteria. In the Space Visualization test used by Atwood and Cermak, a contralateral response was defined as the use of the contralateral hand to pick up the block used for puzzle completion (observation of midline crossing was not required). In the present study the visualization of midline crossing was needed to determine a contralateral response. The hand used for peg manipulation did not enter into the scoring. Observations made during testing found that the use of the contralateral hand for peg manipulation often did not coincide with an observation of midline crossing. Children frequently used the contralateral hand to grasp the peg but then used postural trunk adjustments to avoid midline crossing. This behavior was most commonly seen when the location of peg placement in the pegboard was close to midline. This citing raises a question as to the accuracy of the findings obtained by Atwood and Cermak. Because this behavior was not controlled for in SVCU scoring procedure, their results may contain false positive readings.

The second difference between the two studies relates to the location of midline crossing. In the Atwood and Cermak (1986) study, midline crossing occurred close to the body, when the subject grasped the block needed to complete the puzzle. In the present study midline crossing occurred either close to the body, when the subject removed the peg from the hand placement board, or at a distance, when the subject placed the peg in the pegboard. It is possible that the effect of distance from midline on frequency of contralateral hand use may be different when midline crossing occurs close to the body than when midline crossing occurs at a distance from the body. Unfortunately, since the location of midline crossing (close to vs. at a distance from the body) was not recorded in the present study, the results of the two studies cannot be directly compared.

expansion of knowledge gained from a study by Cermak et al. (1980), which identified a developmental age trend in crossing the body midline in 4- to 9-year-old children. The absence of contralateral responses was a rare citing, indicating that even in 2-year-old children manual midline crossing appears to be a well-established behavior.

Although contralateral hand use was easily elicited during testing, biasing the hand used for peg manipulation strongly influenced the frequency of manual midline crossing. Contralateral responses were produced more often in the demand test condition (peg placed in the hole of the hand placement board located above the hand contralateral to the designated pegboard hole) than in the nondemand test condition (peg placed in the center hole in the hand placement board, with equal distance between hand placements). Although this result was significant for all age groups, it was strongest for the older children (see Figure 3).

The discrepancy in performance between the demand and nondemand test conditions suggests that a completely spontaneous unbiased test response format (preferred with school-age children) may not be the approach of choice for pre-school-age children who produce very few contralateral responses when given equal opportunity for right and left hand use. Thus, greater variability and range of test scores would potentially be produced if biasing the hand used for object manipulation were incorporated into the test design. What remains untested is whether this response format would discriminate adequately between children with and without midline crossing deficits.
Conclusions

The results expand existing knowledge regarding the development of manual midline crossing in children. When the discovery of a developmental age trend in crossing the body midline in pre-school-age children is combined with existing knowledge, it can be said that a developmental age trend in crossing the body midline appears to exist in 2- to 9-year-old children. Whether similar developmental changes occur in children under 2 years of age is unknown and remains open to further investigation.

The research findings also revealed that environmentally induced variables affect the frequency of manual midline crossing produced during testing. Factors analyzed that affect the frequency of manual midline crossing include biasing the hand used for object manipulation and the distance from midline at which an object is placed during task completion. The exact effect that distance from midline has on the frequency of contralateral hand use is inconclusive. The fact that the present finding conflicts with that obtained by Atwood and Cermak (1986) suggests that a replication of this portion of the study is needed. An additional factor in need of future investigation is the distance from the body (close to vs. at a distance from) at which task completion occurs. The relationship between this factor and the effect that the distance from midline at which task completion occurs has on the frequency of contralateral hand use is unknown and an additional avenue for future research.

Acknowledgment

I thank Elizabeth M. Hill, PhD, for her assistance in the data analysis.

References