Consistency of Hand-Preference Across the Early Years: Long-Term Relationship to Verbal Intelligence and Reading Achievement in Girls

Makeba Parramore Wilbourn
Duke University

Allen W. Gottfried and Daniel W. Kee
California State University, Fullerton

The relationship between consistency of hand preference, left hemispheric specialization, and cognitive functioning was examined in an ongoing longitudinal investigation. Children were classified as consistent or inconsistent in their hand preference across 5 assessments from ages 18 to 42 months. Findings demonstrated that (a) this early classification continued to reveal differences in cognitive functioning from 10 to 17 years but only for girls, (b) consistent girls' performances were continually higher relative to the inconsistent girls on measures of verbal intelligence and reading achievement, (c) differences between the female groups were specifically related to left-hemispheric language specialization, and (d) one factor influencing the consistent girls' development may be the amount of reading exposure received during infancy.

Keywords: hand-preference consistency, early reading exposure, verbal intelligence, reading achievement, sex differences

Handedness, and its psychological implications, particularly with respect to cognitive functions, has had a long-standing history in the behavioral sciences (Annett, 2002; Witelson, Beresh, & Kigar, 2006). This type of laterization has been studied across the lifespan, albeit primarily with cross-sectional methods (Brenneman, Decker, Meyers, & Johnson, 2008; Gunstad, Spitznagel, Luyster, Cohen, & Paul, 2007). The preponderance of developmental research has focused on handedness as a function of direction (i.e., left vs. right) or degree or strength (e.g., percentage of tasks using one hand over the other). Research utilizing these conventional measures has often produced inconsistent findings with respect to the relationship between handedness and cognitive functions (Benson, Cherny, Hait, & Fulker, 1993; Kaufman, Zalma, & Kaufman, 1978; McManus et al., 1998; Thilers, MacDonald, & Herlitz, 2007). This inconsistency in findings has been a point of contention and is most often attributed to the various types of measures used to appraise handedness (Brenneman et al., 2008; Brown, Roy, Rohr, Snyder, & Bryden, 2004; De Agostini & Dellatolas, 2001; Hauck & Dewey, 2001; Michel, Ovrut, & Harkins, 1985). Furthermore, much of this research has focused on cognitive deficits (e.g., autism, dyslexia, language disorders, intellectual disabilities; Annett, 1996; Gunstad et al., 2007; Hauck & Dewey, 2001) often associated with the direction and strength of handedness.

In contrast to studying direction or strength of handedness at a given point in time, Gottfried and Bathurst (1983) used a developmental approach to investigate handedness. They used an aggregate measure of consistency versus inconsistency of hand preference across the infant and preschool years. Children were assessed as to which hand they used in a drawing task across five assessment waves (i.e., 18, 24, 30, 36, and 48 months). Children who used the same hand across all five assessments were classified as “consistent” in their preference. Conversely, children who did not use the same hand across all assessments were designated as “inconsistent” in their preference, even if they varied in their preference on a single assessment. Early cognitive functioning was assessed using the Bayley Scales of Infant Development (Bayley, 1969) and the McCarthy Scales of Children’s Abilities (McCarthy, 1972), with analyses conducted separately for boys and girls. There were no significant differences between the two male groups on any of the cognitive measures. However, girls who exhibited an early consistent hand preference had significantly higher scores on the cognitive measures from infancy through preschool compared with the girls who exhibited an inconsistent hand preference. These findings revealed not only a relationship between cross-time consistency of hand preference and cognitive functioning, but also revealed a reliable within-sex difference for girls.

To further investigate the interrelations among early consistency of hand preference, sex, and cognitive functioning, Kee, Gottfried, Bathurst, and Brown (1987) investigated the degree to which the differences between the consistent and inconsistent girls at ages five and six highlighted differences in early manual laterality and hemispheric specialization. The children were asked to perform manual finger-tapping tasks to determine whether the differences in cognitive functioning favoring the consistent girls over the inconsistent girls were a function of cerebral left-hemispheric...
specialization for verbal processing. On some trials, children were required to simultaneously tap their left vs. right index fingers as fast as possible. On alternate trials, they were required to tap as fast as possible while reciting a well-known nursery rhyme (i.e., Jack and Jill).

The findings revealed that consistent girls exhibited more manual asymmetry than did the inconsistent girls when required to simply tap both fingers. Specifically, the consistent girls exhibited a significantly larger right-hand versus left-hand tapping advantage, whereas the inconsistent girls were equally fast with their right and left hand. Likewise, when required to tap both fingers while reciting the nursery rhyme, the consistent girls exhibited significantly more right-hand than left-hand tapping disruptions, indicating a more pronounced left-hemisphere cerebral asymmetry. Similar to the previous study, differences between the consistent and inconsistent boys in manual or cerebral asymmetry were not evident. It is noteworthy that when assessing the asymmetrical tradeoffs with the verbal recitation of the nursery rhyme during the finger tapping, the number of words recited while finger tapping did not differ between the hand preference consistency groups. Kee et al. (1987) contended that these findings clearly demonstrated that the asymmetries found for the consistent girls were specifically a function of left-hemispheric specialization for language. Thus, the findings underscored important linkages between consistency of hand preference during the early years, cerebral hemisphere specialization, and differential language development in girls.

To determine whether the advantages demonstrated by the consistent girls compared with the inconsistent girls were evident in both intellectual and academic domains through middle childhood, Kee, Gottfried, and Bathurst (1991) analyzed five annual assessments (i.e., ages of 5–9 years) of the children’s intellectual functioning (verbal and performance) and academic achievement scores (reading and math). As previously found, the consistent and inconsistent boys did not significantly differ on any measure. However, the consistent girls performed significantly higher than the inconsistent girls at every age. Differences were most pronounced on verbal intelligence and reading achievement tests, whereas performance intelligence (i.e., nonverbal) and math achievement tests were less evident as the girls advanced in age.

This sequence of studies provided compelling evidence that early consistency of hand preference was related to both concurrent and subsequent cognitive skills specifically related to left-hemispheric specialization, but only for girls. However, the extent to which the relationship between early consistency of hand preference and cognitive functioning persisted from middle childhood throughout adolescence has remained unknown. Furthermore, possible mechanisms contributing to these foregoing findings have been unexplored. Thus, the current study offers a long-term longitudinal analysis following these children through adolescence. Our goals were (a) to determine whether the differences found between the consistent and inconsistent girls continued to be evident throughout adolescence and, if so, (b) to explore potential mechanisms that may have contributed to these differences from infancy through adolescence. It is important to note that the focus of this project was not to investigate whether left versus right hand preference in girls compared with boys was related to cognitive functioning. Rather, our focus was to determine whether early consistency in hand preference continued to highlight differences favoring the consistent girls over the inconsistent girls.

Based on the previous findings from 18 months to 9 years of age (Gottfried & Bathurst, 1983; Kee et al., 1987; Kee et al., 1991), the current project addressed the following hypotheses. Our first hypothesis was that differences between the male groups would not emerge as they advanced in age from middle childhood (i.e., 10 years) through adolescence (i.e., 17 years). In contrast, given that reliable differences between the consistent and inconsistent girls persisted from the ages of 18 months to 9 years (Gottfried & Bathurst, 1983; Kee et al., 1987; Kee et al., 1991), our second hypothesis was that this continuity of differences would be maintained through adolescence. Moreover, we predicted that these differences would be most evident on measures of verbal intelligence and reading achievement. However, because differences in performance (i.e., nonverbal) intelligence and math achievement had become unreliable and began to diminish by age nine (Kee et al., 1991), we predicted that differences on these measures would not be present from middle childhood through adolescence.

If it was established that the consistent girls continued to perform higher than the inconsistent girls in the verbal intelligence and reading achievement, our third hypothesis was that these differences would continue to be associated with left-hemispheric language specialization (e.g., speech processing and right-handed tasks) and that tasks involving the right hemisphere (e.g., spatial tasks or left-handed tasks) would not reveal significant differences between the hand consistency groups. The rationale underlying this specific hypothesis is based on Kee et al.’s (1987) findings demonstrating that the consistent girls exhibited (a) greater manual asymmetry relative to the inconsistent girls as evidenced by their significantly faster right-hand tapping speed and (b) more pronounced left-hemispheric language specialization, as evidenced by their greater right-hand versus left-hand tapping disruption while reciting a nursery rhyme, a pattern that was not evident for the inconsistent girls.

If the findings revealed that the differences favoring the consistent girls over the inconsistent girls were associated specifically with differences in left-hemispheric language specialization, our fourth hypothesis was that differences in early linguistic input might be evident. We were specifically interested in early language stimulation in the home prior to the initial hand-preference assessment (i.e., 18 months). Although Gottfried and Bathurst (1983) found that the female (and male) hand-preference groups did not differ in overall stimulation in the home environment during infancy (measured by the Home Observation for Measurement of the Environment Scale; HOME),1 based on Wachs’s (1992) hypothesis of specificity of environmental action and the findings of Bradley, Corwyn, McAdoo, and García Coll (2001), we examined specific experiences related to early language exposure that may have played a role in the cognitive differences found between the female groups on verbal intelligence and reading achievement.

More specifically, we explored measures of conversational language input as well as early shared-book reading. When considering the potential mechanisms that could be involved in the consistent girls’ accelerated left-hemispheric specialization, early conversational language input and reading exposure presented as theoretically relevant candidates. We were particularly interested in comparing these early language measures because early reading exposure is reported to be richer and more complex than conversation language exposure per

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1 This was also the case for mother’s intelligence and educational level.
We explored early reading exposure because recent findings have shown that infants are often exposed to shared book reading before the age of 12 months (Fletcher & Reese, 2005) and that this type of early reading exposure has implications for later verbal and reading skills (Fletcher & Reese, 2005; Posner & Rothbart, 2006). Thus, it is plausible that early reading exposure is involved in the development of left-hemispheric specialization, which, in turn, may be related to early consistency of hand preference. Other longitudinal studies have shown that picture book reading may enhance specific types of language and reading abilities (Fletcher & Reese, 2005; Sénéchal & LeFevre, 2002). Henderson and Ebner (1997) contended that early sensory stimulation, particularly within the first few years of life, affects and enhances the brain’s capacity and efficiency in processing information, particularly linguistic information. They claimed that early interactive, repetitive, and appropriate types of sensory stimulation during infancy have “a permanent effect on developing modifiable circuits in the immature brain” (p. 65). The structured and repetitive aspects of shared reading experiences (Fletcher & Reese, 2005; Sénéchal & LeFevre, 2002) early in development may provide children with the type of linguistic stimulation that enhances their sensitivity to and awareness of the phonological (i.e., sound) structure of language, which has been linked to left-hemispheric specialization (Leonard et al., 1996) and early language and reading abilities (Fletcher & Reese, 2005; Posner & Rothbart, 2006). These findings served as the conceptual and empirical basis for hypothesizing that the differences in verbal abilities continuously found between the female hand-preference groups could be related to differences in early reading exposure, above and beyond conversational language input.

**Method**

**Participants**

The present research is based on the Fullerton Longitudinal Study (FLS), an ongoing long-term prospective investigation of 130 infants and their families. All children who entered the study were full-term babies of normal birth weight and had no reported neurological or visual abnormalities. During the course of the study, children were assessed in the university laboratory at 6-month intervals from ages 12 to 42 months and annually throughout the school years (i.e., 17 years). From infancy through age 17 years, a comprehensive battery of standardized measures was administered at each assessment to examine development across a variety of domains. Home visits were also conducted during the early years, starting at age 15 months. The retention rate of the study sample was never less than 80% across all assessments through age 17 years, with no evidence of attrition bias throughout the course of the study (Guerin, Gottfried, Oliver, & Thomas, 2003). The socioeconomic status of the sample represented a wide, middle-class range, from semiskilled workers through professionals, as determined by the Hollingshead Four-Factor Index of Social Status (Hollingshead, 1975; also see Gottfried, 1985; Gottfried, Gottfried, Bathurst, Guerin, & Parramore, 2003). The mean Hollingshead Social Status Index was 45.6 (SD = 11.9) at the initiation of the FLS and 48.6 (SD = 11.4) at the 17-year assessment (Guerin, Gottfried, Oliver, & Thomas, 2003). The participants were predominantly white (90%) and also from other ethnic backgrounds. The percentages of boys and girls were 52 and 48, respectively. For further details concerning the longitudinal sample characteristics and study design, see Gottfried and Gottfried (1984); Gottfried, Gottfried, Bathurst, and Guerin (1994); Gottfried, Gottfried, and Guerin (2006); and Guerin et al., (2003).

The hand-preference consistency groups were determined by assessing children’s drawing hand preference at ages of 18, 24, 30, 36, and 42 months during the administration of the Bayley (1969) and McCarthy (1972) scales. Each participant was seated at a table across from an experimenter. The experimenter positioned a piece of paper with a crayon in the center, directly in front of the child. This was done so that the position of the crayon did not bias the child to use one hand over the other. The hand the child used to pick up and draw with the crayon was recorded. The hand a child used to retrieve the crayon was invariably the same hand used to draw.

Of the 130 children in the entire sample, 89 children (41 girls) provided complete data to be classified into hand-preference consistency groups based on the following criteria: (a) child participated and provided data for all five assessments (i.e., 18, 24, 30, 36, and 42 months); (b) used the same hand on a drawing task on all five assessments, in order to be classified as “consistent”; or (c) exhibited at least one change in hand choice at any assessment and thus was classified as “inconsistent” (Gottfried & Bathurst, 1983). At the 42-month assessment, of the 48 boys assessed, 24 were classified as consistent and 24 were classified as inconsistent. Of the 41 girls assessed, 23 girls were classified as consistent and 18 were classified as inconsistent.

At the 6-year assessment, of the 79 returning children across the handedness groups, all but six (one consistent boy, two inconsistent boys, and three inconsistent girls) of the children were right-handed, as evidenced by their performance on the Harris Test of Lateral Dominance (Harris, 1974). At the 12-year assessment, children’s hand preference revealed no change from the 6-year assessment.

**Procedures and Materials**

**Intellectual and achievement measures.** Measures of intellectual development were collected when the children were 12, 15, and 17 years old. At the 12-year assessment, the Wechsler Intelligence Scale for Children–Revised (WISC-R; Wechsler, 1974) was administered. At the 15-year assessment, the Wechsler Intelligence Scale for Children–Third Edition (WISC-III; Wechsler, 1991) was administered. At the 17-year assessment, the Wechsler Adult Intelligence Scale–Revised (WAIS-R; Wechsler, 1997) was administered. The verbal and performance percentile scores were analyzed across the three assessment periods. The Woodcock-Johnson Psycho-Educational Battery (Woodcock, 1977) was conducted on the Broad Math and Reading age percentile scores.

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2 At the 10-year assessment, the Dyslexia Screener test (Guerin, Griffin, Gottfried, & Christenson, 1993) was administered. Analyses did not yield significant differences between the female or male hand-preference consistency groups on the Dyslexia Screener (all ps > .10). In addition, none of the girls in either hand-preference group was classified as dyslexic.
Manual laterality and cerebral hemispheric measures. To explore the specificity of the advantage for girls and whether or not the differences were found primarily in tasks involving the left hemisphere, we analyzed manual laterality and nonverbal cerebral hemispheric measures administered when the participants were 6 and 7 years old. It has been well established that differences in hand skill on particular types of manual tasks (e.g., finger tapping, peg moving) infer cerebral hemispheric asymmetry (Annett, 1973; Carlier, Dumont, Beau, & Michel, 1993; Kee et al., 1987; Kinsbourne & McMurray, 1975). Considering that Kee et al. (1987) had administered finger-tapping tasks to the children in the current study and previously reported those findings, we sought to find converging evidence that the differences found between the consistent and inconsistent girls are a function of differences in hemispheric laterality. Therefore, we analyzed a manual laterality measure (e.g., peg-moving task; Annett, 1973) administered when the children were 6 years old.

Data from the peg-moving task were analyzed because hand performance is considered to be a better indicator of manual and hemispheric laterality than hand preference alone (Pedersen, Sigmundsson, Whiting, & Ingvaldsen, 2003). In addition, the peg-moving task is known to highlight the relationships among cognitive processes, laterality, vocabulary development (Annett, 1970), and readings skills throughout development (Brenneman et al., 2008). Furthermore, this task has also been used to determine the relationship between motor development, hemispheric laterality, and dyslexia (Stodley & Stein, 2006). Stodley and Stein (2006) report that dyslexic and nondyslexic people’s peg-moving speed was correlated with the speed at which they made phonological judgments. Considering that, in past investigations, the consistent girls repeatedly outperformed the inconsistent girls on measures of verbal and reading abilities, we hypothesized that their performances on the peg-moving task would provide additional insights into whether or not these differences were restricted to left-hemispheric tasks.

In the current study in the peg-moving task, children were seated in front of a pegboard that had two rows of 10 holes on each side (Annett, 1973). They were required to move each peg from one side of the board to the other as quickly as possible. Children completed the task six times with both their left and right hands. If the participant dropped a peg, the trial was repeated. The children’s peg-moving speed (in seconds) was correlated with the speed at which they made phonological judgments. Considering that, in past investigations, the consistent girls repeatedly outperformed the inconsistent girls on measures of verbal and reading abilities, we hypothesized that their performances on the peg-moving task would provide additional insights into whether or not these differences were restricted to left-hemispheric tasks.

In addition, we analyzed participants’ hemispheric bias score on the chimeric faces task (Levy, Heller, & Banich, 1983) that was administered when they were 7 years old. This task is known to reveal greater right-versus left-hemispheric activation in right-handers because the right hemisphere is thought to be highly specialized for the visual processing of faces. In this task, children looked at 36 pairs of photographs of male faces (i.e., four pairs of nine different faces). Each face depicted a smiling expression on one side and a neutral expression on the other side (see Levy et al., 1983, for a detailed description of the stimuli). Children were instructed to look at each face and decide which position of the face (top, bottom, or undecided) looked the happiest. Performances on this task offer indices of laterality and typically expose a left-visual field bias, which is suggestive of greater right-hemispheric activation (Levy et al., 1983; Killgore & Yurgelun-Todd, 2007). For each participant, a hemispheric bias score was calculated by taking the number of faces identified as happier in the left-visual field and subtracting it from the number of happier faces identified in the right-visual field, then dividing this number by the number of left-visual field plus right-visual field happier faces. A negative score, which is typically observed, is suggestive of a left-visual field/right-hemispheric bias (Killgore & Yurgelun-Todd, 2007; Levy et al., 1983).

At the 6- and 12-year assessments, the children’s hand preferences on a writing task were documented, and the Harris Test of Lateral Dominance was administered (Harris, 1974).

Early language and reading-exposure measures. To assess early conversational language input, a composite score was calculated using four specifically selected items from the HOME inventory (Caldwell & Bradley, 1984) at the 15-month in-home assessment. The HOME is based primarily on a semi-structured interview with the mother. The four items selected from the HOME explicitly measured conversational language input directed toward the infant by the mother. The four items were coded by an in-home observer and scored on a yes/no basis. “Yes” responses were scored as a 2, and “no” responses were scored as a 1. Thus, for each infant, the maximum score was 8. The selected items were (a) mother spontaneously vocalizes to the infant, (b) mother verbally responds to infant’s vocalizations, (c) mother names objects or people, and (d) mother spontaneously praises infant.

To assess early reading exposure, two specific items were selected from the HOME (Caldwell & Bradley, 1984) and Purdue Home Stimulation Inventory (PHSI; Wachs, 1976), both administered at the 15-month in-home assessment. From the HOME, the frequency of early reading measure was based on the mothers’ response as to how often they read to their child in a typical week (i.e., an affirmative response was based on reading at least three times per week). From the PHSI, the intensity of early reading exposure was mothers’ estimates of how long (in minutes) they read to their infants per day.

Results

As in all of the previous studies (Gottfried & Bathurst, 1983; Kee et al., 1987; Kee et al., 1991), a preliminary 2 (Sex: male vs. female) × 2 (Handedness Group: consistent vs. inconsistent) multivariate repeated-measures analyses of variance (ANOVA) was conducted and failed to yield a significant main effect of sex, \( F(1, 70) = .47, p > .10, \eta_p^2 = .01 \), or any significant interactions between sex and hand preference consistency group (all \( Fs < 2.0, ps > .10 \)). Thus, the boys and girls did not significantly differ regardless of handedness group classification across the longitudinal analysis. However, based on the foundational findings from the previous research, we conducted comparisons within sex. In addition, analyses were conducted including and excluding the four (two boys, two girls) left-handed participants who provided data for each assessment (6, 7, and 10–17 years) and yielded similar patterns of results. Therefore, the analyses reported here

3 At these assessments, the data were collected but were not part of the conceptualization or analyses for the Kee et al. (1987) report.
include both right and left-handed participants. For all analyses, two-tailed tests at the .05 level were used.

Hypothesis 1

Differences between the male hand-preference groups would not be present from 10 to 17 years.

Verbal assessments. Participants’ average percentile scores on reading achievement and verbal intelligence measures were subjected to a 2 (Hand-Preference Group) × 8 (Verbal Assessments: 10, 11, 12, 13, 14, 15, 16, 17 years) multivariate repeated-measures ANOVA (Fitzmaurice, Davidian, Verbeke, & Molenberghs, 2009). In accord with previous studies (Gottfried & Bathurst, 1983; Kee et al., 1987; Kee et al., 1991) and as expected, the analyses did not yield a significant main effect of hand-preference group, \( F(1, 37) = 1.75, \ p > .10, \ \eta^2_p = .05 \), or any interactions (all \( ps > .10 \)).

Nonverbal assessments. An additional 2 (Hand-Preference Group) × 8 (Nonverbal Assessments: 10, 11, 12, 13, 14, 15, 16, 17 years) multivariate mixed-model ANOVA was conducted on the average percentile scores on math achievement and performance intelligence tests. Again, the analyses failed to yield a significant main effect of hand-preference group, \( F(1, 37) = .798, \ p > .10, \ \eta^2_p = .02 \), or any significant interactions (all \( ps > .10 \)). Table 1 displays the mean scores (and standard deviations) for the hand-consistency groups within sex for all of the dependent measures.

Hypothesis 2

Differences between the female hand preference groups will persist through adolescence, particularly in the verbal intelligence and reading achievement domains.

Verbal assessments. To test our prediction, a 2 (Hand-Preference Group) × 8 (Verbal Assessments) multivariate repeated-measures ANOVA was conducted on the reading achievement and verbal intelligence percentile scores. As predicted, the findings revealed a significant main effect of hand-preference group, \( F(1, 33) = 5.50, \ p < .05, \ \eta^2_p = .14 \), indicating that the consistent girls significantly outperformed the inconsistent girls on measures of verbal intelligence and reading achievement. No interactions yielded significant results (all \( ps > .10 \)).

Nonverbal assessments. Also in line with our predictions, a 2 (Hand-Preference Group) × 8 (Nonverbal Assessments) multivariate repeated-measures ANOVA conducted on the percentile scores on the math achievement and performance intelligence tests failed to yield a significant main effect of hand-preference group, \( F(1, 33) = 2.28, \ p > .10, \ \eta^2_p = .07 \). This indicates that the consistent girls’ scores did not significantly differ from the inconsistent girls’ scores on the math achievement or performance intelligence tests from 10 to 17 years. Again, no significant interactions emerged (all \( ps > .10 \)).

Hypothesis 3

If the consistent girls continue to perform higher than the inconsistent girls in the verbal and reading domains, the differences would be associated specifically with left-hemispheric language specialization.\(^4\)

Peg moving (manual laterality task). A 2 (Hand-Preference Group) × 2 (Peg-Moving Speed: left hand vs. right hand) mixed-model ANOVA was conducted on the average peg-moving speed (in seconds) for the left and the right hand. The findings revealed a significant main effect of peg-moving speed, indicating that all of the girls were significantly faster moving the pegs with their right hands (\( M = 9.05s, \ SD = 1.07s \) ) than their left hands (\( M = 10.85s, \ SD = 1.35s \) ), \( F(1, 29) = 59.39, \ p < .001, \ \eta^2_p = .67 \). This main effect was qualified by a significant Hand-Preference Group × Peg-Moving Speed interaction, \( F(1, 29) = 7.11, \ p < .01, \ \eta^2_p = .20 \), demonstrating that the consistent girls were significantly faster at moving the pegs with their right hand than were the inconsistent girls, \( t(29) = -2.81, \ p < .01, \ \eta^2_p = .21 \), suggestive of greater left-hemispheric specialization. However, with their left hands, a difference between the consistent and inconsistent girls was not evident, \( t(29) = 0.70, \ p > .10, \ \eta^2_p = .01 \). No other main effects emerged significant (all \( ps > .10 \)). These findings provide additional support for our hypothesis that, for girls, the differences found between the consistent and inconsistent hand-preference groups are specifically related to manual and cerebral asymmetry involving the left hemisphere.

Chimeric faces (right-hemispheric task). To further explore our claim that the differences favoring the consistent girls are restricted to tasks involving the left hemisphere and not evident in tasks involving the right hemisphere, we analyzed the bias scores calculated from the chimeric face task (Levy et al., 1983) administered when the children were 7 years old. The computed bias scores were subjected to an independent-samples \( t \) test comparing the hand-preference consistency groups. The findings revealed that the groups did not differ in their degree of left-visual field/right-hemisphere bias, \( t(33) = -0.51, \ p > .10, \ \eta^2_p = .01 \). In addition, a 2 (Hand-Preference Group) by 2 (Visual Field Bias: left biased vs. right biased) mixed-model ANOVA was conducted. Hand-preference group was administered as a between-subjects variable and visual field bias was administered as a within-subjects variable. As expected, the findings revealed a significant main effect of visual field bias, \( F(1, 33) = 15.47, \ p < .001, \ \eta^2_p = .32 \), indicating that overall, the girls identified significantly more faces as happier when the expression was in their left visual field (i.e., right hemisphere) than in their right visual field (i.e., left hemisphere), suggesting a stronger right-hemisphere bias. However, the Hand-Preference Group × Visual Field Bias interaction did not emerge significant, \( F(1, 33) = .19, \ p > .10, \ \eta^2_p = .01 \), indicating that the consistent girls did not significantly differ from the inconsistent girls as a function of right-hemispheric bias. Likewise, the main effect of hand-preference group did not emerge as significant, \( F(1, 33) = .25, \ p > .10, \ \eta^2_p = .01 \).

\(^4\) Significant main effects of verbal assessments and nonverbal assessments are not reported. Overall, these main effects indicated that there were age-related changes with all of the girls throughout development. The absence of significant interactions with hand-preference group demonstrates that the effects of renaming these standardized measures over the years were the same for both the consistent and inconsistent hand-preference groups.

\(^5\) Analyses for the boys were conducted on all outcome measures analyzed for the girls. None of these analyses revealed significant results (all \( ps > .05 \), two-tailed). Thus, the remainder of the analyses reported for Hypothesis 3 focus only on the girls.
Table 1
Means and Standard Deviations for Consistent and Inconsistent Male and Female Groups

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Male</th>
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<th>Female</th>
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<tr>
<td></td>
<td>Consistent</td>
<td>Inconsistent</td>
<td>Consistent</td>
<td>Inconsistent</td>
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<tr>
<td>Woodcock-Johnson: Age percentiles</td>
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<td>10 years</td>
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<tr>
<td>Reading</td>
<td>$N = 20$</td>
<td>$N = 19$</td>
<td>$N = 19$</td>
<td>$N = 16$</td>
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<tr>
<td>Mathematics</td>
<td>71.90 (21.90)</td>
<td>60.37 (24.90)</td>
<td>71.00 (24.80)</td>
<td>51.75 (21.86)</td>
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<td></td>
<td>70.75 (25.29)</td>
<td>67.42 (25.43)</td>
<td>76.79 (22.74)</td>
<td>64.38 (21.30)</td>
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<td>11 years</td>
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<tr>
<td>Reading</td>
<td>$N = 20$</td>
<td>$N = 19$</td>
<td>$N = 19$</td>
<td>$N = 16$</td>
</tr>
<tr>
<td>Mathematics</td>
<td>78.05 (21.48)</td>
<td>67.37 (26.72)</td>
<td>78.21 (24.24)</td>
<td>66.25 (18.76)</td>
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<td>83.75 (17.03)</td>
<td>78.21 (18.01)</td>
<td>84.00 (17.89)</td>
<td>69.81 (18.97)</td>
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<td>WISC-R: Age percentiles</td>
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<td>12 years</td>
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<tr>
<td>Verbal</td>
<td>76.60 (20.94)</td>
<td>73.63 (22.84)</td>
<td>74.42 (19.02)</td>
<td>66.56 (18.46)</td>
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<td>Performance</td>
<td>84.80 (13.54)</td>
<td>73.32 (22.11)</td>
<td>82.84 (19.73)</td>
<td>75.63 (14.35)</td>
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<td>Woodcock-Johnson: Age percentiles</td>
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<td>Reading</td>
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<td>$N = 19$</td>
<td>$N = 19$</td>
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<tr>
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<td>69.74 (23.56)</td>
<td>86.00 (18.58)</td>
<td>69.25 (21.11)</td>
</tr>
<tr>
<td></td>
<td>76.50 (22.03)</td>
<td>70.32 (26.61)</td>
<td>80.95 (19.69)</td>
<td>71.62 (16.08)</td>
</tr>
<tr>
<td>WISC-R: Age percentiles</td>
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<td></td>
<td></td>
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<tr>
<td>14 years</td>
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<tr>
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<td>83.05 (19.02)</td>
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<tr>
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<td>15 years</td>
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<td></td>
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<tr>
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<tr>
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<td>16 years</td>
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<tr>
<td>Verbal</td>
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<td>51.12 (19.20)</td>
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<td>17 years</td>
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<tr>
<td>Verbal</td>
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Peg-moving task: Time (in s)

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<th>Assessment</th>
<th>Male</th>
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<th>Female</th>
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<td>Consistent</td>
<td>Inconsistent</td>
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<td>$N = 18$</td>
<td>$N = 11$</td>
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<td>10.91 (1.10)</td>
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<td>14.78 (4.05)</td>
<td>15.61 (4.99)</td>
<td>14.40 (6.30)</td>
<td>13.80 (3.97)</td>
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</table>
Hypothesis 4

Differences in the environment specifically related to language stimulation may be evident between the female hand-preference groups.

**Conversational language exposure.** Infants’ composite scores were subjected to a one-way ANOVA with hand-preference consistency group as the between-subjects variable. The results indicate that the consistent group did not significantly differ from the inconsistent group in the amount of conversational language input observed during the 15-month assessments, \( F(1, 40) = .37, p > .10, \eta^2_p = .01 \).

**Weekly reading exposure (frequency).** We conducted a chi-square analysis on the mother’s report, at the 15-month assessment, of whether or not she read to her infant at least three times per week. The findings showed that the number of girls who were read to at least three times per week differed significantly as a function of the hand-preference consistency groupings, \( \chi^2(1, N = 40) = 6.21, p < .05, \eta^2_p = .16 \).

**Daily reading exposure (intensity).** The estimated amount of time (in minutes) reading per day for both the consistent and inconsistent girls was subjected to an independent-samples \( t \) test. The analysis revealed that at 15 months of age, the consistent girls received significantly more reading exposure (in minutes) per day than the inconsistent girls, \( t(38) = 2.45, p < .05, \eta^2_p = .14 \).

To further assess the relationship between the intensity of this early reading exposure and subsequent hand-preference consistency, we conducted a logistic regression to determine whether or not girls’ classification in either the consistent or inconsistent hand-preference group could be predicted by early reading exposure at 15 months. The findings revealed that the amount of reading time per day at 15 months predicted the girls’ classification membership (i.e., whether they were in the consistent or inconsistent hand preference groups), \( \beta = -.049, \text{Wald}(40) = 4.29, p < .05 \).

**Discussion**

The findings from this long-term longitudinal investigation provide continuous evidence that using a cross-time measure of hand-preference consistency or inconsistency during the early years provides insights into cognitive functioning through adolescence. Based on Gottfried and Bathurst’s (1983) classification of girls as either consistent or inconsistent in their early hand preference, the results from the present investigation found that the emergence of handedness in girls from infancy through the preschool years revealed a relationship between early hand-preference consistency and both concurrent and subsequent cognitive performance.

It is important to reiterate that, with the exception of four participants (two boys and two girls in the inconsistent groups), all of the remaining participants were classified as right-handers at the 12-year assessment. This result in and of itself is not surprising, given that the majority of the population demonstrates a right-hand/left-hemisphere bias (Annett, 1967), which is evident in very young infants (Corbetta & Thelen, 2002; Michel & Harkins, 1986; Shucard & Shucard, 1990). However, if we had only assessed the direction (left or right) or strength (strong vs. weak) of handedness across tasks at the 6- and 12-year assessments, we would not have been able to detect the robust differences among girls that were evident using this cross-time hand-preference consistency measure from the ages of 18 to 42 months. This underscores the fact that, in the current study, the differences between the consistent and inconsistent girls are specifically related to the consistency of early hand preference, as opposed to left versus right hand preference or performance.

Throughout the course of this investigation, the consistent and inconsistent boys did not significantly differ on any measure. And although the trends show that the consistent boys scored higher than the inconsistent boys on most measures throughout adolescence, at no point did this pattern yield robust differences between the groups. These findings support and extend the conclusions of the previous studies (Gottfried & Bathurst, 1983; Kee et al., 1987; Kee et al., 1991) asserting that, in this sample, the effects of early hand-preference consistency on later development is not evident with boys.

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**Note.** Woodcock-Johnson = Woodcock-Johnson Psycho-Educational Battery (Woodcock, 1977); WISC-R = Wechsler Intelligence Scale for Children–Revised (Wechsler, 1974). Standard deviations are presented in parentheses.
However, for girls, the consistent hand-preference group continued to score significantly higher than the inconsistent hand-preference group on measures of verbal intelligence from infancy (Gottfried & Bathurst, 1983; Kee et al., 1991) through adolescence (i.e., 10–17 years). From the onset of formal schooling (i.e., 5–9 years; Kee et al., 1991), the consistent girls scored significantly higher than the inconsistent girls on measures of reading achievement through adolescence. This was not the case for measures of performance intelligence (i.e., perceptual or nonverbal types of intelligence) or math achievement.

In laboratory tests, the girls’ performances on tasks known to reflect a left-hemispheric bias (i.e., right-hand use on the peg-moving task) revealed significant differences between the groups. Yet the girls’ performances on tasks known to reflect right hemispheric activation or bias (i.e., chimeric faces and left-hand use on the peg-moving task) did not reveal significant differences between the groups. Thus, it is within the verbal domain where the differences clearly reside. This higher performance on tasks related to verbal cognitive abilities, from infancy through adolescence, favoring the consistent girls appeared to be a function of early left-hemispheric specialization for language.

The current finding of a within gender difference pertaining specifically to girls and language abilities is not isolated. Previously, two longitudinal studies reported that verbal skills during infancy were related to subsequent cognitive functioning but only for girls (Cameron, Livson, & Bayley, 1967; Moore, 1967). Cameron et al. (1967) found that girl infants’ vocalizations and productive language between the ages of 6 to 14 months were predictive of their intelligence scores from 6 to 26 years of age. These abilities were not predictive for boys. Similarly, Moore (1967) found that 18-month-old girls’ language scores reliably predicted their IQ scores at 3, 5, and 8 years, but this was not the case for boys. These longitudinal findings are parallel to the current findings in that cross-time relationships related to language abilities often pertain only to girls. Taken together, it is possible that the differences found in early language measures, and their ability to predict subsequent cognitive functioning, reflect differences in the development of left-hemispheric language specialization in girls.

When speculating as to why girls in the current study showed this particular pattern of results and boys did not, we must first consider maturational differences between the sexes. Previous research has also reported that the relationship between early hand preference and left-hemispheric specialization proceeds differently for girls than boys (Molfese, 1989, 1990; Shucard & Shucard, 1990; Shucard, Shucard, Cummins, & Campos, 1981). Some studies have shown that girls demonstrate accelerated development of the left hemisphere (Burman, Bitan, & Booth, 2008; Shucard & Shucard, 1990; Taylor, 1969; Weber, 1976) and become left lateralized earlier than boys (Carlier et al., 1993; Shucard et al., 1981). For example, Molfese (1989, 1990) reported that sex differences in brain activity were evident in 14- and 16-month-olds when presented with both familiar and unfamiliar auditory words. Infant girls were more left lateralized in their responsiveness to the stimuli than the boys, who were more bilateral in their responsiveness.

Furthermore, Shucard and Shucard (1990) examined the sex differences in the development of hemispheric specialization and its relationship with early handedness. Using a hand-preference consistency measure similar to that used by Gottfried and Bathurst (1983), Shucard and Shucard (1990) assessed 6-month-olds’ consistency of reaching hand preference twice during a 12-week period. Auditory evoked potentials (AEP) were recorded while the infant was presented with verbal and musical stimuli. The findings revealed that there was a significant relationship between AEP cerebral asymmetries and consistency of hand preference for both sexes. However, similar to the findings of Gottfried and Bathurst (1983), significant relationships, in both direction and strength, were observed for girls but not for boys. In particular, the findings showed that for girls, every correlation was positively related with greater peak amplitude measures (e.g., greater left- than right-hemispheric activation during presentation of verbal stimuli) associated with a stronger degree of handedness. This was not the case for boys. Shucard and Shucard (1990) concluded that these sex differences were a function of “ontogenic differences” in cortical development reflected in early hand preference (p. 930).

In the current study, it is possible that for girls, accelerated development of the left hemisphere and more (or less) pronounced hemispheric specialization played a role in their consistency (or inconsistency) of hand preference from 18 to 42 months of age. The girls’ hand-preference consistency during this time frame may have been an indicator of different developmental paths to becoming right-handed because of differences in the degree of cerebral hemispheric asymmetry and specialization (Gabbard, Hart, & Kanipe, 1993). This hypothesis is supported by the results of the current study demonstrating that the consistent girls exhibited more pronounced left-hemispheric asymmetry than the inconsistent girls on both manual tasks (e.g., peg moving with right hand) and verbal tasks (e.g., finger tapping with right finger while speaking; Kee et al., 1987). Shucard and Shucard (1990) have also suggested that for girls, accelerated development of left hemisphere leads to “asymmetrical cortical processes purported to be involved in different types of information processing, such as language and music” (p. 929).

So what are the long-term outcomes of this accelerated left-hemispheric specialization? Initially, the differences favoring the consistent girls were evident across various domains early in development (Gottfried & Bathurst, 1983). However, only differences in verbal and reading abilities persisted continually through adolescence. The differences between the consistent girls on measures of performance intelligence or math achievement became less evident and diminished over time. Kee et al. (1991) found that from the ages of 5 to 9 years, the differences between the consistent and inconsistent girls on these measures were much less robust than on measures of verbal intelligence and reading achievement during this 5-year span. This finding is in accord with Shucard et al.’s (1981) results revealing that 3-month-old girls exhibited greater variability in their right-hemispheric cortical processing when presented with musical stimuli and less variability in their left-hemispheric cortical processing when presented with linguistic stimuli. Taken together, it is possible that the higher performances of the consistent girls relative to the inconsistent girls in math and spatial abilities dissipated over time because they were less stable and more variable from the beginning.

On the other hand, the consistent girls’ pronounced left-hemispheric specialization was evident and continual from the preschool years through adolescence. In addition to differences in maturational rates, the findings may also be related to the greater intensity and frequency of early reading exposure that the consis-
tent girls received compared with the inconsistent girls. The analysis of early reading experience revealed that differences between the female groups in reading exposure were evident before the initial hand preference consistency assessment at 18 months of age. Two conceptually specific measures of reading, collected when the participants were 15 months old, revealed that the consistent girls were more likely to be read to three or more times per week and had significantly more daily reading exposure than the inconsistent girls. Moreover, reading exposure per day at age 15 months predicted for girls their hand-preference group classification by age 42 months.

Although it cannot definitively be determined in this study whether early reading exposure caused the consistent girls to have more pronounced left-hemispheric asymmetry, it is possible that this early reading exposure may have played some role in accelerating or enhancing this process. More specifically, it is possible that the consistent girls’ increased exposure to patterned and structured language input, in the form of shared book reading, influenced the development of phonological awareness. Leonard et al. (1996) found that an anatomical correlate for left-hemispheric specialization for language (i.e., horizontal surface area of the planum temporale or H-planum, an area also linked to hand skill; Annett, 1992) accurately predicted phonological awareness in young children between the ages of 5 and 9 years. In the Leonard et al. (1996) study, children with more advanced levels of phonological awareness demonstrated greater asymmetry of this particular anatomical area in the left hemisphere (i.e., H planum; Leonard et al., 1996). Because of the cross-sectional design of their research, Leonard et al. (1996) stated that it was difficult, based on their findings, to determine “whether children born with more marked asymmetries have a special talent for phonemes or children who work hard at conquering phonological awareness develop asymmetry faster” (p. 92).

Although the findings from the current longitudinal investigation also cannot ascertain the direction of the relationship between left-hemispheric specialization and phonological awareness, we suggest the following possibilities. In line with Leonard et al.’s (1996) conjecture, one possibility is that the consistent girls had greater propensities to attend to, differentiate, and generalize language stimulation early in infancy, which may have directly (or indirectly) influenced their parents’ behavior. Scarr and McCartney (1983) have long argued that young children seek out experiences that are relevant for them and their development. Likewise, Henderson and Ebner (1997) stated, “parents are often intuitively quite insightful concerning the sorts of experiences from which their infant can best benefit” (p. 65). This intuitive sense may have compelled the parents of the consistent girls to provide more frequent and intense types of reading experiences. These experiences may have reinforced and augmented the consistent girls’ earlier established propensities (e.g., attention), which, in turn, may have influenced left hemisphere specialization (e.g., more rapid formations of synaptic connections; Leonard et al., 1996). This accelerated development of the left hemisphere, which manifested itself in their early (right-) hand preference consistency, possibly facilitated the consistent girls’ phonological awareness. This enhanced phonological awareness may have provided the scaffolding upon which early language and reading skills were developed. Considering that the participants were only 15 months old when this early reading exposure was assessed, given their limited mobility and language abilities, it is less likely that they were driving their parents’ behaviors (Lonigan, 1994).

A second possibility is that the repetitive and continual exposure to patterned phonological input (i.e., book reading) early in development (i.e., 15 months) may have influenced the consistent girls’ left-hemispheric specialization for language by increasing phonological awareness (Tremblay, Ansado, Walter, & Joanette, 2007). Ridley (2003) contended that the infant’s brain is preprogrammed to be acutely receptive and sensitive to early language stimulation and that there are significant neurological benefits gained from increased phonological input. This contention has been supported by research demonstrating that infants as young as 6 months of age can discriminate between the relevant speech sounds of their native language (Werker & Tae, 1984) and by 18 months of age can distinguish words in their native language by classically defined phonological categories (Werker & Pegg, 1992). In fact, Tsao, Liu, and Kuhl (2004) found that 6-month-olds’ abilities to accurately discriminate speech contrasts predicted subsequent language development throughout the second year of life.

Using event-related potentials, Mills, Coffey-Corina, & Neville (1997) reported that, in their study exploring developmental changes in cortical activity, 13- to 17-month-olds who had higher receptive vocabularies exhibited greater left than right asymmetry within the first 100 ms after stimulus presentation (i.e., P100), compared with their same-aged peers who had lower receptive vocabularies. Often, peaked activity at P100 is considered to be an index of how sensory information is processed with a greater left than right asymmetry being reflective of left-hemispheric specialization for processing linguistic input (Mills, Coffey-Corina, & Neville, 1993, 1997). Mills et al. (1997) stated that infants with more advanced language skills demonstrated a “left-hemispheric bias for processing familiar phonological stimuli.” (p. 434). In the current study, the girls in the consistent hand-preference group not only received significantly more language input in the form of early book reading relative to the inconsistent girls at 15-months but also had significantly higher verbal skills at 18 months (Gottfried & Bathurst, 1983). It is important to note that it was at the 18-month assessment that hand preference was first noted. Thus, it is possible that the consistent girls, with more early reading exposure and advanced language skills at 18 months, were already more left lateralized than the inconsistent girls.

Congruent with this suggestion, Posner and Rothbart (2006) posited that between the first and second year, reading stimulation shapes developing the neural networks that ultimately lay the foundation and shape the mechanisms driving early literacy skills. This proposal lends support for the possibility that early reading exposure might have facilitated the consistent girls’ early left-hemispheric specialization for language relative to the inconsistent girls, which, in turn, was manifested in their consistency of (right-) hand preference from 18 to 42 months. As the girls developed, this early left-hemispheric specialization for language, coupled with their advanced level of phonological awareness, may have affected their development of language and early literacy (Leonard et al., 1996). This would explain the higher functioning of the consistent girls compared with the inconsistent girls on measures of verbal intelligence and reading achievement from the ages of 5 years (Kee et al., 1991) to 17 years.

It is important to emphasize that the findings of the current and previous investigations (Gottfried & Bathurst, 1983; Kee et al.,
1987; Kee et al., 1991) highlight a robust within-sex difference pertaining specifically to girls. Within this sample of girls, we found that, in addition to early maturational differences, the consistent girls received significantly more shared-book reading exposure at 15 months, which, in turn, predicted their subsequent hand-preference consistency classification at 42 months. This classification exposed reliable differences, from infancy through adolescence, between the consistent and inconsistent girls in intellectual abilities, particularly in the verbal domain. In speculating about potential mechanisms driving these results, it is not our intention to suggest that reading to boys during infancy is consequential. Recall that for the male hand-preference groups, mothers were equally likely to read to their sons three or more times per week and for about 14 min per day. It is important to consider the possibility that, had the contrast in early reading exposure between the male hand-preference consistency groups been similar to the contrast between the female hand-preference consistency groups (i.e., 24 min vs. 5 min), similar patterns between the male hand-preference groups may have emerged. Nonetheless, some boys exhibited a consistent hand preference by 42 months and others did not. Although on the majority of the measures, the consistent boys scored higher than the inconsistent boys, robust differences in intellectual abilities did not emerge across 17 years (Gottfried & Bathurst, 1983; Kee et al., 1987; Kee et al., 1991). This suggests that the development of hand-preference consistency and its relation to later intellectual functioning may be influenced by both early reading exposure and sex differences in cortical development. Thus, additional research is needed to pinpoint the individual contributions of sex differences in cortical development relative to experience-dependent brain plasticity on early hand-preference consistency and hemispheric specialization.

Although the hand-preference consistency classification used by Gottfried and Bathurst (1983) provided insights into the relations between the development of handedness and cognitive functions from infancy through adolescence, it is not without its limitations. Future research is needed to address several important issues. For example, previous research has shown that assessing consistency in hand use in infancy can be fairly complex and often difficult to detect by the naked eye (Corbetta & Thelen, 2002; Rönnqvist & Domellof, 2006). This makes the findings of the current study even more intriguing given the seemingly straightforward and easy method in which consistency of hand preference was appraised during infancy and the robust and continual differences found between the female hand-preference groups throughout adolescence. As a consequence, future research should utilize various types of measures of early hand-preference consistency both across time as well as across tasks. In addition, more research is needed to determine the relative influence of parental handedness and/or explicit instruction from adults on early hand-preference consistency (Harkins & Michel, 1988; Michel, 1992) and how this may impact later cognitive functioning.

References


Hollingshead, A. B. (1975). Four-factor index of social status. Unpublished manuscript, Yale University, New Haven, CT.


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**Correction to Kalcher-Sommersguter et al. (2011)**

In the article “Social Competence of Adult Chimpanzees (*Pan troglodytes*) With Severe Deprivation History: I. An Individual Approach,” by Elfriede Kalcher-Sommersguter, Signe Preuschoft, Karl Crailsheim, and Cornelia Franz (*Developmental Psychology, 2011, Vol. 47, No. 1, pp. 77–90*), Table 4 (p. 86) contained an error. The development of stationary vicinity for LD (late deprived) chimpanzees is misstated as ns. However, the difference is highly significant as \( p = .008 \).

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