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BRIEF REPORT

Early Handedness in Infancy Predicts Language Ability in Toddlers

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Researchers have long been interested in the relationship between handedness and language in development. However, traditional handedness studies using single age groups, small samples, or too few measurement time points have not capitalized on individual variability and may have masked 2 recently identified patterns in infants: those with a consistent hand-use preference and those with an inconsistent preference. In this study, we asked whether a consistent infant hand-use preference is related to later language ability. We assessed handedness in 38 children at monthly intervals from 6–14 months (infant visits) and again from 18–24 months (toddler visits). We found that consistent right-handedness during infancy was associated with advanced language skills at 24 months, as measured by the Bayley Scales of Infant and Toddler Development (Bayley–III; Bayley, 2006). Children who were not lateralized as infants but who became right-handed or left-handed as toddlers had typical language scores. Neither timing nor direction of lateralization was related to cognitive or general motor skills. This study builds on previous literature linking right-handedness and language during the first 2 years of life.

Keywords: handedness, language development, motor development, infant, toddler

Descending motor pathways have a crossed innervation such that the actions of the right hand are controlled by the left hemisphere and vice versa (Serrien, Ivry, & Swinnen, 2006; Volkmann, Schnitzler, Witte, & Freund, 1998). Manual actions are characterized behaviorally by a marked preference for one hand over the other; typically the right hand is the preferred hand (e.g., Annett, 2002). The right shift observed in the distribution of handedness corresponds to the asymmetric distribution of speech and language in the left hemisphere. Thus, right-handedness and language are both lateralized left-hemispheric functions in most adults (e.g., Knecht et al., 2000, but see Kuhl & Damasio, 2013). Infants, like adults, are also predominantly right-handed (e.g., Fagard, 1998; Ferre, Babik, & Michel, 2010; Hinojosa, Sheu, & Michel, 2003; Ramsay, 1980). The nature of the relationship between handedness and the emergence of language skills in development remains a relatively understudied question, however.

A common approach to tackling this question developmentally has been to compare hand use for manipulative actions with hand use for communicative actions, particularly pointing. As in infant reaching and object manipulation, a right hand bias has been reported for infant pointing (e.g., Esseily, Jacquet, & Fagard, 2011; Franco & Butterworth, 1996). Nevertheless, efforts to connect hand-use preferences across these two different contexts of hand use have yielded mixed results. Previous studies have generally found that hand-use preferences for manipulation and gesture are only loosely related, with the strongest links observed during major language gains (e.g., Bates, O'Connell, Vaid, Sledge, & Oakes, 1986; Jacquet, Esseily, Rider, & Fagard, 2012; Ramsay, 1984, 1985; Vauclair & Imbault, 2009). Although these studies have provided valuable "snapshots" of typical development, they have failed to capture and interpret the individual variability in hand-use preference seen in children followed longitudinally. Indeed, investigators are now calling for greater longitudinal efforts to examine differences in the rate of acquiring language (Vauclair & Cochet, 2012).

We propose that handedness development should be examined with a similar approach. Typically, fluctuations in infant hand use within or across test sessions have been interpreted as evidence that infant handedness is generally unstable or that handedness does not solidify until later childhood (e.g., Corbetta & Thelen, 1999; Gesell & Ames, 1947). Notably, however, recent work from multiple investigators has observed that a subset of children followed longitudinally show consistent hand-use preferences for manipulation and gesture, whereas other children were characterized as having variable hand-use trajectories (e.g., Cochet, 2012; Kotwica, Ferre, & Michel, 2008; Michel, Sheu, & Brumley, 2002). Traditional studies that have examined small samples, single age groups, or too few measurement time points have masked these two types of children: those with a consistent hand-use preference

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and those without. What advantages, if any, might be associated with having a consistent hand-use preference during development?

Investigators from the Fullerton Longitudinal Study (FLS) have explored the relations between handedness consistency in the toddler and preschool years (18, 24, 30, 36, and 42 months) and later cognitive outcomes through 17 years of age (Gottfried & Bathurst, 1983; Kee, Gottfried, & Bathurst, 1991; Kee, Gottfried, Bathurst, & Brown, 1987; Wilbourn, Gottfried, & Kee, 2011). In this project, hand preference was measured by observing which hand the child chose to draw with while completing test items from either the Bayley Mental Scale or the McCarthy Scales of Children's Abilities, depending on age. Children who used the same hand at all five assessments were considered *consistent*, and those with any differences in hand use across assessments were considered *inconsistent*. A critical finding that persisted across infancy into adolescence in these data was enhanced verbal cognitive abilities in girls with a consistent hand preference (Wilbourn et al., 2011). Children in the consistent group were all right-handed, providing some evidence for a developmental link between right-handedness, language and the left hemisphere.

To the best of our knowledge, there are no equivalent studies of handedness consistency during infancy and emerging skills such as language. In the study reported here, we investigated whether the timing of lateralization for manipulative actions in infancy is related to language skills during toddlerhood. We also examined whether early handedness is related to advances in general motor skill and cognition. To do this, we measured handedness at monthly intervals from 6 to 14 months (infant visits) and again from 18 to 24 months (toddler visits). Language, motor, and cognitive skills were measured at 24 months using the third edition of the Bayley Scales of Infant and Toddler Development (Bayley–III; Bayley, 2006). We hypothesized that early hemispheric specialization in motor skills, manifested as consistent infant handedness, is related to another specialized hemispheric function: the development of language. Specifically, we predicted that children with an early left hemispheric specialization (consistently right-handed infants) would have higher scores on the language scale of the Bayley than would children with no consistent hand preference during infancy.

How could having a consistent hand preference as an infant be related to language acquisition? Kotwica et al. (2008) reported that infants with a stable hand-use preference (95% of the sample were right-handed) were better multiple object "managers" than infants without a stable preference. Consistent infants transferred objects to the opposite hand more readily than inconsistent infants and also stored objects within reach while acquiring new objects. The importance of this distinction between groups in object play is that consistent infants experience the world differently than do their inconsistent counterparts, and this has potential implications for language development. Bruner (1973) argued that such object management skills depend upon, and therefore represent, a developing ability of symbolic representation. Storing an object depends upon the infant's ability to "represent" the location of the object for later retrieval.

Moreover, Lifter and Bloom (1989) observed that changes in how infants manipulate objects were linked to the timing of infants' first words and growth in vocabulary size. In this longitudinal study, 14 monolingual English children were followed from 8 to 26 months of age. Infants' actions prespeech largely consisted of taking objects apart, but after the advent of their first words (M = 13.8 months), infants shifted to putting objects together, and they began pairing labels and their referents. During the vocabulary spurt (M = 19.4 months), object manipulation complexity increased again, and infants demonstrated increasing knowledge about the details of object properties. Although infants acquired language at varying rates, the dynamic relationship between object skill and language skill was observed in all infants independent of age. As Iverson (2010) so elegantly summarized, ". . . changes in motor skills (i.e., achievements and advances in posture, independent locomotion and object manipulation) provide infants with a broader and more diverse set of opportunities for acting in the world" (p. 230).

Conceptualized in this way, consistent infant hand preference is a marker for advanced object manipulation skills, and this differential early organization of motor ability may be related to the rate of language acquisition. By comparison, an inconsistent preference is an indicator of lower skill level, and perhaps a different pattern of hemispheric organization. The purpose of this study was to examine whether language outcome at 2 years could be accounted for, in part, by different patterns of change in the motor system during infancy (measured by handedness). We predicted that children who exhibited consistent right-handedness during infancy would have higher scores on the Bayley language scale as toddlers than would those without a consistent bias.

Method

Participants

Thirty-eight children (21 girls) participated in a longitudinal study involving 16 visits. Three additional children completed the infant portion of the project, but missed more than two toddler sessions and were not included in our analyses. Families were recruited for the project using birth records obtained from the local courthouse in Greensboro, North Carolina, a midsized metropolitan area in the southeastern United States. Study inclusion criteria included full-term pregnancy of at least 37 weeks gestation and delivery without complications. The sample was representative of the ethnic backgrounds found in the local community (sample = 65% Caucasian White, 15.8% African American, 13.2% multiracial, 2.6% Hispanic, 2.6% other race). Families provided information regarding current income level and education attainment for mothers and fathers when available either by paper or electronic questionnaire. Yearly family incomes ranged from $10,000–$19,999 to $150,000 or more, with a median income of $70,000–$79,999. Mothers' education level ranged from one or more years of college/no degree to a professional degree and fathers' education level varied from a high school diploma or GED equivalent to a professional degree. The median education level for both mothers and fathers was a bachelor's degree.[1] The primary language spoken in the home was English, with the exception of one

[1] Nonparametric Mann-Whitney U tests found no effect of family income (U = 56, $p > .05$), mothers' education level (U = 62, $p > .05$), or fathers' education level (U = 54, $p > .05$) on infant handedness status. Thus, identification of infants as right-handed or no preference was not due to a socioeconomic advantage in family income or parents' education attainment.

participant, and this child was therefore not scored on the language scale of the Bayley.

Procedures and Materials

The University of North Carolina at Greensboro Institutional Review Board approved the following procedures, and parents gave written consent for their child to participate in this study. Data collection began when the child was 6 months old, and each assessment occurred within 7 days of the child's monthly birthday. In total, there were 16 monthly visits occurring from 6 to 14 months (9 infant visits) and from 18 to 24 months (7 toddler visits). Parents received a $10 Target gift card for each visit to the lab.

To assess hand preference, we offered children one of two measures designed to recruit age-appropriate manual skills. The infant handedness measure assessed hand use for acquiring objects unimanually and consisted of 22 objects presented singly at the infant's midline and 10 pairs of objects presented dually in line with the infant's shoulders (for details on this procedure, see Michel, Ovrut, & Harkins, 1985, and Ferre et al., 2010). The toddler handedness measure assessed hand use for role-differentiated bimanual manipulation in which one hand stabilizes an object for the other hand's manipulation (manipulating hand = preferred hand) and consisted of 29 scorable actions such as pulling a toy out from a container, taking the lid off a jar, or unzipping a pouch. These tasks were designed to require the use of both hands to successfully complete the target action (for details on this procedure, see Nelson, Campbell, & Michel, 2013).

We would like to note that measuring handedness in any sample requires targeting skillful behavior, and, as such, it would not be appropriate to utilize the same set of tasks over the first two years of life, when a child's manual repertoire changes considerably. Infants are not capable of reliably performing the complex bimanual tasks given to toddlers, and, likewise, toddlers are not sufficiently challenged simply reaching for objects. Thus the assessment of handedness in both infants and toddlers shared the same function of serving as an explicit measure of manual skill.

For both handedness measures, the child was seated at a table on a parent's lap. Sessions were recorded with two Panasonic digital cameras that were linked by a Videonics mixer, providing overhead and left-facing views of the child's actions that were combined into a single frame for later coding. Video coding of the handedness assessments was done offline by trained observers using the Observer XT program (Noldus Information Technology, v.10). Coders for the toddler data were blind to infant handedness status. Interrater reliability was calculated using percent agreement between coder pairs for each object presented (up to 34 coding decisions per infant per session). Coders scored seven–eight videos from each month tested, or approximately 20% of the data. Reliability for the infant handedness measure was 93%, and reliability for the toddler handedness measure was 96%.

Following the final handedness assessment at 24 months, the 38 children for whom we had complete handedness data were administered the Bayley Scales of Infant and Toddler Development (Bayley–III; Bayley, 2006) by a clinically trained observer. Thirty-four children completed all three scales (language, motor, and cognitive). One child could not be evaluated on language because English was not the primary language spoken in the home. One additional child (right-handed as an infant; see description of handedness groups below) could not be tested due to illness during the eligible age period (i.e., chicken pox), and two children (one right-handed as an infant and one right-handed as a toddler) were unable to complete the Bayley due to behavioral problems. Analyses were conducted on the composite score for each scale. Scales are normalized at 100, with a standard deviation of 15.

Results

To determine handedness, we first calculated the child's percentage of right-hand use (%R) from each visit using the formula $[R/(R + L)]^*100$, where R is the number of right-hand actions and L is the number of left-hand actions. Next, we computed 95% confidence intervals (CI) derived from each child's monthly right-hand use percentages for his or her block of infant visits (Visits 1–9 from 6–14 months) and separately for their block of toddler visits (Visits 10–16 from 18–24 months). Children were classified as left-handed if their mean %R + CI $< 50\%$ and right-handed if their mean %R – CI $> 50\%$; values that were within 5% of the 50% level were also considered lateralized. Children were classified as having no statistically reliable preference if their mean %R $\pm$ CI crossed the 50% level by more than 5%.

We assigned an infant handedness status and a toddler handedness status to each child who completed the Bayley ($N = 35$). By infant status, 13 children were right-handed and 22 had no preference. By toddler status, 26 children were right-handed, 8 were left-handed, and 1 had no preference. Using the relationship between infant handedness status and toddler handedness status, we grouped children into three handedness trajectories: (a) early right-handed ($n = 12$): children who were consistently right-handed as infants and stayed consistently right-handed as toddlers; (b) late right-handed ($n = 14$): children who had no preference as infants but became right-handed as toddlers; and (c) late left-handed ($n = 8$): children who exhibited consistent left-handedness as toddlers. This last group included one child who had been classified as right-handed as an infant but became left-handed as a toddler. No other child switched handedness status. There were no children in the sample with a left-hand preference as infants. Finally, one child did not exhibit a consistent hand preference by the conclusion of the study. Data from this child were used in the infant analyses but not in the toddler analyses, given the insufficient cell size for the no-preference toddler group.

We used independent samples t tests and one-way between-subjects analyses of variance (ANOVAs) to examine the effects of gender (male or female), infant handedness status (right-handed or no preference) and handedness trajectory (early right-handed, late right-handed, late left-handed) on cognitive, language, and motor abilities at 2 years of age, as measured by the Bayley. There was no effect of gender on cognitive level, $t(33) = -0.284$, $p > .05$, $d = 0.10$, language level, $t(32) = -0.252$, $p > .05$, $d = 0.09$, or motor level, $t(33) = -0.169$, $p > .05$, $d = 0.06$. Means, standard deviations, and ranges for each Bayley scale grouped by infant handedness status and by infant to toddler trajectory status are given in Table 1. We found a large effect of infant handedness status on language outcome at 2 years. Children who exhibited consistent right handedness as infants scored significantly higher on the language scale compared with their later lateralized counterparts (children with inconsistent hand use as infants), $t(31) = -2.187$, $p < .05$, $d = 0.77$. However, early right-handed infants

Table 1
Means, Standard Deviations, and Ranges for Bayley Scales by Handedness Groups

	Infant handedness			Infant-to-toddler trajectory			
Bayley Scales	Right (consistent)		No preference (inconsistent)	Early right		Late left	Late right
Language	$n = 12$		$n = 22$	$n = 11$		$n = 8$	$n = 14$
	121.67 (13.95)	>	**108.86 (17.42)**	**123.91 (12.15)**	>	**100.88 (10.84)**	111.93 (19.55)
	Range: 97–153		Range: 77–144	Range: 106–153		Range: 83–118	Range: 77–144
Motor	$n = 13$		$n = 22$	$n = 12$		$n = 8$	$n = 14$
	111.15 (11.68)		107.18 (14.75)	111.83 (11.92)		98.63 (10.54)	111.57 (15.05)
	Range: 91–133		Range: 79–136	Range: 91–133		Range: 79–112	Range: 86–136
Cognitive	$n = 13$		$n = 22$	$n = 12$		$n = 8$	$n = 14$
	111.92 (14.22)		108.41 (11.89)	110.83 (14.28)		105.63 (11.16)	111.43 (12.92)
	Range: 95–145		Range: 95–145	Range: 95–145		Range: 95–125	Range: 95–145

Note. Bayley Scales = Bayley Scales of Infant and Toddler Development (3rd ed., Bayley, 2006), administered at 24 months of age; Infant = 6–14 months; toddler = 18–24 months. Significant differences between groups appear in bold ($p < .05$).

were not more advanced on motor, $t(33) = -0.828$, $p > .05$, $d = 0.29$, or cognitive skills, $t(33) = 0.786$, $p > .05$, $d = 0.27$. There was a significant difference in language scores across the three handedness trajectory groups at 24 months, $F(2, 30) = 5.159$, $p < .05$, $\eta^2 = 0.256$. Handedness trajectory accounted for approximately one quarter of the variability in language scores observed at 2 years of age. Post hoc analyses using the Bonferroni correction found that early right-handers differed from late left-handers, $p < .01$. Late right-handers did not differ from late left-handers or early right-handers on language outcome, all ps $> .05$. There was no effect of handedness trajectory group on cognitive level, $F(2, 31) = 0.555$, $p > .05$, $\eta^2 = 0.035$, or general motor level, $F(2, 31) = 3.065$, $p > .05$, $\eta^2 = 0.165$.

Discussion

We examined the relationship between handedness and language development in the first two years of life using a longitudinal design that focused on differences in timing of lateralization, rather than age-related links or group-level biases. Our study expanded on previous work linking handedness consistency and language in toddlers and preschoolers (Gottfried & Bathurst, 1983; Kee et al., 1991; Kee et al., 1987; Wilbourn et al., 2011). In the previous set of studies by FLS investigators, the earliest measurement of handedness was at 18 months, and only drawing hand was examined. In the 30 years since this landmark project, there has been a growing body of literature on assessing hand-use preferences across development and measures, which did not exist at that time, for testing younger ages (e.g., Fagard, 1998; Ferre et al., 2010; Hinojosa et al., 2003). The handedness measures used in this study involved a diverse set of objects and assessed multiple age-appropriate manual skills beginning at 6 months of age and consisted of 16 visits in total (Michel et al., 1985; Nelson et al., 2013). Given the scope of our project, we were able to determine whether children exhibited consistent handedness during infancy, as well as to classify our sample into three developmental trajectories of handedness extending through 2 years of age.

Our primary findings suggest that differences in the timing of handedness consistency (infancy vs. toddlerhood) and the direction of hand preference (right vs. left) contribute, in part, to differences observed in language level at 2 years of age. Children with a consistent right-hand preference as infants (measured from 6–14 months) scored higher on the language scale of the Bayley when tested at 24 months compared with children who had exhibited an inconsistent hand preference as infants. Children who did not show consistent handedness until toddlerhood did not have a language deficit; rather, they had language scores in the typical range for their age. The handedness difference during infancy on later language was not the result of differences in cognition or general motor skills, as the two groups (consistent vs. inconsistent as infants) did not differ on the Bayley scores for these other domains. As toddlers, all children except one exhibited either consistent right-handedness or left-handedness (measured from 18 to 24 months). Thus we observed three patterns in the timing of handedness consistency: (a) early right-handed (children with a consistent right-hand preference as infants who stayed consistently right-handed as toddlers), (b) late right-handed (children with no consistent infant preference that became consistently right-handed as toddlers), and (c) late left-handed (children who exhibited consistent left-handedness as toddlers). Early right-handers had advanced language skills compared to late left-handers; however, early right-handers did not differ from late right-handers. Late right-handers and late left-handers were also not different on language level. Finally, cognitive and motor ability did not vary by handedness trajectory.

Does this association between early right-handedness and language level necessarily imply that handedness or language is driving the development of hemispheric specialization? Although it is tempting to consider which came first, consistent hand preference or language, in fact, the relationship between these two systems may be bidirectional. Moreover, only 25% of the variance in language ability at 2 years was accounted for by handedness trajectories. Although this is a large effect in its own right, there are likely many additional factors in this developmental relationship. For example, parenting style may influence the acquisition of both manual skills and language. Another factor may be differences in the rate of development between the left and right hemispheres. An additional caveat is that there were no children in this sample with a consistent left-hand preference during infancy. We can only speculate that the right-handedness contributed to the language differences we observed when in fact it may be the

establishment of a consistent early motor bias (independent of direction) that is important for links between handedness consistency and the emergence of language skills. Ongoing work with additional cohorts may be able to address some of these issues in the future.

An additional limitation of our study was that we were able to assess language level at only one time point. In a related cross-sectional study, Vauclair and Cochet (2012) examined language level using the Brunet-Lézine scale and hand preference for pointing in children 12 to 30 months old ($M = 22.5$). Like the Bayley, the Brunet-Lézine scale is also normalized at 100, and they used this cutoff to create two groups in their sample. Children with scores below 100 were considered low language users, and those with scores above 100 were considered high language users. The relationship between language and pointing differed between the groups such that right-hand preference for pointing strengthened as language scores increased in the high language users, whereas the reverse pattern was observed in low language users. The authors suggested that the different rates of language acquisition reflect differences in left hemisphere activity (Vauclair & Cochet, 2012). Future work should investigate these relationships described now in two separate samples between high levels of language and right-hand preference for both manipulative and communicative actions across the first two years of life.

It is worth noting that we did not find any gender differences in our analyses. This is in contrast to the FLS investigators who reported advanced verbal cognition skills in consistently right-handed girls, but no effects in boys (Wilbourn et al., 2011). Fenson et al. (1994) also reported a slight advantage for language skills in females, but gender accounted for only approximately 1%–2% of the variance in language development among a sample of 1,789 children ages 8 to 30 months. Despite our much smaller sample of 34 children, the effect size for gender on language was similarly small ($d = 0.09$). Perhaps more interesting than pursuing the small contribution of gender on language development is to try to understand what factors shape handedness consistency and may be contributing to differences in language acquisition.

Why do some children have a consistent hand-use preference but other children do not? Returning to the FLS data, Wilbourn et al. (2011) were able to predict membership in either the consistent or the inconsistent handedness group from the amount of reading time per day that girls received at 15 months of age. The authors proposed that the consistent girls may have had a greater ability for attending to and processing language stimuli, prompting mothers to spend more time reading to them. In turn, this increased reading exposure may have had a bidirectional effect to further enhance phonological awareness. Alternatively, mothers may have spent more time reading to their daughters, which then enhanced the girls' language processing. Regardless of the direction of this proposed relationship, reading exposure and subsequent verbal cognitive ability was linked to handedness consistency in girls. As discussed earlier, Lifter and Bloom (1989) documented a dynamic relationship between language level and object skills. Kotwica et al. (2008) further linked superior object management (more acquisition of objects and storage acts) to consistent infant hand-use preference. Additional studies are now needed to examine reading exposure over the course of development as well as other factors that may be shaping the acquisition of language and/or handedness, particularly the multiple handedness trajectories that we have described here.

In summary, this study provides some evidence that timing matters when it comes to handedness trajectories. Handedness represents different patterns of hemispheric specialization. Early consistent right-handedness in infancy was related to advanced language ability measured at 2 years of age, and this may be due to greater activity in the left hemisphere in brain regions that have long been associated with language (i.e., Broca's area and Wernicke's area), although our data cannot address this hypothesis. Surprisingly, recent work examining gray-matter and white-matter concentrations in infants found links between nontraditional areas in the right hemisphere (i.e., cerebellum and hippocampus) imaged at 7 months and language scores at 12 months (Deniz Can, Richards, & Kuhl, 2013). Particularly notable is the cerebellum link, which has historically been regarded as a motor area. These findings suggest that we actually know very little about the development of the brain in infants with regard to language, and less still about the connection between the motor and language systems in development.

Returning to the idea of a left hemispheric specialization, we observed a language advantage for early right-handers over late left-handers (but not late right-handers). Greater numbers of left-handers are needed in future studies to validate this finding. Even with this difference between groups, left-handers were still within the normal range for their age. We want to reiterate that a lack of handedness consistency during infancy or the establishment of a left preference did not create a disadvantage in any domain that we investigated. Rather, motor development is "normally participatory" in language development (Iverson, 2010). Handedness is neither necessary nor sufficient for language acquisition, but the timing of handedness may shift the timing of language skills. Overall, these results build on previous literature linking right-handedness and language across the life span.

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