D. V. M. Bishop
Department of Experimental Psychology
University of Oxford
Oxford OX1 3UD
United Kingdom
E-mail: dorothy.bishop@psy.ox.ac.uk

Handedness and Specific Language Impairment: A Study of 6-Year-Old Twins

ABSTRACT: *Handedness and language skills were assessed in 196 same-sex twin pairs (101 MZ and 95 DZ), who were selected from an epidemiological study of twins, so that children with risk of language impairment were over-represented. When assessed at 6 years of age, 83 children met criteria for specific language impairment (SLI), 32 had general developmental (GD) delay, and the remaining 277 were typically-developing (TD). Hand preference (HP) assessed by inventory did not distinguish SLI, TD, or GD groups. The quantification of hand preference (QHP) measure, which measures persistence of a HP when reaching across the midline, did show weaker HP in those with SLI compared to the other two groups. It is suggested that the QHP measure assesses developmental aspects of manual lateralization, and is sensitive to neurodevelopmental immaturity in SLI. Furthermore, genetic analysis showed that the QHP measure, unlike the handedness inventory, was significantly heritable. © 2005 Wiley-Liss, Inc.* Dev Psychobiol 46: 362–369, 2005.

Keywords: *language impairment; handedness; genetics*

Handedness is often assessed in neuropsychological investigations with children, and there is a widespread belief that unusual patterns of cerebral and manual lateralization are common in developmental disorders such as dyslexia and specific language impairment (SLI). This idea can be traced back to early writings of Orton (1925), who attributed developmental dyslexia to delayed neurological development with associated failure to develop cerebral dominance. He suggested that lack of clear hand preference (HP) was especially frequent in children with developmental language or literacy problems. Although Orton's ideas remain influential eight decades later, the empirical data in support of his position are contradictory. Bishop (1990a) reviewed studies of dyslexia and SLI and concluded that there was little support for theories that predicted differences in rates of left-handedness or relative skill of the two hands in either dyslexia or SLI.

In subsequent work, Hill and Bishop (1998) found that although a traditional HP inventory did not differentiate between 7- and 11-year-old children with SLI and an age-matched control group, the SLI group were less lateralized when tested using a novel method that assessed the extent to which a HP was maintained when reaching across the midline. In this method, the quantification of hand preference (QHP) task, children were asked to pick up cards that were positioned in seven locations ranging from left to right of the midline (three cards in each location, selected in quasi-random order) and the hand used to pick up the card was noted on each trial. Most children will reach across the midline, maintaining use of the preferred hand to reach into the contralateral side of space on at least some trials. However, those with SLI were more likely to use the right hand to reach for cards on the right side of the body, and the left hand to reach for cards on the left side of the body. The tendency not to cross the midline in SLI was seen even when attention was restricted to those children who were strongly right-handed on an inventory that assessed HP for activities such as writing, throwing a ball, and cutting with a knife.

Bishop (2001) replicated this result in a sample of 122 twin children aged from 7 to 13 years, 9 of whom met

Received 1 September 2004; Accepted 5 December 2004
Correspondence to: D. V. M. Bishop
Contract grant sponsor: Wellcome Trust (programme grant)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/dev.20062

criteria for SLI. In line with Hill and Bishop (1998), it was found that a HP inventory did not distinguish children with SLI from those with typical language development, but the QHP task did.

In interpreting these findings, Bishop (2001) distinguished two classes of explanation for handedness differences between groups. The first type of explanation regards individual differences in handedness as indicators of stable individual differences in underlying cerebral lateralization. One of the best-known theories of this kind is Annett's (1985) Right Shift Theory, which postulates a single major gene which has two alleles: the RS+ allele shifts HP to the right, whereas the RS− allele does not bias handedness in either direction. According to this theory, the determinants of handedness in children are the same as those in adulthood, and RS genotype is related to cognitive profile. Bishop (2001) argued against this kind of account as an explanation for her findings because; first, measures of HP and relative hand skill did not show the expected associations with SLI and second, genetic analysis of twin data failed to find any evidence of heritability of these handedness traits.

Bishop (2001) argued instead for a second type of explanation that is more akin to Orton's original speculations, in that it regards lack of midline crossing on the QHP task as a sign of developmental immaturity rather than a stable trait. According to this view, children's preference for one side becomes stronger as they grow older, but most conventional HP measures are not sensitive to this, because they simply ask which hand is usually preferred for a task, without assessing the strength of that preference. As Bishop, Ross, Daniels, and Bright (1996) noted, some inventories do ask people to judge strength of a preference, by rating if they 'usually' or 'always' prefer a given hand. However, these inventories do not reliably distinguish between people who show consistency of HP within activities but inconsistency between activities, and those who are inconsistent for preference even within a given activity. Furthermore, it is doubtful whether people can make accurate judgements about frequency of hand use. The QHP task, in contrast, challenges HP by seeing how far the preference is maintained when the arrangement of the physical environment would make use of the other hand easier. It is well established that manual midline crossing increases with age in pre-school and school-aged children (e.g., Cermak, Quintero, & Cohen, 1980), and Hill and Bishop (1998) found this to be the case for the QHP. They showed that typically-developing (TD) children aged from 5 to 6 years resembled older children with SLI, in that they were less likely than older TD children to use the preferred hand across the midline. This conceptualization of weak HP as a sign of immaturity fits well with other data suggesting that SLI is characterized by neurodevelopmental immaturity (e.g., Bishop & Edmundson, 1987; Bishop & McArthur, 2004). The origins of such immaturity remain uncertain, but delayed neuromotor development could plausibly be influenced by the same genes that put the child at risk for SLI (Bishop, 2002). If so, we would expect the QHP task to show genetic influence. It was not possible to conduct an adequate test of heritability of this measure in the study by Bishop (2001) because only a small sample of twins had done this test.

Goals of the Current Study

The data reported here come from a group of 6-year-old twins who were recruited via the Twins Early Development Study (TEDS), a large-scale epidemiological study of twins born in England and Wales during 1994–1996 (Trouton, Spinath, & Plomin, 2002). When the children were 6 years old, a subset of the main sample were invited to take part in an individual assessment of language and related skills, with the children being selected so as to oversample those likely to have language impairments (see below). The goals of the current study were twofold.

The first goal was to see whether the QHP task would differentiate between language-impaired and TD children in the 6-year-old TEDS sample. The previous studies by Bishop (2001) and Hill and Bishop (1998) had focused on children aged 7 years and above; if lack of midline crossing corresponds to developmental immaturity, it is possible that different effects will be seen in a younger sample. As in the previous studies, as well as the QHP task, a conventional HP inventory was also administered. On the basis of previous findings, it was predicted that this would not differentiate between language-impaired and control children. The second goal was to compare heritability of the QHP measure with that seen for a conventional HP inventory.

METHODS

Participants

The main TEDS sample was recruited via the Office of National Statistics from the population of live twins born in 1994–1996 in England and Wales. Their parents were contacted and invited to take part when the twins were around a year old. Parents who gave their consent completed assessments of their children's language and non-verbal abilities at 2, 3, and 4 years of age (Dale, Price, Bishop, & Plomin, 2003). Zygosity was assessed using a parent-rated questionnaire, supplemented by DNA testing in cases of uncertainty. On the basis of parental report at 4 years, children were identified as at risk of language impairment ('LI risk') if any of three conditions were met: (i) child was described as not yet talking in full sentences; (ii) child's vocabulary (rated on a checklist where a parent identified words the child used) was at or below the 10th centile; (iii) parent

answered 'yes' to the question 'Do you have any concerns about your child's speech and language?' and selected the option 'his/her language is developing slowly' when asked to specify the nature of the concern. Children who did not meet criteria for LI risk were designated as 'low risk.' Of 5,426 same-sex twin pairs with 4-year parental report data, 547 (10.6%) met criteria for LI risk at 4 years in one or both twins. A subset of LI risk children (see Table 1) were selected for in-depth study and compared with a group of twins who were selected on the basis that both twins were in the low-risk category at 4 years.

Table 1 shows the numbers of monozygotic (MZ) and dizygotic (DZ) males and females in the sample after excluding cases of sensorineural hearing loss, physical handicap, autism, or another syndrome affecting cognitive development. To avoid effects of ethnic stratification in future molecular genetic studies, only families who identified themselves as White were included in the sample. Children who failed a hearing screen when assessed (average hearing threshold for frequencies 500 to 4,000 Hz higher than 26 dB in the better ear) were also excluded, as well as families where English was not the only language spoken in the home. Only same-sex twin pairs were included in this part of the study. The subset of children selected for in-depth study did not differ from the remainder of the sample in terms of socio-economic status.

Assessments

Each child was seen individually in a quiet room at home or school for an assessment lasting around 90 min, which included the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999), three subtests from the Clinical Evaluation of Language Fundamentals—Revised (Semel, Wiig, & Secord, 1987), and the Children's Non-Word Repetition Test (Gathercole, Willis, Baddeley, & Emslie, 1994). Raw scores on these assessments were transformed to age-scaled scores on the basis of published norms, and then re-scaled to mean, 100 and SD, 15.

Two measures of handedness were used. The first was a HP inventory based on the Edinburgh Handedness Inventory (Oldfield, 1971), but modified to avoid one item deemed unsuitable for children (striking a match). The examiner observed the hand used as the child demonstrated 10 actions: writing, drawing, throwing a ball, using scissors, using toothbrush, cutting with a knife, using a spoon, using a broom (upper hand), taking the lid off a box, and dealing cards. In general, children were able to demonstrate these activities by miming, but if there was any uncertainty, materials were provided so the child could carry out the action with a relevant object. Two points were awarded for each action done with the right hand, 1 point for bimanual usage or unclear preference, and 0 points for left HP, to give a total HP score ranging from 0 (completely left-handed) to 20 (completely right-handed).

The second measure was the QHP task, which quantifies strength of HP by having the child stand up and reach for named cards that are located on a waist-high table in one of seven positions extending at 30 degree intervals from the left to the right of the child's midline. An initial check was made to ensure the placement of the cards such that the child could reach the most distant card with the opposite hand across the midline. The procedure was the same as used by Bishop (2001), with the cards showing familiar brightly-drawn objects. The child was asked to pick up the named cards one at a time and place them in the central box. The child was unaware that handedness was being assessed, and no instructions were given about how to handle the cards or how to stand, other than that the child should remain in the central location in front of the box. The same quasi-random order of positions was used for all children, starting with a card at the midline and continuing until the child had reached for three cards at each of seven locations, to give a total of 21 trials. The examiner noted the hand used by the child to pick up the card. Two points were awarded for a right-handed reach, 0 points for a left-handed reach, and 1 point if the child transferred the card from one hand to another in the course of placing it in the box. The latter kind of response was seen on 9.2% of trials.

Table 1. Numbers of Twin Pairs Selected for In-Depth Study in Relation to Zygosity, Sex, and LI Risk Status

	Twins With LI Risk			
	Neither Twin	One Twin	Both Twins	Total
MZ female	17	8	16	41
DZ female	16	22	9	47
MZ male	19	17	24	60
DZ male	13	23	12	48
Total	65	70	61	196

RESULTS

Classification of Language Status at 6 Years

The sample had been selected to be over-representative of children likely to be at risk of SLI, as judged by parental report at 4 years, but many children grow out of early language delays (Bishop & Edmundson, 1987), and so it was not anticipated that all the LI risk group would show signs of language difficulties at 6 years. Language status at 6 years was categorized according to the psychometric battery. SLI was identified if WASI Performance IQ (PIQ) was 85 or above, and scores on two or more of the four language tests (three CELF-R subtests or non-word repetition) were below 85. Any child with PIQ below 85 was categorized as a case of general delay. At 6 years of age, there were 83 children in the SLI group, 32 with general delay (GD), and 277 TD children. Data on twin–cotwin similarities in language status and on relationships between 4-year risk status and 6-year language status are reported elsewhere (Bishop, Adams, & Norbury, 2004; Bishop, Laws, Adams, & Norbury, under review). Mean cognitive test scores for children in these three groups are shown in Table 2. These data contravene the assumption of ANOVA that data points should be sampled independently because both members of a twin pair are included.

Table 2. Mean (SD) Cognitive Test Scores for Children in Relation to 6-Year-Old Language Status

	TD, $N = 277$	SLI, $N = 83$	GD, $N = 32$
WASI performance IQ	101.50_a (10.55)	97.36_b (7.87)	81.84_c (2.26)
WASI verbal IQ	100.77_a (12.54)	86.23_b (10.07)	85.31_b (10.94)
CELF-R listening to paragraphs	101.84_a (12.03)	84.40_b (14.09)	86.09_b (16.05)
CELF-R sentence structure	100.31_a (11.48)	85.06_b (9.25)	84.35_b (14.59)
CELF-R recalling sentences	96.96_a (11.48)	75.49_b (8.20)	82.86_c (11.58)
Non-word repetition	96.86_a (15.65)	74.32_b (15.82)	81.43_b (19.63)

Note. Means with different subscripts differ significantly from one another at .05 level on Scheffé test.

A series of simulations was carried out to assess the impact of this, comparing *F*-ratios obtained when 200 independent data points were simulated, as compared with the case where the values in the first 100 data points were correlated with those in the second 100 data points. The simulations showed that *F*-ratios were equivalent for correlated and uncorrelated datasets across a wide range of levels of correlation and effect size.

Table 2 shows that the SLI group scored well within normal limits on the measure of PIQ, but resembled the GD group on most of the language measures, though they did worse than the GD group on recalling sentences.

Relationship Between Handedness and Language Status

Figure 1 shows the distribution of scores on the Edinburgh Handedness Inventory for the three subgroups of children. As is typical with HP inventories, the distribution was J-shaped, with the majority of children being completely right-handed. Because the data were non-normal, the Kruskal–Wallis test was used to compare the distribution of HP scores for the three groups. No significant difference was found, $\chi^2 = 2.35$, d.f. $= 2$, $p = .309$.

Figure 2 shows performance of the three groups on the QHP task at each spatial position. Data were missing for two children with SLI and three TD children because of lack of a suitable table for administering the test. Two-way ANOVA was conducted with group (TD, SLI, or GD) as between-subjects factor and spatial position as repeated measure. The Mauchly sphericity test gave a significant value indicating that the assumption of homogeneity of covariance was not met, and so the degrees of freedom were adjusted using the Greenhouse–Geisser correction. Effect sizes are given in terms of η^2, which indicates the proportion of variance accounted for by a given factor or interaction. There was a large main effect of spatial position, F (3.55, 1362) $= 158.8$, $p < .001$, $\eta^2 = .29$, no main effect of group, F (2, 384) $= 1.24$, $p = .291$, and a small but significant interaction between spatial position and group, F (7.09, 1362) $= 2.4$, $p = .019$, $\eta^2 = .012$). As can be seen in Figure 2, the pattern of performance is similar to that reported by Bishop (2001), with the SLI group showing more left-handed reaches for positions to the left of the midline. Note that this contrasts with the results from the Edinburgh Handedness Inventory, where left-handedness was not unusually common in the children with SLI (see Figure 1). This was confirmed by subdividing children into left-handers (EHI total below 11) and right-handers (EHI total 11 or more): on this criterion, 17.2% of the TD group, 20.5% of the SLI group, and 6.3% of the GD group were left-handed, a non-significant different, $\chi^2(2) = 3.34$, $p = .188$.

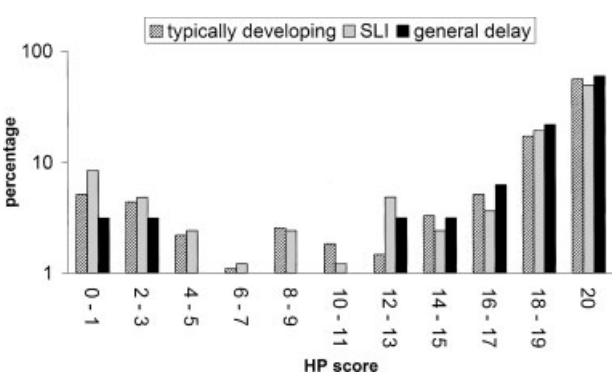

FIGURE 1 Percentage (on log scale) of sample with given hand preference score.

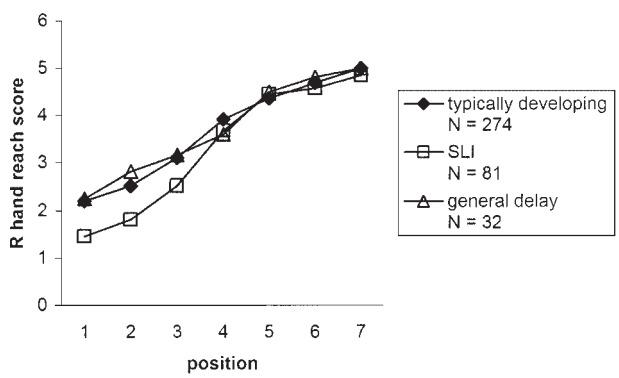

FIGURE 2 R handed reach score (out of 6) in relation to spatial position, where 1 is leftmost position, 4 is midline, and 7 is rightmost position.

Two further analyses were carried out to explore the QHP data more fully. First, the slope of the function relating reaching score to position was computed for each child. This gives a measure of the extent to which reaching is influenced by spatial position, regardless of HP. If the number of right-handed reaches increases with rightward position of the cards, the slope will be positive. A child who persists in reaching with the same hand (either right or left) across the midline will have a flat function with zero slope. The independent variables of sex and zygosity, as well as language status, were included in the analysis of slope scores. No interactions were significant at the .05 level, and the only main effect to reach significance was that of language status, $F\ (2, 375) = 4.95$, $p = .008$, $\eta^2 = .026$. The mean slope for the TD group was .50 (SD = .38), for the SLI group it was .63 (SD = .44), and for the GD group it was .49 (SD = .37). Post-hoc Scheffé tests gave a significant difference between the SLI and control groups at the .05 level. A supplementary correlational analysis showed that EHI HP score was unrelated to QHP slope in both control (Spearman's $\rho = -.047$, $N = 273$, $p = .438$) and SLI groups ($\rho = .009$, $N = 81$, $p = .936$).

In the second analysis, children were categorized according to their profile on the reaching test as follows. Group RR: reached exclusively with the right hand; group R: reached predominantly with the right hand (reach score totals, out of 18, for the three reaches on the left side and the three reaches on the right side positions were both greater than 9); group B: reached predominantly with the left hand in the left side of space and with the right hand in the right side of space; group L: reached predominantly with the left hand in both sides; group LL: reached exclusively with the left hand; group O: any other pattern. The distributions of children in these subgroups, shown in Table 3, differ significantly for the three language subgroups, $\chi^2(10) = 18.31$, $p = .050$. These categorical data confirm the picture suggested by the quantitative analyses, in showing that the bilateral response pattern, which is the most common in the whole sample, is especially likely to be seen for children in the SLI group.

Table 3. Numbers (%) of Children in QHP Classes in Relation to Language Status

QHP class	TD (%)	SLI (%)	GD (%)
LL (sole L)	10 (3.6)	5 (6.2)	0 (0)
L (predominant L)	39 (14.2)	9 (11.1)	5 (15.6)
B (bilateral)	99 (36.1)	46 (56.8)	13 (40.6)
R (predominant R)	71 (25.9)	14 (17.3)	10 (31.3)
RR (sole R)	34 (12.4)	6 (7.4)	3 (9.4)
O (other)	21 (7.7)	1 (1.2)	1 (3.1)
N	274	81	32

Genetic Analysis

This twin sample provided the opportunity not only to consider the association between language impairment and handedness, but also to estimate genetic influences on measures of handedness. Twins growing up together are expected to resemble one another because they share many environmental influences (including prenatal factors), and they also share genetic material. However, whereas MZ twins share all their segregating alleles, DZ twins share on average 50% of segregating alleles (i.e., genes that take different allelic forms in different people), so if genes are important in influencing a trait, we expect to see greater similarity for MZ than for DZ twins. A preliminary impression of the importance of genetic factors may be obtained by scrutinizing the intraclass correlations for twins and their cotwins in relation to zygosity. Relevant data are shown in Table 4. The HP data have been transformed to achieve a greater approximation to normality by the formula [3−ln (sqrt (1 + 100 × % L))]. One of the first points to note is that the correlations between twins and their cotwins are uniformly low for DZ pairs. The only DZ correlation that is (marginally) significant is that for the slope measure from the QHP. Given that DZ twins share half of their segregating alleles, a low correlation indicates that a single major gene is unlikely to be implicated in any trait showing this pattern. In addition, a low twin−cotwin correlation for DZ pairs indicates that environmental factors shared by both twins do not play a major role in determining handedness.

To obtain estimates of heritability for these measures, the Mx program (Neale, Boker, Xie, & Maes, 1999) was used to obtain maximum-likelihood estimates for a simple model that treats the observed phenotypic variance of a trait as the sum of three types of influence: a^2 = additive genetic variance, c^2 = common environmental influences (shared by both twins), and e^2 (environmental influences unique to the individual, including measurement error). Because MZ twins are subject to the same genetic influences, the phenotypic covariance between MZ twins is estimated as $a^2 + c^2$. DZ twins have only half their segregating genes in common, and so their covariance is estimated as $.5a^2 + c^2$. Mx can take raw data as input, and by successive iteration works out the values of a, c, and e that give best fit to the observed variances and covariances. When converted to standardized values, a^2, c^2,

Table 4. Intraclass Correlations Between Twins and Their Cotwins for Three Handedness Measures

	MZ ($N = 99$)	DZ ($N = 95$)
Transformed HP	.246	.107
Reach total from QHP	.291	−.086
Slope from QHP	.449	.176

and e^2 estimate the proportions of variance attributable to additive genetic, shared environment, and unique environmental influences. Confidence intervals around these estimates enable one to judge whether effects are significantly different from zero. In addition, the same model can be re-run with *a* or *c* fixed to zero, and the fit of the models compared.

As would be expected, given the low twin–cotwin correlations for DZ twins, estimates of common environmental effects were non-significant and close to zero for all three of the handedness measures shown in Table 4. In addition, the transformed HP score from the handedness inventory and the R hand total reaching score for the QHP gave non-significant estimates of heritability (a^2): .25 (CI = 0–.408) for HP, and .21 (CI = 0–.37) for R hand reaching score. For both measures, a model that included only the *e* term (unique environment/measurement error) gave as good a fit as one that included a genetic term. In contrast, the slope measure from the QHP showed a significant genetic effect, with a^2 of .43 (95% CI = .02–.56), and dropping the genetic term from the model gave a significantly worsened fit, $\chi^2(1) = 4.28$, $p = .038$.

A logical next step would be to consider whether the same genetic influences that were implicated in the QHP slope measure also affected language status. Although multivariate methods exist that would allow one to test this notion, these were not pursued because the phenotypic correlations between the QHP slope measure and the language test scores were uniformly low, and reached statistical significance for only one test, Sentence Repetition, where Pearson $r\,(380) = -.13$, $p = .013$. (Note that a negative correlation is predicted, in so far as a high slope indicates weaker tendency to prefer one hand.) In addition, we may note that although with this large sample, the slope measure differed significantly between the SLI and TD groups, the effect size was very small, accounting for less than 3% of the variance. With such a weak phenotypic relationship between language disorder and the laterality measure, it would be unrealistic to expect to be able to demonstrate any overlap in genetic influences.

DISCUSSION

The results obtained here are consistent with previous data from our research group in three respects. First, no relationship was found between a traditional measure of HP and language impairment. Second, a weak but statistically significant relationship was found between language impairment and the QHP measure, which measures the extent to which a HP is maintained across the midline. Third, there was no evidence of any heritable influence on HP assessed by inventory. A novel finding from this study was that there was modest but significant heritability for a measure from the QHP task that reflected the tendency to maintain HP (whether left or right) across the midline.

The failure to find any evidence of heritability on a traditional handedness measure may seem surprising in the light of widespread acceptance of the idea that handedness is a heritable trait. The literature in this field has tended to focus more on the question of which type of genetic model can best account for handedness data, rather than with discussing whether genetic influences are plausible. Bishop (2001) argued that there were two reasons for this focus. First, humans show handedness at the population level, whereas other species generally do not (at least, not to such a marked extent). This has led to the conclusion that there must be a biological basis for handedness, and genetic variation for HP has been assumed as a corollary of this. In fact, however, there could well be a biological basis to the human bias to right-handedness, without this needing to show any allelic variation: such a model has been shown by Laland, Kumm, Van Horn, and Feldman (1995) to give a good fit to human data. In this model, a genetic bias to right-handedness operates in a probabilistic rather than deterministic fashion, and non-right-handedness is due to chance factors or cultural transmission. The second reason for belief in a genetic basis to human handedness is evidence that handedness is (weakly) familial. However, data from family pedigrees do not allow one to disentangle genetic influences from the effects of shared environment and cultural transmission. Twins do allow such a partition to be made, by comparing concordance in MZ and DZ twin pairs, but twin data have yielded little or no support for a genetic basis to handedness. This lack of evidence has been noted but has been explained by arguing that twinning itself affects handedness, so one cannot generalize from twins to the broader population. However, a large-scale study by Medland et al. (2003) found no evidence of any twin-specific influences on handedness.

Annett's (1985) Right Shift Theory would predict that clearer evidence of heritable influences on HP should be seen if a quantitative measure of relative hand skill is used. Such a measure was not included in the current study because previous studies showed that not only did this measure fail to distinguish between language-impaired and TD children (Bishop, 1990b), but it showed no heritability in twin studies (Bishop, 2001; Carlier et al, 1996). However, in a sib-pair analysis, a whole genome scan by Francks et al. (2002) found linkage of relative hand skill on a pegmoving task to a quantitative trait locus on the short arm of chromosome 2. Although this linkage was not replicated in a second sample of sibling pairs, it was subsequently confirmed in a sample of left-handed brothers (Francks et al., 2003a). This discrepancy between

behavioral and molecular genetic results is not easy to explain, though it could simply indicate that the studies by Francks et al. were more powerful than the twin studies because of a larger sample size. In addition, the pegmoving measure used by Francks et al. included five trials per hand, whereas Bishop (2001) used only three trials per hand, which could have made the measure less reliable. In one important regard, the findings of Francks et al. are compatible with prior work: the measure of relative hand skill was unrelated to dyslexia (Francks et al., 2003b).

The results obtained here with the QHP measure suggest a further factor that might prove to be important in genetic studies of handedness, namely the extent to which the handedness measure is sensitive to developmental aspects of laterality. The slope measure obtained from the QHP reflects the tendency to persist in using a preferred hand across the midline, a trait that plausibly is more heavily influenced by development and maturation than more traditional handedness measures. The fact that this measure, rather than a conventional preference measure, is associated with SLI, fits with Orton's (1925) original speculation that there is abnormal development of lateralization in these disorders. One reason why the literature on links between laterality and language impairments has been so contradictory may be because researchers have not adequately distinguished between atypical lateralization that reflects developmental immaturity, and atypical lateralization that is a stable, life-long trait. The QHP has promise as a measure that may help us make this distinction more clearly—though it is clear that non-developmental factors also affect performance, given that we can find mature adults who do not persist in using the preferred hand across the midline (Bishop et al., 1996; Calvert & Bishop, 1998; Doyen & Carlier, 2002).

The relationship between the QHP and SLI was weak: it is possible that a stronger relationship could be obtained with a more reliable measure. Calvert and Bishop (1998) found that different versions of the QHP were intercorrelations at around .6, but a longer version of the test appears more satisfactory in psychometric terms: Doyen and Carlier (2002) obtained test-retest reliability of .78 with a lengthened version of the test using six cards at each position, instead of three.

A surprising finding was that the QHP slope measure differentiated those with SLI from the TD group, but did not show any abnormality in the GD group, who had poor language skills in the context of relatively low nonverbal IQ. The GD group excluded children with known syndromes, and so contained only children whose low level of overall functioning did not have an obvious medical explanation. In previous studies, it has been hard to demonstrate either etiological differences between children whose language deficits occur in the context of normal IQ and those who have weak language and low non-verbal ability (Viding et al., 2003). There were relatively few children in the GD group, so interpretation needs to be cautious, but the fact that they did not show evidence of weak HP would be consistent with Orton's view that failure to develop lateralization has a selective influence on language-related skills. This result also makes it implausible that the weaker HP of those with SLI is simply a consequence of limited skill in handwriting, as this should apply equally to those with GD.

In summary, this study showed that a measure of strength of HP derived from the QHP task was significantly heritable, and was weaker in children with SLI than in other children. It is suggested that this reflects immaturity of lateralization rather than a stable individual difference. However, it should be noted that, although of theoretical interest, these relationships were small in magnitude.

NOTES

We thank the twins and their families, who generously gave their time to help with this research. This study would not have been possible without generous assistance of Robert Plomin, Bonamy Oliver, Alexandra Trouton, and other staff from the Twins Early Development Study. Particular thanks are due to Courtenay Norbury and Caroline Adams, who gathered the bulk of data for this study. Thanks are also due to Glynis Laws, Barbara Arfe, and Lesley Bretherton for assistance with data collection, and Faith Ayre for assistance with data entry.

REFERENCES

Annett, M. (1985). Left, right, hand and brain: The Right Shift Theory. Hillsdale, NJ: Erlbaum.

Bishop, D. V. M. (1990a). Handedness and developmental disorder. Oxford, Blackwell Scientific, and Philadelphia: J.B. Lippincott.

Bishop, D. V. M. (1990b). Handedness, clumsiness and developmental language disorders. Neuropsychologia, 28, 681–690.

Bishop, D. V. M. (2001). Individual differences in handedness and specific language impairment: Evidence against a genetic link. Behavior Genetics, 31, 339–351.

Bishop, D. V. M. (2002). Motor immaturity and specific speech and language impairment: Evidence for a common genetic basis. American Journal of Medical Genetics: Neuropsychiatric Genetics, 114, 56–63.

Bishop, D. V. M., Adams, C. V., & Norbury, C. (2004). Using nonword repetition to distinguish genetic and environmental influences on early literacy development: A study of 6-year-old twins. American Journal of Medical Genetics (Neuropsychiatric Genetics), 129B, 94–96.

Bishop, D. V. M., & Edmundson, A. (1987). Specific language impairment as a maturational lag: Evidence from longitudinal data on language and motor development. Developmental Medicine and Child Neurology, 29, 442–459.

Bishop, D. V. M., Laws, G., Adams, C. V., & Norbury, C. (under review). High heritability of speech and language impairments in 6-year-old twins demonstrated using parent and teacher report.

Bishop, D. V. M., & McArthur, G. (2004). Immature cortical responses to auditory stimuli in specific language impairment: Evidence from ERPs to rapid tone sequences. Developmental Science, 7, F11–F18.

Bishop, D. V. M., Ross, V., Daniels, M. S., & Bright, P. (1996). The measurement of hand preference: A validation study comparing three groups of right-handers. British Journal of Psychology, 87, 269–285.

Calvert, G., & Bishop, D. V. M. (1998). Quantifying hand preference using a behavioural continuum. Laterality, 3, 255–268.

Carlier, M., Spitz, E., Vacher-Lavenu, M. C., Villeger, P., Martin, B., & Michel, F. (1996). Manual performance and laterality in twins of known chorion type. Behavior Genetics, 26, 409–417.

Cermak, S., Quintero, E., & Cohen, P. (1980). Developmental age trends in crossing the body midline in normal children. American Journal of Occupational Therapy, 34, 313–319.

Dale, P. S., Price, T. S., Bishop, D. V. M., & Plomin, R. (2003). Outcomes of early language delay: I. Predicting persistent and transient delay at 3 and 4 years. Journal of Speech, Language, and Hearing Research, 46, 544–560.

Doyen, A. L., & Carlier, M. F. (2002). Measuring handedness: A validation study of Bishop's reaching card test. Laterality, 7, 115–130.

Francks, C., DeLisi, L. E., Fisher, S. E., Laval, S. H., Rue, J. E., Stein, J. F., & Monaco, A. J. (2003a). Confirmatory evidence for linkage of relative hand skill to 2p12-q11. American Journal of Human Genetics, 72, 499–502.

Francks, C., Fisher, S. E., MacPhie, L., Richardson, A. J., Marlow, A. J., Stein, J. F., & Monaco, A. J. (2002). A genomewide linkage screen for relative hand skill in sibling pairs. American Journal of Human Genetics, 70, 800–805.

Francks, C., Fisher, S. E., Marlow, A. J., MacPhie, I. L., Taylor, K. E., Richardson, A. J., Stein, J. F., & Monaco, A. P. (2003b). Familial and genetic effects of motor coordination, laterality, and reading-related cognition. American Journal of Psychiatry, 160, 1970–1977.

Gathercole, S. E., Willis, C., Baddeley, A. D., & Emslie, H. (1994). The children's test of nonword repetition: A test of phonological working memory. Memory, 2, 103–127.

Hill, E. L., & Bishop, D. V. M. (1998). A reaching test reveals weak hand preference in specific language impairment and developmental coordination disorder. Laterality, 3, 295–301.

Laland, K. N., Kumm, J., Van Horn, J. D., & Feldman, M. W. (1995). A gene-culture model of human handedness. Behavior Genetics, 25, 433–445.

Medland, S. E., Wright, M. J., Geffen, G. M., Hay, D. A., Levy, F., Martin, N. G., & Duffy, D. L. (2003). Special twin environments, genetic influences and their effects on the handedness of twins and their siblings. Twin Research, 6, 119–130.

Neale, M. C., Boker, S. M., Xie, G., & Maes, H. H. (1999). Mx: Statistical modeling, (5th ed.) Virginia Commonwealth University Box 900126, Richmond, VA 23298: Department of Psychiatry.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. British Journal of Psychology, 66, 53–59.

Orton, S. T. (1925). ''Word-blindness'' in school children. Archives of Neurology and Psychiatry, 14, 581–615.

Semel, E. M., Wiig, E. H., & Secord, W. (1987). Clinical evaluation of language fundamentals—revised. San Antonio, Texas: Psychological Corporation.

Trouton, A., Spinath, F. M., & Plomin, R. (2002). Twins Early Development Study (TEDS): A multivariate, longitudinal genetic investigation of language, cognition and behaviour problems in childhood. Twin Research, 5, 444–448.

Viding, E., Price, T. S., Spinath, F. M., Bishop, D. V. M., Dale, P. S., & Plomin, R. (2003). Genetic and environmental mediation of the relationship between language and nonverbal impairment in 4-year-old twins. Journal of Speech, Language and Hearing Research, 46, 1271–1282.

Wechsler, D. (1999). Wechsler abbreviated scale of intelligence. San Antonio: Psychological Corporation.